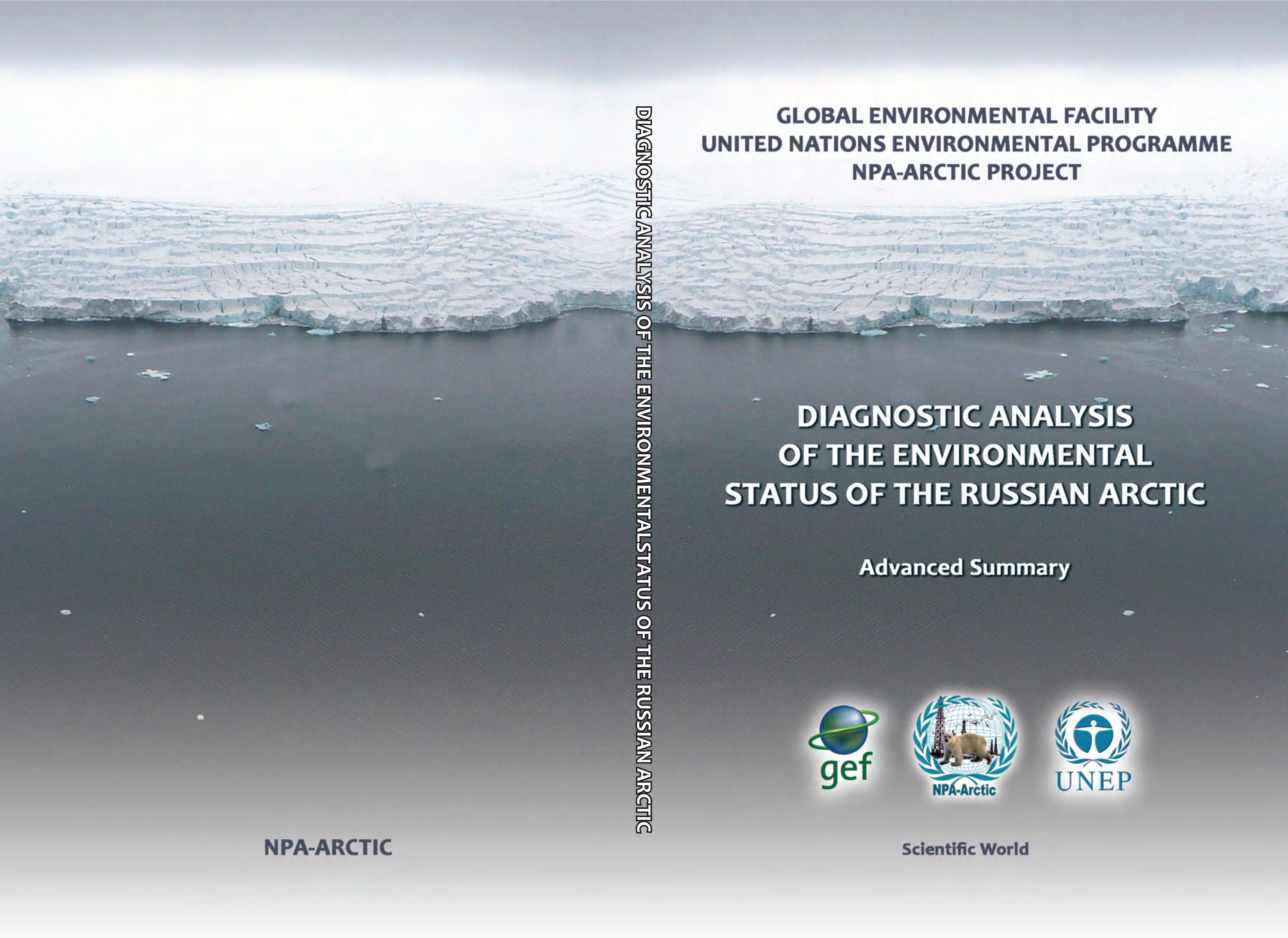

GLOBAL ENVIRONMENTAL FACILITY
UNITED NATIONS ENVIRONMENTAL PROGRAMME
NPA-ARCTIC PROJECT

DIAGNOSTIC ANALYSIS OF THE ENVIRONMENTAL STATUS OF THE RUSSIAN ARCTIC

Advanced Summary

Scientific World

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INTRODUCTION

The environmental status of the Arctic and, particularly, the Arctic Region of the Russian Federation (hereinafter referred to as the Russian Arctic) is still under study and is of growing concern due to developing hot spots where the level of natural ecosystems degradation is extremely critical and the pollution level is much higher than permissible. Another cause for concern lies in qualitative changes of the environmental background. All these require the development and immediate action intended not only to mitigate the existing environmental damage but also to prevent potential risks for Arctic ecosystems related to increasing business and other activities in this region, especially activities of extractive industries. Such actions shall be supported by both the opinion of scientists and experts (based on long-term but often fragmented results of industrial, academic and specific studies related to environmental components) and systematic assessment of the revealed cause and effect relations between the actual environmental status, current anthropogenic impact and environmental policy implemented in the Arctic. This comprehensive approach to environmental assessment of the Russian Arctic is secured by applying the diagnostic analysis methods used to assess the transboundary waters, past environmental damage and other environmental issues.

One of the key goals of the diagnostic analysis of the current situation and potential environmental changes of the Russian Arctic (hereinafter referred to as DA) based on natural changes of climatic conditions and considering the current results of domestic and foreign studies of the Arctic is the substantiation of a well-balanced environmental policy providing for environmentally-friendly strategic decisions related to the future industrial development of the Arctic and its resources as well as the preservation of a favorable environment for sustainable social and economic development.

Complex environmental studies of different parts of the Arctic Region have been performed for more than 50 years and in the Russian Arctic for more than 80 years. The range of studies was constantly extended from geographic, geodetic, mapping, hydrographic and weather studies (used to ensure the experimental sailing of icebreaking and transport vessels in arctic conditions and then to maintain the Northern Sea Route (Russian studies) and North-West Passage through the Arctic Archipelago (Western European and North American polar explorers' studies)) to biological, environmental, zoological and microbiological studies related to Arctic ecosystems.

Scientific studies of seas, insular and coastal Arctic areas were extended as a result of the industrial development of some parts of the Russian Arctic. Scientists determined fundamental results on pollutant content in different natural habitats, wildlife and plants species, marine, aquatic and marsh ecosystems of the Russian Arctic. They documented facts of local and background pollution of Arctic natural habitats and received firm data on long-range transboundary transport of air and water pollution; determined the substantial composition of Arctic air pollutants (fuel combustion products, oil vapors, dust, heavy metals, etc.) and industrial developed areas adjacent to the Arctic and polluting the Russian Arctic. This information required the detailed study of all processes of transboundary pollution transport to the Arctic and features of air and water circulation processes in the Arctic Region and particularly in the Russian Arctic.

The studies were used to compile a list of metallurgical and other enterprises located in the Russian Arctic and many industrial facilities located in Northern Europe and America responsible for polluting the Arctic air, ice and waters. For example, it was found that the Kola and Taimyr Peninsulas of the Russian Arctic are under extreme pressure of industrial pollution. Modern assessments of the total annual pollution level of enterprises located in these areas of the Russian Arctic showed that it amounts to hundred thousand tons of carbon dioxide (CO) and NOx as well as approximately 4m tons of sulfur dioxide per year. A great deal of effort was spent studying the contribution of water pollution transport to the Arctic, starting from runoff analysis of Northern rivers to Arctic seas of the Russian Arctic to transport and mixing of pollutants in the marine habitat as a result of sea currents and Arctic ice streamline effects as well as seasonal repeating patterns of river runoff and water pollution transport on the whole.

The Russian Geographical Society (RGS), Arctic and Antarctic Research Institute (AARI) and the academic institutes of the Academy of Sciences (AS of USSR, then RAS) have contributed much to research of the Russian Arctic. New results were obtained by remote sensing using air and spacecrafts, water level sounding using research vessels, applying recent technologies for collection and sample analysis of different Arctic objects.

Research of the global pollution transport by air, rivers, sea currents and migrators showed that the Arctic Region has unique features requiring accurate interpretation. Global pollution of the Russian Arctic mainly results from air transport as well as being connected with the Gulfstream, runoff from Siberian rivers and ocean currents from the northern seas of the Atlantic and Pacific Oceans. Local pollution of the Russian Arctic always relates to industrial development of the Russian Arctic and other use of Arctic areas. A significant contribution is made by emissions and discharge of industrial waste, accidental spills of oil and oil products on land and into the sea, natural siphoning of oil sources in Arctic coastal oil and gas areas and shelf area of the Arctic seas, operation of engineering facilities in the coastal area of the Arctic seas, waste discharge by marine and river vessels, discharge of by-products of fuel combustion, decomposition and emissions of oil, gas, petroleum, fuel oil and jet kerosene during operation and maintenance of all types of vehicles (water, air, land), and other unpredictable pollution of the Arctic habitat due to accidents and negligence.

Severe pollution of Russian Arctic surface waters has also been found beyond the boundaries of oil and gas fields and even the basins of Northern rivers. But different research has shown that direct ingress of crude oil into the marine environment, freshwater bodies, and onto the coastal landscapes of the Russian Arctic is currently limited in nature and not viewed as a factor that exacerbates the environmental situation in the region. Research performed made it possible to reveal soil and water acidification processes. Results showed that acid precipitation in the Russian Arctic is the main cause of leaching (washing) of metals from the tailings, rock refuse, clinker, with a consequent intrusion of metals into rivers, lakes, and seas of the Russian Arctic. The studies showed that the long-term pollution of the environment has resulted in the contamination of some drinking water sources in some areas of the Russian Arctic.

Transboundary pollution of the Russian Arctic by persistent organic pollutants (hereinafter referred to as POPs) poses a particular hazard. POPs are transported long distances (thousands of kilometres from the source) and accumulate in tissues of plants and all living organisms, and as a result, they are transferred to the human body with food, drinking water or air. POP pollution assessment of the Russian Arctic is still not complete. Available results on POP pollution in the Russian Arctic are local and fragmented.

Materials used in the DA refer to different scale of assessments and issues (ranging from local to regional and global). Upon execution of the DA, we used the complementary analytical consolidation of different scale data collected as at the date of the DAE.

The initial level of information scale is international and national reports and reviews on the Arctic environmental status. We shall pay special attention to reports of the Arctic Monitoring and Assessment Programme Working Group (AMAP) of the Arctic Council. The next information scale level is results of interviews of experts and heads of different regional organizations who worked in the Arctic Region, including fundamental scientific publications. An additional level of information is provided by materials on environmental assessment of the Russian Arctic, including the latest scientific and statistical data as well as materials on scientific rationale of the Arctic ecosystems reaction to anthropogenic pollution and other impacts related to development of the Arctic areas (if necessary).

The method used in the DA is based on the integrated analysis model considering both methodological recommendations of the Global Environment Facility (GEF) and features of different areas of the Russian Arctic. The GEF recommendations related to methodology of the DA contemplate the following analysis model: detailed assessment, cause and effect analysis, prioritization of issues and choice of issues elimination policy.

For the purposes of DA we used the scientific and expert assessment analysis of the social and economic status of the Russian Arctic and analytical materials related to opinions of expert and regional organizations prepared by the leading experts for DA.

The results of current well-known physical, chemical, geological, geographical, biological and planetary components of the Arctic environment on the whole, and the Russian Arctic in particular, make it possible to substantiate the perspective results of DA, including the description of the Russian Arctic environment components status and data of the cause and effect analysis related to environmental issues of the Russian Arctic (including polls of stakeholders) connected with identification of direct, industry-related and root causes of environmental issues.

The key priority result of the DA is the comprehensive confirmation of anthropogenic and climatic impact on the Russian Arctic environmental status. The causes of this impact have been thoroughly studied and published in domestic and foreign research publications and multiple analytical reports.

Multiple research shows that in the nearest future, the impact of perspective climatic changes on transboundary air and water pollution transport processes and other transport processes in the Russian Arctic is inevitable. Thus, a key aspect of DA is specification of the geographic exposure of these processes in the Russian Arctic, assessment of the transport rate of pollutants and specification of the contribution to pollution of the Russian Arctic of different directions of transregional transport.

Degradation of permafrost soils and issues of land use development in the context of global warming in the territory of the Russian Arctic and mechanisms thereof are well-known, but we still have insufficient data on the geographical range of these processes. Nevertheless, the intended result of DA is the primary assessment and subregional forecast of the proposed reaction of the permafrost level to the forecasted climatic changes up to 2020 and beyond.

Current changes in the biodiversity of the Russian Arctic and its pattern of depletion of biological resources is still geographically fragmented. The planned result of DA is prioritization of issues related to biodiversity preservation, prevention of depletion of biological resources in the Russian Arctic, development of specially protected natural areas (SPNAs) in terms of territories of subjects of the Russian Federation located in the Russian Arctic and with respect to marine, terrestrial, aquatic and wetland ecosystems.

Issues of protection and improvement of the habitat of the Northern indigenous population and the quality of life of those working in the Russian Arctic are also under study. But still the planned result of DA is determination of key cause and effect relationships between the current and forecasted change of the indigenous population's habitat, traditional land use, quality of life and pollution rate, impact of climate change on main environmental processes, and industrial development of the territory and natural resources of the Russian Arctic.

The final planned results of the diagnostic analysis, besides the general description of the environmental status and cause and effect analysis of the Russian Arctic environmental status, include the following:

- Formation of the list of priority environmental issues of the Russian Arctic;
- Formation of the list of the most significant direct, industry-related and root causes of the current environmental status of the Russian Arctic;

- Formation of the list of key factors to be analyzed in detail at the stage of planning and solving priority environmental issues of the Russian Arctic;
- Formation of required policy decisions on governmental support of sustainable development of the Russian Arctic in the foreseeable future.

One of the key features of policy assessment within DA is to determine the direction of required policy decisions on environmental support of sustainable development of the Russian Arctic on the whole.

This publication is the short version of the diagnostic analysis of the environmental status of the Russian Arctic performed as part of implementation of the UNEP/GEF Project «Russian Federation: Support to the National Action Programme for Protection of the Russian Arctic Marine Environment (SAP-Arctic Project)». The full text of DA is published on the Project site: http://npa-arctic.ru.

Chapter 1

PHYSICAL AND GEOGRAPHICAL CHARACTERISTICS OF THE RUSSIAN ARCTIC

1.1. Key geographical characteristics of the Russian Arctic

Based on the data provided by the Institute of Geography of RAS, physical and geographical identification of the Arctic has been improving during the 20th century. At the beginning the Arctic territory was narrowly viewed and included only seas and islands related to the Arctic Ocean and bound in the South by the isotherm line of the warmest month (July, +5ºC). Some authors referred to the Arctic only as the northern part of the tundra area (Arctic tundra) and Arctic prairies area. In this case, the Arctic territory included both islands with Arctic prairies and Arctic tundra landscapes and continental edges with Arctic tundra landscape. There is no general identification of the Arctic today.

The atlas of the Arctic published in the USSR contains the following physical and geographical definition of this region: the Arctic is a Northern Polar region of the Earth including the Arctic Ocean and circumfluent continental edges of Eurasia and Northern America. It also includes territories located within the average long-term July isotherm line +10°C where glaciers, open tundra areas and sea areas exist in permafrost conditions. Here, one-year old ice may not fully melt in late spring and can continue to exist year-round.

This definition of the Arctic was the basis of the Resolution of the Arctic State Committee of the Council of Ministers of the USSR dated April 22, 1989 which specified the territories included in the Russian Arctic. It was simultaneously resolved to set its southern boundary considering the requirement of preserving the integrity of related municipal communities, i.e. more protruded to the South than in the physical and geographical definition.

In accordance with the Basic Principles of the Arctic Policy of the Russian Federation for 2020 and further, No. Pr-1969, approved by the President of the Russian Federation on September 18, 2008 the Arctic zone of the Russian Federation (Russian Arctic) is defined as a part of the Arctic region which includes all or parts of the territories of the Republic of Sakha (Yakutia), Murmansk and Arkhangelsk oblasts, Krasnoyarsk Region, and Nenets, Yamalo-Nenets, and Chukchi Autonomous Districts defined by the State Commission on Arctic Affairs under the USSR Council of Ministers, April 22, 1989, as well as lands and islands named in the Decree of the Presidium of the USSR Central Executive Committee of April 15, 1926, «On Declaration of the Lands and Islands Located in the Arctic Ocean as Territory of the USSR» and the internal marine waters adjacent to these territories, lands, and islands of the Russian Federation, as well as the territorial sea, exclusive economic zone, and continental shelf of the Russian Federation, within the boundaries of which Russia enjoys sovereign rights and jurisdiction in accordance with international law.

In scientific publications the territory of the Arctic and the Russian Arctic is identified in relation to arctic and subarctic geographic or climatic zones. The Arctic Zone covers the northern part of Novaya Zemlya, the northern part of the Yamal Peninsula, Taimyr Peninsula and spreads along the coast to Cape Dezhnev in the Chukchi Peninsula. The Subarctic zones are located southwards of the Arctic zone. They include tundra and forest tundra zones, and occupy the northern part of the Kola Peninsula, along the Arctic coast to the Arctic Urals and then in Western Europe, Eastern Siberia shifting to the south in the Far East. If European Russia lies to the north of the Subarctic zone or on the Arctic Circle line, then farther in Western Siberia it crosses the Arctic Circle, and gradually expands to the south, overlooking the Sea of Okhotsk and the northern part of Kamchatka Peninsula – up to 60°N.

The Arctic and Subarctic zones are defined by the combination of climate and landscape characteristics dependant on latitude and amount of incoming solar energy, as well as the influence of many azonal factors, such as ocean currents providing relatively warm water masses from the Atlantic to the Arctic Ocean, changes in types of climate from marine to continental in the meridional direction, influence of altitudinal zonation (changes in climatic characteristics with increasing altitude above the sea level), and so forth.

The Arctic zone is characterized by negative or small positive values of the radiation balance, prevailing Arctic air masses, long polar night, low air and surface ocean water temperatures. The Arctic seas are characterised by stable ice cover. In the subarctic zone cold climate prevails, the highest precipitation amount falls in the solid state, snow cover remains for 7–8 months. The Subarctic zone is characterized by permafrost and associated types of terrain.

The Arctic Circle has a fixed position (66°33″N), but the boundaries of the above geographic zones have no strict latitudinal orientation. This is associated with the influence of the specified azonal factors.

In the mountains the geographical zonation is superimposed and replaced by altitudinal variation of climatic and landscape zones. Altitudinal zonation is accompanied by changes in geomorphologic, hydrological and soil formation processes, and composition of flora and fauna. Many features of the altitudinal zonation are determined by slope aspect, their location in relation to prevailing air masses, and distance from oceans.

1.2. Hydrometeorology background

The Arctic seas washing the Russian coasts (Barents, White, Kara, Laptev, East Siberian, Chukchi and a part of the Bering sea adjacent to Chukchi Autonomous District) are characterised by a monsoon atmospheric circulation pattern. The West and East areas are distinguished by the developed cyclone activity: cyclones moving from the Pacific and Atlantic Oceans result in strengthening of wind and fast weather changes. The central section is featured by anticyclones, mainly clear weather conditions with low wind. In summer, the climatic differences between the particular seas are smoothed as the atmospheric circulation pattern changes and it becomes less active. Summer cyclones are not as deep as in winter, and they terminate rapidly. The key factor during this season is the constant solar radiation inflow during the polar day.

Apart from prevailing zonal transfers, a large-scale northern hemisphere atmospheric circulation (including the Arctic) comprises regular meridional transfers. The distance covered by meridional flows going from south to north is dictated by the physics of atmospheric processes. It is well-known that the bases of long thermobaric waves lie at 35–50°N, on average, whereas their tops reach as far north as 70–80°N.

Analyzing long-term background circulation characteristics observed above open water and coastal areas of the Russian Arctic seas, drawing on high-latitude index departures and prevailing air flow determination showed that in the winter to spring period:

north-western air flows prevail over the open water areas of the Barents and Kara seas (up to 80%);

– the Laptev Sea is characterised by south-western and southern air flows (up to 65%);

– south-western, south-eastern and southern air flows prevail in the East Siberian and Chukchi seas (up to 77%).

In summer (till the end of September) most of Russian Arctic open water areas have prevailing western, north-western and eastern flows (Fig. 1).

Atmospheric precipitation (rain- and snowfall) and solid depositions play the key role among all air cleaning processes.

Pollution levels in the near-ground atmosphere closely correlate with the way the temperatures stratify in the lower troposphere. In particular, a

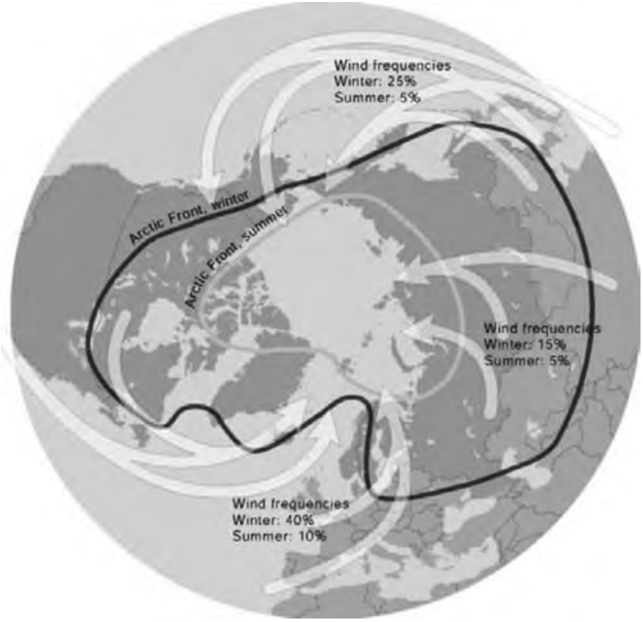

Fig. 1. Prevailing air flows and Arctic front boundaries in winter and in summer

correlation has been established between aerosol particle levels near the ground with the strength of ground inversions, caused by radiation cooling in the near-ground air layer.

Within the period from December to March, i.e. when there is a maximum transfer of pollutants from temperate to high latitudes most of the north of the Asian part of Russia and fringing seas have a frequency of inversions of over 80% with low points below 50% in the Western Arctic. The polar day is the time when existing radiation inversions are eliminated – from May inversions are formed largely as a result of warmer air advection.

As a rule, snow accumulation does not begin in the Arctic until the end of August. Snow normally has a maximum depth from April to May. Higher rates of snow accumulation at its early stages are reported in the Siberian region, where peripheral seas and coastal areas have snow accumulating at 7 to 8 cm per month on average from September to October, and October to November. In the Chukchi region, snow depths increase by an average of approximately 5 cm per month. In subsequent months snow accumulation rates in all Arctic marine regions decrease to an average of below 3 cm per month.

The seas of the Russian Arctic are tidal. The height of tides depends on the coastal configuration. The seas in question receive a lot of freshwater through huge mainland runoff. That into the seas of Arctic Siberia is especially large, as the respective rivers supply around 2,340 km^3 of freshwater per annum. Mainland runoff is distributed very unevenly across the year. Most of the mainland runoff enters the seas in the spring when they are still icebound, as well as during the short summer. Over three quarters of the annual runoff falls during the warm months (from May to September). There is a west to east trend toward more irregular runoff distribution. The Kara Sea receives the largest volume of freshwater – 1,320 km^3/year, with large river discharge accounting for 93% of the runoff. It is the Laptev Sea basin that has the largest portion of river discharge, up to 96%, in the respective total mainland runoff. Much less river water gets into the Barents Sea, where the main runoff amount is concentrated in the south-eastern part.

In the springtime, it is near-estuarial areas in the seas where discharged river water effects are most felt, it is here that the sea gets cleared of ice the earliest, and ensuing active sun energy accumulation leads to more and more adjacent areas becoming ice-free too. The river water which has a lower specific weight, spreads over the surface layer of the sea and can be traced far from the estuary. In the summer, a sum of such factors as ice melting, mainland runoff and precipitation results in the formation of a low salinity surface water layer of 10 to 50 meters thick with a high hydrostatic stability that prevents deep lying water from heating up due to turbulent heat exchange. In autumn, this layer is liable to cool down quickly and form ice early, as its special hydro-physical properties prevent it from mixing with warmer sea waters lying deeper. In winter, there is a significant area of the sea that has a low salinity water layer.

The Arctic seas receive water from the central part (Arctic Basin) of the Arctic, Atlantic and Pacific oceans. Cold surface waters of the Central Arctic Basin spread to the external area of all shelf areas of the Arctic seas.

It is mainly winds that influence sea currents in the Arctic Ocean, while the former depend in turn on atmospheric pressure, geographical patterns and fluctuations. The two main patterns of circulation of surface waters and ice in the Arctic Basin are composed of the Trans-Arctic Current and Eastern Anticyclonic Circulation (Fig. 2).

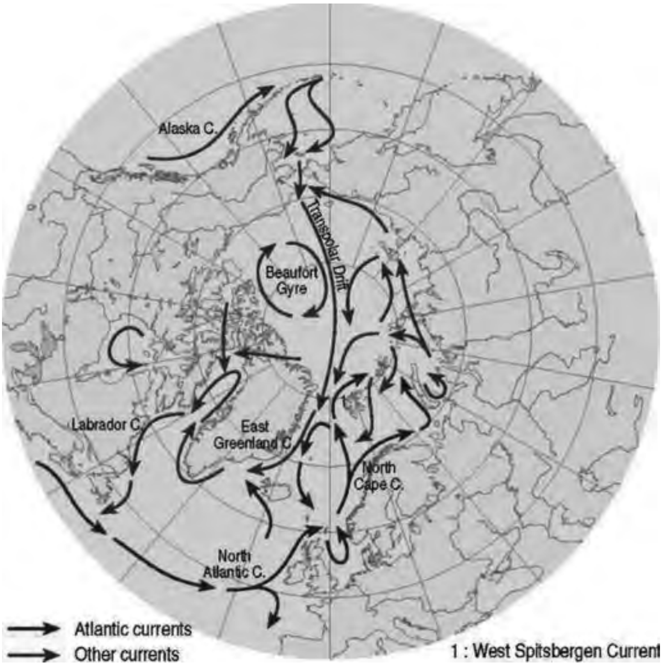

Fig. 2. Surface sea currents in the Arctic Ocean

The wide Trans-Arctic Current rising in the north of the Chukchi Sea transverses the Arctic Basin, with its general direction being the strait between Spitsbergen and Greenland. The current has a low speed: up to 2 cm/sec in the American-Asian sub-basin, and 3–4 cm/sec in the Eurasian one.

The Eastern Anticyclonic Circulation (with its centre being at about 78°N and 150°W), fully contained within the American-Asian sub-basin, is characterized by a very slow velocity of water and ice (1–3 cm/sec) circulating clockwise.

Atlantic warm and high-salinity waters brought in by the North Atlantic Drift form a system of warm surface currents in the Norwegian, Greenland and Barents seas, including the Norwegian, West-Spitsbergen, North Cape and East Iceland currents. Northwards of Spitsbergen, the West-Spitsbergen current's waters sink under low-salinity Arctic waters, due to their higher specific weight caused by their higher salinity, so that the Arctic Basin has them already as a warm deep current. Traveling further on, along the Eurasian and North-American continental shelves, the deepwater current completes a cyclonic circle in the Arctic Basin and arrives in the Greenland Sea through the western part of the strait between Spitsbergen and Greenland. The deepwater current is quite slow. It takes 5–6 years for the Atlantic waters to cover the distance from Spitsbergen to the Beaufort Sea.

The Pacific water coming through the Bering Strait forms a surface current in the Chukchi Sea. As it moves north, the water grows colder, and after sinking under lighter Arctic waters, it proceeds further into the Artic Basin as a relatively warm, deepwater current. It has quite distinctive boundaries in the American-Asian sub-basin (up to Lomonosov Ridge). Using indirect indicators (biogenic matter), it is traceable further on – to Greenland and the Canadian Arctic Archipelago. It has a very low water velocity – measured in tenths of a cm/sec.

Within a calendar year in the Arctic seas it takes around seven months (from October to May) for ice formation and growth processes. In wintertime, all the Siberian shelf seas are fully ice bound, with ice of varying age (thickness) and concentration of 9–10 cm. Ice grows thicker at varying rates in different areas, however, the pattern of growth is similar: in November ice growth rate is the highest (on the average, 12 cm in a decade), then, as the thickness increases, ice begins growing at a reduced rate, ending up in May as slow as 2 cm in a decade on average. Beginning in May-early June, as thermal processes proceed, ice cover begins melting and breaking up. Almost at the same time as ice starts melting, its area begins shrinking and, respectively, the sea begins clearing of ice.

The highest decade-long average rate of ice growth in winter is reported in the east of the Laptev Sea, while the lowest - in the south-west of the Kara Sea. Ice with compaction of 7–10 cm occurs as ice massifs. The largest of these are the Ayonsky (the East Siberian Sea), Taimyrsky (the Laptev Sea) and Severo-Zemelsky (in the northeast of the Kara Sea). Another group of ice massifs is formed by one-year-old ice of local origin. These include the Novozemelsky (the south-west of the Kara Sea), Yansky (the east of the Laptev Sea) and Vrangelevsky (the south-west of the Chukchi Sea). These massifs disappear almost altogether by the end of the melting period more often than not.

In shallow coastal areas of the Russian Arctic seas fast ice is formed. Fast ice is formed in Arctic seas during different periods: from mid-September to early December. Fast ice is formed especially quickly in closed bays and on shallows: during 10 days following the beginning of ice formation. In shallow areas, the fast ice can lie at a distance of several dozens to few hundreds of kilometers off the mainland shore. The furthest fast ice perimeter is reported near the Novosibirsk Islands – up to 360 km off the mainland, and in the west of the East Siberian Sea – up to 250 km.

On average, open water areas covered by fast ice account for 6 to 53% of the total area of the Russian Arctic seas. The least fast ice area is characteristic of the south-west of the Chukchi Sea, and the largest off the east of the Laptev Sea and the west of the East Siberian seas.

As the ice begins to melt, and dynamic processes activate, ice-free areas appear with thin (concentration 4–6) and scarce (concentration 1–3) ice.

However, different seas begin to clear of ice at different times and the process of clearance runs at a different pace, which is related to the specific properties of each of the Arctic regions. Ice clearance in the Arctic seas occurs most actively during August and comes to an end in late September.

On average, before ice starts to form all over again, areas almost fully free of ice include the south-west of the Kara Sea, whereas the east of the Laptev and southwest of the Chukchi Sea are 80% free. Areas 50% free of ice include the north-east of the Kara and the west of the East Siberian Sea. On average, the eastern part of the East Siberian Sea has only 27% of the surface cleared from ice by the end of the melting period.

The ice is almost continuously drifting to the North of the fast ice areas. The key factors to determine ice drift include atmospheric circulations over the seas, as well as general ice drift in adjacent areas of the Arctic Basin. There is prevailing transport of ice out of the Kara and Laptev seas in winter and autumn (from October to December), and into the East Siberian and Chukchi seas from the Arctic Basin. In January to March main features of ice drift remain, except in northern parts of the East Siberian Sea where transit of ice begins to dominate.

The period April to June sees significant changes in drifting ice. While transport of ice out of the Laptev Sea continues, ice drift in the Kara Sea reverses its direction, and ice movement in the East Siberian and Chukchi seas switches to transit mode.

Drift ice in most of the Arctic seas has a speed of around 70–75 km/month in the autumn- winter period, whereas in the south-west of the Chukchi Sea ice speeds are some 50 km/month.

In July-September, the drift ice has an average speed not exceeding 50–60 km/month across all the seas. Low drift ice speeds increase the probability of incursions of ice from the Arctic Basin to the Kara and Laptev seas and, concomitantly, that of transferring ice out of the East Siberian and Chukchi seas.

1.3. Hydrochemistry background

The zone where river and sea waters have active contact (marginal filter) functions as a natural system in which can observe significant transformations in the hydrophysical characteristics of the river and sea waters in contact, resulting in a special hydrochemical regime and highly variable hydrobiological and sedimentation processes.

The hydrochemical conditions of the Russian Arctic seas have many similarities and differences. The main differences are related to the influence of cold waters of the Arctic basin, Atlantic or Pacific waters and significant freshening of the water under the influence of Siberian rivers.

In particular, waters of the Barents Sea are well aerated. Oxygen levels in the midst of the water column are close to saturation. The top 25 m of water have maximum oxygen levels reaching as high as 130% during the summer. Minimum levels of 70–75% are found in deepwater parts of the Medvezhinskaya depression and in the north of the Pechora Sea. Decreased oxygen levels occur at the 50 m horizon, usually with a water layer with well-developed phytoplankton above. Nitrate levels grow from the mainland to the north, and from the surface to the seabed. In summer, nitrate levels in the surface (0–25 m) layer decline gradually, and by the end of the summer, nitrates are almost fully consumed by phytoplankton. In autumn, as vertical circulation increases, surface nitrate levels start to grow as a result of supply from below.

Phosphates have a similar annual stratification cycle to that of nitrates. It should be noted that in areas where a cold intermediate layer is present, it slows down exchange of gases and nutrients between the surface and deep lying layers. In the summer the surface layer gets replenished with nutrients coming from water produced by melting ice. This explains the outbreaks of phytoplankton populations near the edge of the ice.

Good communication with the ocean, ice formation and melting, and large river runoff all have a bearing on hydrochemistry in the sea, in particular on the levels and distribution of oxygen and biogenic matter. In early summer and in the autumn in the north of the sea, its surface layer is usually oversaturated with oxygen. As the sea gets warmer, oxygen levels fall dramatically. The main reasons behind this include decreased oxygen solubility as water temperature rises.

It is characteristic of the south-east of the sea to have low oxygen levels at the surface. These fluctuate in this region within 80–90% of saturation.

Biogenic matter levels decline from south to north. In the summer the top layer (25–30 m thick) is usually short of phosphates and nitrates as these are actively consumed by phytoplankton. At lower layers, levels of these nutrients are somewhat higher. The presence of ice has no effect on phosphate levels, contrary to that of nitrates. The lowest nitrate levels are found in rare ice areas, whereas the highest occurs in areas free of ice. This is because nitrates are consumed by phytoplankton which are abundant close to ice edges and much sparser in open water areas.

Large mainland runoff and free communication with the Arctic Ocean affect hydrochemistry in the Laptev Sea. The north of the sea is somewhat richer in oxygen than the south, which is linked to poorer aeration due to abrupt density changes along the water column. In late summer, the surface layer in most areas in the sea has around 100% oxygen saturation. In other seasons oxygen levels are likely to be lower. As one descends deeper, oxygen levels tend to decrease.

In contrast to oxygen levels, the surface layer has very low levels of phosphates and nitrates. This sea has somewhat lower magnesium, sulfates and chlorine levels than is usual for a typical sea, whereas levels of sodium, potassium, calcium and carbon dioxide are higher than in the ocean.

Specific features of hydrochemistry in the East Siberian Sea are well illustrated by oxygen and phosphate levels and distribution patterns. In the autumn and winter, waters in the East Siberian Sea receive enough oxygen. Oxygen levels vary in time insignificantly: from 96 to 93% of saturation. Declining oxygen levels are due I part to its consumption in the process of oxidation, and it is at the seabed where most oxidation takes place. It is for this reason that the near- seabed layer has an oxygen minimum.

The same times of the year see rather high phosphate levels (125 to 40 µg/l) in the sea water. The reason for this is the low numbers of phytoplankton under the ice. In spring and summer, active gas exchange with the atmosphere and intensive photosynthesis lead to an increase in oxygen levels to 105–110% of saturation. Phytoplankton undergoing rapid growth, especially near the ice edge, consume phosphates actively, and, in turn, their levels drop to 20 or even 10 µg/l.

Unrestricted communication with the Central Arctic Basin, small river discharge and an inflow of Pacific waters make hydrochemistry in the Chukchi Sea similar to that in the ocean, and almost free of any influence on the part of mainland runoff. Oxygen and nutrient levels differ area to area and horizon to horizon, as well as showing seasonal variations. Relatively high levels (112–130%) are observed in the top layers, which embrace depths of 0–50 m in the south, 0-10 m in the north, and only 0–5 m amidst ice.

For the same reason the levels are lower at surface horizons than at deeper ones. In the north of the sea, phosphate levels at the surface are 40 µg/l, while at the seabed they reach 70–80 µg/l. In the south, the levels drop to 6 µg/l at the surface, and are reach a maximum of 50 µg/l at the seabed.

1.4. Terrain

The Arctic Region has two largest morphostructures: the Arctic Ocean basin and the northern continental edges. These macro morphostructures have the following structure:

within marine areas

– deepwater Arctic Ocean bed with underwater troughs and ranges;

– continental slope characterised by high seabed slopes;

– continental shelf formed by the shallow underwater flatland with complex archipelagos, lands, islands and peninsula relief. Within the shelf area they form marginal and continental seas as well as bays, harbours and gulfs;

within terrestrial areas

– thin coastal plains located along the coast line or smoothly transiting to Eurasian and Nothern America's continental plains;

– mountain ridges and uplands sometimes located close to the Arctic coast.

Features of the Arctic Eurasian Basin are caused by the combination of geological structures of different nature and history: East European and Siberian Platforms, and orogens respectively. They are formed by terrigenous, carbon-bearing, chemogenic and volcanogenic sediments from Archean to Quarternary age. Easily washed formations (plaster stone, anhydrite, salt rock, etc.) are also present together with relatively highly-mineralized ground waters (more than 10 g/l) materially affecting the chemical composition of river water, especially in winter.

Kola Peninsula is located in the North-East of the Baltic fundamental crystalline formation, mainly formed by granites and gneiss. The main relief features of the peninsula are caused by multiple splits and cavities of the crystalline formation and they show signs of strong impact of glaciers such as leveled mountain peaks and morainic deposits. The North part is formed by a table sharply breaking to the Barents sea shore and White Sea neck. The table is crossed by canyons with rivers Kharlovka, Iokanga, Eastern Litsa and lower course of Ponoy river. In the South the table is gradually rising up to 300 m and then sharply breaking to the central swale.

Generally, the territory of Arkhangelsk Region is a wide-spread flatland with a slight slope to the White and Barents Seas. The flatland is locally crossed by frontal moraine hills created as a result of a relict glacier movement. To the North-East of the Region there are large boulder walls. In the East the Region includes Northern and Middle Timan, a low-hill terrain consisting of parallel ridges with table-like peaks up to 400-450 m high. Formation of the relief has been highly affected by river erosion. River runoff transports a large quantity of sediments thus forming estuaries.

Nenets District is located in the Pechora Lowland spread from the Timan Ridge up to Pay-Khoy Range and covers Malozemelnaya tundra (to the West) and Bolshezemelnaya tundra (to the East). The terrain is flatland with the upland area on the Yugra Peninsula (Bolshaya Nadeya mountain, 428 m high) thus allowing the industrial development of this area. The territory of the district is characterized by large permafrost areas.

The terrain of Yamalo-Nenets Autonomous District is represented by a lowland plain with average height of 100 m above sea level with multiple lakes and marshes. The right-bank continental part of the district (to the East from Ob river) is a hilly table with some slope to the North. According to the terrain type, the Yamal Peninsula is divided into 3 parts: the North Siberian Plain, the Byrranga Mountains (up to 1.146 m high) spreading from the South-West to the North-East, and a coastal plain along the Kara Sea coast. The district is characterized by the occurrence of virtually all freeze-thaw actions. Soil frost weathering with mottled nanorelief is the most widespread and diverse solifluction forms are developed.

The main area of Taimyr (Dolgano-Nenets) Municipal District of Krasnoyarsk Region is covered by Taimyr Lowland (a wavy plain 50–250 m high) formed by glacial drifts and varves, marine and modern lacrustral-alluvial and alluvial deposits. Marine plains are formed by Kargin Kazantsev clays and Sanchugov age (in the west), there are brackish clays along the rivers and streams. Cryogenic processes (thermokarst, cryogenic solifluction, polygonal-cavern ice formation, cryogenic weathering, spotting and related forms of micro-and nano-terrain such as silt pinnacles, mud boils, webbings, thermokarst pockets and polygonal ridges) are widespread. These processes are also characteristic of a narrow strip of coastal plains extending to the north of the Byrranga mountains. The major area is occupied by glaciers and permafrost.

In the territory of the Norilsk industrial region, there is the Enisey plain and Putoran mountains. The plain is an extension of the West Siberian Plain and is a lowland, laky surface with weak bias in the north-west mainly formed by glacial, lacustrine-glacieral and alluvial deposits. The Putoran mountains include the surrounding Haraelakh mountains, the Norilsk table Lontokoysky Stone and Lamskie mountains. They are formed by very hard diabase and basalts, being the volcanic lava of Permian and Triassic age, as well as by easily weathered volcanic tuff. The table is extremely dissected by deep, steep-slope river valleys radiating in all directions from the central part of the massif and reaching depths of 800–1200 m.

The territory of Yakutia mainly belongs to two major tectonic structures, namely the the Siberian platform and the Verkhoyansk-Chukchi region of Mesozoic orogenesis. On the Siberian platform there are developed tables, sheered tables and plains. On its southern outskirts, within the Aldanian Shield, there is a high table with heavily dissected terrain. Upstream of Vilyui lies the Vilyui table with a highest point of 962 m. Further to the South, the Prilenskoye table extends in the east-west direction. Along the Laptev Sea coast, there is the North-Siberian lowland. Its absolute heights are mostly less than 100 m and only in hilly, glacial terrain areas does it reach 150–200 m.

All territories of Eastern Yakutia, including the basins of the Alazeya, Indigirka, Yana, partly Aldan and Lena rivers (right-bank tributaries) are included in the Verkhoyansk-Chukchi region of Mesozoic orogenesis. It is extremely heterogeneous with a view to topographic and geological properties. Along the right bank of the Lena lies the Verkhoyansk Range.

The modern terrain of the Chukotka Autonomous Okrug is contrasted and heterogeneous. The Kolyma-Chukotka mountain area includes the Anyui highlands, the northern part of the Chukchi Plateau and extends to the east up to the Bering Strait. Low-mountain terrain prevails. The Great Anuy river basin includes the Anyui group of volcanoes. The Okhotsk-Chukotka mountain area includes the Anadyr Plateau and the southern part of the Chukchi Plateau. The relief is contrasted with an Alpine look and mountains are followed by low mountains and midlands of intermontane troughs. The Anadyr-Koryak mountain area is located in the south-east of the Chukchi Peninsula. A significant part of this area is occupied by the Koryak Highlands consisting of ridges separated by intermontane depressions. The Anyui lowland covering the lower courses of the Big and Small Anyui, Hetagan and Yarovaya is a swampy and relatively hilly plain. Highly developed thermokarst areas occupy the majority of the lowland.

Morphostructures of the Russian Arctic spread to the adjacent areas. Thus, the Komi Republic terrain is mainly flat. The Timan Ridge stretches from the south-east to the north-west, in the east lie the ridges of the Northern, Subarctic (up to 1895 meters high, Narodnaya mountain) and Arctic Urals. Karst terrain (craters, polje, caves) is widely spread. Pechora lowland is located between the Urals and Timan Ridge.

The terrain of the Khanty-Mansiysk Autonomous District is characterised by a combination of plains, foothills and mountains. There are elevated plains (150–301 m), lowland plains (100–150 m) and lowlands (less than 100 m). In the floodplains of the Ob and the Irtysh, absolute heights are 10–50 m. A part of the Urals area is characterized by midland terrain. The length of the mountainous area is 450 km and the width is 30–45 km.

Chapter 2

ECONOMIC AND GEOGRAPHIC PROPERTIES OF THE RUSSIAN ARCTIC, REPUBLIC OF KOMI AND KHANTY-MANSIYSK AUTONOMOUS DISTRICT (YUGRA)

2.1. General characteristics

The Russian Arctic plays a great role in the Russian economy. Products representing 11 percent of the national income of Russia (with 1 percent headcount) and approximately 22 percent of domestic export are manufactured in this region. Since the 1930s, the region has shown rapid development in mining, metallurgical, shipbuilding, forest, wood, pulp and paper, and other industries as well as transportation. Economic demands and deterioration of natural resources in the developed areas actually predetermine the increase in production thereof in the Russian Arctic, including the continental shelf. The Arctic contains the largest amount of hydrocarbon resources on the continental shelf of the Russian Federation. In Arctic Russia, natural gas, apatite concentrate, and many strategic nonferrous and precious metals such as nickel, copper and cobalt are produced. The Barents Sea is one of the most important fishing and seafood production regions in Russia. There is a transportation corridor through the Russian Arctic seas to Western Europe, South-East Asia and North American ports, and its use is increasing due to increased business activities in the Russian Arctic coupled with the effects of climate change. Cross-polar air transportation provides a link between Eastern and Western hemispheres by the shortest routes.

In the document 'Fundamental Provisions of Government Policy of the Russian Federation in the Arctic until 2020 and beyond' which was approved by the President of the Russian Federation on September 18, 2008, the goal of the Russian Arctic resource base improvement is to cover the

Russian demand in hydrocarbon resources, water biological resources and other types of strategic commodities. Within the period through 2020, the Russian Arctic shall be transformed to the leading strategic resource base of the Russian Federation.

To ensure the economic development of the Russian Arctic, we shall consider the following features which differentiate this region from others:

– extreme weather and climatic conditions adversely affecting human health;

– low density of population and local economic development of territories;

– remoteness from key industrial centers, high production costs and specific types of management (wide use of human resources from other regions);

– dependency of the population life support on fuel, food and other goods supplies applying complex logistic patterns within limited open-water term.

The Arctic Region has rich biological resources both marine (fish, Pinnipedia and whales) and terrestrial (including such valuable commercial species as the Arctic fox and sable). The fisheries industry of the Russian Arctic provides up to 15% of water bioresources and fish products manufactured in the Russian Federation. The most valuable fishing species are herring, cod, flatfish and salmon.

The Arctic is very rich in virtually all mineral resources. In the 21st century, the Russian Arctic shelf may become the main sources of hydrocarbons both for Russia and the global market. Modern assessments show that more than two thirds of the Russian Arctic continental shelf is potentially oil and gas-bearing. The estimated aggregate hydrocarbon profile in oil equivalent amounts to 110 billion tons.

In the Russian Arctic, Russia extracts 100% of its diamonds, antimony, apatite, phlogopite, vermiculite, rare and rare-earth metals, 98% of its platinoids, 95% of its gas, 90% of its nickel and cobalt, and 60% of its copper and oil. The estimated total value of in-situ mineral resources is more than USD30 trillion and two thirds of this amount is represented by energy sources.

90% of the Russian Arctic population are migrants. The most intensive migration process was observed in the 1970s and 1980s when Russia started to develop its Northern oil and gas fields. The population is concentrated in towns created in mineral extraction and transportation points with

Murmansk, Norilsk, Vorkuta, Arkhangelsk and other cities among the largest. The relative density of the population is 1–5 persons/km^2 compared to the average of 9 across Russia. A high percentage in the total population headcount is represented by indigenous peoples (approximately 200,000) resided mainly in rural areas. The key activities are hunting, fishing and trapping. Within the period 1989 to 2002, the population of the Polar Region fell by 25%.

2.2. Territorial development

Mineral and biological resources of different Russian Arctic areas have been studied and developed irregularly. The resources of the Murmansk and Arkhangelsk Regions are well-known, but those of the Republic of Sakha (Yakutia), the Taimyr (Dolgano-Nenets) Region and the Chukchi Peninsula are less well-known, including their oil and gas profiles. The same may be said of the marine area of this region, with well-studied Barents and Kara Sea shelves and less well-known Laptev, East-Siberian and Chukchi Seas shelves.

Since the beginning of the 20th century, the Murmansk Region has developed more dynamically when apatite, nefelite, copper, nickel and ferrous ore deposits were discovered. Today, the Murmansk Region Russia produces and processes apatite ore - being the raw material for phosphate fertilizers manufacturing. Also trawling and timber logging are currently experiencing rapid development. The Russian Arctic includes the Kola, Lovozero and Pecheng Regions.

The key industries of the Kola Region are agriculture, power and food processing. The economy of the Region is related to agriculture. Agricultural companies represent 65% of the regional output of manufactured products and agricultural land represents 0.3% of the total amount of regional land with 91% being ploughland. The agricultural companies specialise in dairy cattle husbandry, hog breeding, poultry breeding, reindeer and valuable fur game breeding.

There are 4 HPPs in the Region (2 located on the Tuloma Cascade and 2 on the Serebryansky Cascade) and power grid facilities. Power is transported to Karelia, Norway and Finland.

The key economic center of the Pechenga Region is Pechenganickel Integrated Plant which produces and processes ores to be used for production of nickel, copper and rare-earth metals (platinum). Since 1999 the plant has been a structural subdivision of Kola Mining Company JSC with headquarters in Monchegorsk. Today the production facilities of the Company are concentrated in the villages of Zapolyarny and Nickel, where multiple mines are located (the largest are Centralny and Severny). The main product of the plant is nickel matte which is used for nickel, copper, cobalt, precious metals and sulfuric acid production. The majority of nickel matte is shipped by Kola Mining Company to Severonickel plant (Monchegorsk).

There are 5 HPPs in the Region owned by Kolenergo JSC which are combined as a cascade of Hydro Power Plants located on the Paz river. The most powerful is Borisoglebsk HPP. The transport framework includes a motorway and railway routes. Agricultural lands represent 0.2% of the total regional land with 97% being ploughland. Agricultural companies specialize in dairy cattle husbandry.

Lovozero Region is located in the central and eastern part of the Kola Peninsula. The key industries of the Region are nonferrous industry (the share of production output being 73% of the industrial total of the region), power industry (15.4%) and food processing (11.2%).

Rare and rare-earth metal deposits have been developed by Lovozero Mining Company JSC. The main product is loparite concentrate used in the production of rare earth compounds such as columbium, tantalum and titanium.

The transport framework of the region is badly developed. There is an asphalt motorway from Murmansk to Lovozero village. Some settlements are deemed remote due to lack of roads and transportation is performed irregularly by local airlines and marine vessels. Agricultural companies specialise in reindeer breeding and dairy cattle husbandry.

The Russian Arctic in the Arkhangelsk Region includes the undeveloped islands of Novaya Zemlya and Frantz Joseph Archipelagos. There are specially protected natural areas: the federal wildlife reserve (Frantz Joseph Land) and national park (Russian Arctic, Novaya Zemlya).

All territories of Nenets Autonomous District are included in the Russian Arctic. The population of the district amounts to 42,000 people (2009) with 59.7% in urban areas. The population density is 0.3 per 1 km^2. Ethnic composition: Nenets (12%), Russian (65.8%), Komi (9.5%) and other.

The main industry of the district is based on mineral resources and 90% of industrial products consist of oil products. There are known hydrocarbon resources in the Nenets AD. As of January 1, 2009, 83 hydrocarbon fields had been discovered in its territory: 60 are included in the distributed fields list and 32 are developing. The undistributed fields contain 24% of explored oil reserves and 19% of non-associated gas. Based on the level of industrial development, 16 fields are listed as developing, 19 are ready for industrial development, 38 are being explored and 2 are abandoned. During in the near future, approximately 10 hydrocarbon fields are planned for commissioning and 8 are preparing for commercial development. For the purposes of oil transportation from all developed fields, it is required to build intra- and inter-field oil pipelines.

The District is characterised by high degree of oil and gas-bearing areas, their compact location and proximity to European sales markets. The Nenets Autonomous District is one of the most promising Russian regions with a view to development of domestic oil production.

Today 20.2% of known oil and gas reserves are under production within the production operation of the Haryaginsk, Ardalinsk and Peschano-Ozersk fields. Oil reserve depletion level is less than 10%, unassociated gas – less than 1%. The largest oil production companies are Rosneft JSC, Lucoil-Komi LLC, Polyarnoe Siyanie LLC among others.

Fluorspar, agate and amber deposits have also been explored in the district. Copper, nickel and cobalt deposits are found; and there is potential for diamond and gold extraction. Other mineral resources are clay for brick making (more than 4 M tons of reserves), sands, sand-gravels and gravels (more than 100 deposits), limestone and charcoal. Fuel and food processing industries are also developed. Occurrences of lead-zinc and copper ores have been found on Vaigach island.

There are 1120 enterprises and organizations in the district as well as two sea ports in Naryan-Mar and Amderma. A pipeline to Arkhangelsk and a port and oil terminal in Indiga bay (Barents Sea) are planned for construction as well as further oil and gas transportation. An oil pipeline to Komi Republic has been built.

The leading agricultural industries of the district are reindeer breeding, fisheries and hunting. Valuable fur game breeds are being cultivated. Among the water biological resources, the most commercially valuable are fish stock. The fishery stock of the Nenets Autonomous District (besides offshore strips of the White, Barents and Kara Seas) includes 1,542 rivers and ponds 266,000 km long. The fishery stock also includes 161 large lakes with the total water surface area of 1,002,000 ha. 25 companies of different ownership types, 38 farms and 192 private subsidiary farms are involved in agricultural production, employing approximately 3,000 people (2,000 indigenous peoples of the North).

The territory of the Nenets Autonomous District includes one urban community (Naryan-Mar) and Subarctic Region contemplating all territories of the district, excluding Naryan-Mar Municipal District.

All territories of Yamalo-Nenets Autonomous District are included in the Russian Arctic. The surface area of the district is 75,030,000 km^2, the population is 543,651 (2009), including Russians (46.9%), Nenets (21.9%), Khanty (8.1%), Komi (6.8%), Selkup among others. The population mainly resides along the Ob and other river banks as well in the South part of the Gulf of Ob. The urban population represents 58% of the total. The district is divided into 7 administrative districts, including 3 cities (Salekhard, the capital of the district, Nadym and Lanytnangy) and 2 urban settlements (Tazovsky and Tarko-Sale).

The leading industries are gas production and fisheries. The district is one of the leading regions in Russia with a view to hydrocarbon reserves, especially natural gas and oil. Proven oil reserves of the district amount to more than 250 m tons with more than 7 trillion m^3 of gas reserves. Gas fields are being developed, including the largest – Urengoy (since 1978) and Yamburg (since 1986). Within the territory of the district the main gas transportation stream to Ural, Central Russia, Eastern and Western Europe have been established.

70% of global white fish reserves (muksun, humpback salmon, nelma) are registered in the district. There are 2 fish factories and 5 fish farms (Salekhard, Tazovsky, Novy Port). Timber and wood industries are being developed. Wood removal amounts to 932,000 solid m^3 annually. The wod industry is represented by timber production (Salekhard and other). The construction materials industry is also being developed. The district is one of the largest Russian reindeer breeding regions and reindeer livestock amounts to more than 400,000 animals. Large reindeer farms such as Nadymsky and Purovsky have been incorporated into the region. The Yamalo-Nenets Autonomous District is a large fur game supplier. Fur farms breed black foxes, blue foxes and coloured minks. Polar fox, sable, squirrel and weasel are of the highest commercial value.

The Taimyr (Dolgano-Nenets) Municipal District was created on January 1, 2007 (previously being a separate subject of the Russian Federation). The total area of the District is 862,100 km2 with a population of 37,042

(2009). The capital of the region is Dudinka (population of 268,000). The indigenous population includes Dolgans (8.8%), Nenets (4.4%) and Nganasan (1.5%). The key industries are fuel, construction materials, consumer and food processing industries; polymetallic ores, hard coal and salt stone deposits. Mortar sands and gravels are extracted near Dudinka. The main transportation modes are marine (Northern Sea Route, Dudinka, Dixon and Khatanga ports), internal waterway (shipping by the Enisey and Khatanga rivers) and air transportation. Dudinka–Norilsk–Talnakh railroad has been laid and the Messoyakha-Norilsk gas pipeline is under operation.

Dudinka, a sea port in the lower course of the Enisey, is the largest in Siberia. It has all-season sea links with Arkhangelsk and Murmansk and with Krasnoyarsk and Dixon during the summer navigation (by river routes). The Dudinka sea port is the only port in the world flooded every year during the spring breakup period. The Dixon urban community is the most northerly port in Russia. There is a Research Station with a Radio Meteorological Station and Geophysical Lab which has been operational since 1919.

Taimyr is the least geologically studied region in Russia with a well-researched mineral resources profile. There are occurrences of nonferrous and ferrous metals similar to those of the Norilsk field, copper, titanium, polymetals, gold, molybdenum, iron, antimony, borium, mercury, salt, hard coal, oil, gas, mica, plaster stone and other in-situ mineral resources. But the remoteness of the region, and its harsh environment, hinders development. Unique industrial (impact) diamond deposits have been discovered in Khatanga near the Popygay crytoexplosion structure. Two diamond deposits were found in this area (Udarnoe and Skalnoe) constituting more than half of the global resources. Popygay diamond technological testing results revealed a wide range of possible applications - from surgical scalpels and tips for soldering products to drill bits, diamond tools and high-quality abrasive materials. The relative inaccessibility of the territory and low interest in these types of commodities in Russia do not make it possible to develop these deposits nowadays. The Khatanga and Koyui rivers basins are rich in natural gas and oil.

The Taimyr (Dolgano-Nenets) District includes the Norilsk Mining Plant, the largest plant in Russia producing and processing copper-nickel ores. The ore base of the plant includes rich cupriferous and impregnated copper-nickel ore deposits: Norilsk – 1, Talnakh and Oktyabrsk. Norilsk is not included in the Taimyr (Dolgano-Nenets) Municipal District being a separate municipal community governed by the Krasnoyarsk Krai administration.

For some years Norilsk was included in the list of the most air-polluted cities of the Russian Federation caused by the material amount of pollutant emissions (mainly sulfur dioxide) by the Norilsk Mining Plant.

The industrial activities of the Norilsk Mining Plant are characterized by a high level of extracting industry waste, including overburden rock and final tailings.

The Russian Arctic in the Republic of Sakha (Yakutia) includes the Anabarsky, Allaikhovsky, Bulunsky, Nizhnekolymsky and Ust-Yansky Districts. Sakha is the largest region in Russia with a potentially high amount of commercial natural resources. In its territory there are large diamond deposits, gold, phlogopit mica, hard and pitch coal, iron ore, natural gas, tin, tungsten, polymetallic ores, piezoquartz, antimony, mercury, apatite, uranium, diamond and gold deposits. It also contains the largest Uranium deposit in Russia with proven reserves amounting to 344,000 tons.

The main industry of the Republic is the extraction of mineral resources and associated processing. The following industries are also developed: the power industry, timber and wood industries, construction materials production, and consumer and food processing industries. Shipping is performed by the Northern Sea Route, the Lena river and its tributaries with sea ports at Tiksi and Zeleny Mys (Cherskiy). The agricultural industry specialises in trapping and fur game breeding, dairy and meat production, and potato and vegetable production. Reindeer breeding, animal breeding and trapping are widely spread in Northern Yakutia.

Anabarsky District is the center of the development of diamond deposits. Three diamond mining companies are operating in the region: Anabarsky Proceessing Plant of AC ALROSA CJSC, Nizhneelenskoe JSC, and Anabar Diamonds LLC, seasonal processing plant No. 13. The population of the district is traditionally involved in reindeer breeding, trapping and fishing.

Agriculural production (reindeer breeding), trapping and fishing are the leading industries of the Allaikhovsky, Bulunsky and Nizhnekolymsky Districts. To the East of the Lena estuary, on the bank of Tiksi Bay in the Laptev Sea lies the Tiksi urban settlement, a sea port created in 1933 due to exploitation of the Northern Sea Route. A Research Station and the Tiksi Polar Geospace Research Observatory are also located there.

The main industries of the Ust-Yansky District are tin and gold production, and reindeer and animal breeding. The single largest company of the district is the Deputatsky Mining Plant LLC producing and processing tin ores.

All territories of the Chukchi Autonomous District are included in the Russian Arctic. The District is situated in the far North-East of Russia, the capital is Anadyr. The area of the district is 737,700 km^2 and the population is 49,520 (2009), including an urban population amounting to approximately 68% of the total with 4,738 people representing the indigenous population (Chukchi, Eskimos, Evenk, Koryak, Chuvan and Yukaghir among others). The district has copper and mercury ores deposits, hard and pitch coal, gas and other mineral deposits. The key industry is mining (gold, tin, tungsten, mercury, hard and pitch coal) with such developed industries as construction materials production, power industry (Bilibino NPP, Chaun and Anadyr CHPPs, Bering and Egvekinot HPPs, Northern Lights Floating Power Plant on Cape Schmidt), fishing industry and local arts. The key industrial centers are: Anadyr, Pevek, Bilibino; Iultin and the Beringovsky urban communities. Bilibino NPP generates both electrical and thermal power. The plant began operating in 1974 although its service life expired in 2003. The Pevek Sea Port, the largest in Chukchika, is a transfer point from main to coastal lines and provides winter quarters of coastway vessels.

The key industries of the regional agriculture are reindeer breeding, fishing, fur game and marine animal hunting (seals, walruses). Dairy cattle husbandry, poultry breeding, hog breeding, caged animal breeding and glasshouse harvesting industries are being developed.

The Republic of Komi is a highly developed Russian subarctic region materially affecting the environmental status of adjacent regions of the Russian Arctic. The key industries are mineral production (57.8% of the total industrial turnover in 2005), processing industry (30.5%), production and power distribution.

The Republic has a unique combination of mineral resources in terms of stock, position, diversity and quality. These are coal, oil, gas, bauxite, titanium ores, salts, gold, diamonds, nonferrous and rare metal ores, fluorspar, oil shales, mineral waters and construction material reserves. The key position in this potential (up to 97%) is assigned to energy sources which are expected to dominate in the near future. The Pechora coal basin and the Timan-Pechora petroleum province are quite well-developed and some ore deposits have been prepared for development (Timan Ridge, Northern and Arctic Ural).

Oil and gas reserves of the Republic of Komi are concentrated in the central and southern parts of the Timan-Pechora petroleum province. The main amount of oil is produced on the four largest fields: Usinsk, Vozeisk and Yagerskoe. The Vyktyl field contains approximately half of the industrial combustion gas reserves of the Republic of Komi. The Pechora coal basin is the second largest Russian basin in terms of stock and contains the complete range of coals providing the raw materials for the coke chemistry and power industry to exist and develop.

The Khanty-Mansiysk Autonomous District (Yugra) is the second subarctic Russian region considered during the diagnostic analysis of environmental problems of the Russian Arctic**.** The main mineral resources of the district are oil and gas, the largest fields being Samotlor, Fedorovskoe, Mamontovskoe and Priobskoe. Alluvial gold, gangue quartz and collectors raw material are produced in the district, and pitch and hard coal deposits as well as iron ore, copper, zinc, lead, columbium, tantalum deposits and bauxite deposits have been explored. It is the key oil and gas-bearing region in Russia and one of the largest oil producing regions in the world. The oil and gas industry represents 89.4% of the industrial output of the district.

The Nizhnevartovsk Region of the district is one of the key Russian industrial centres. The basic industry is energy. More than 80 hydrocarbon fields are being developed in the region by leading oil companies (Lucoil, Tyumen Oil Company, Slavneft, Sidanko, Sibneft, Bashneft). During the previous 10 years, oil production companies located in the region have produced 765,000,000 tons of oil. Each fifth ton of Russian oil is produced in the Nizhnevartovsk region.

Chapter 3

CURRENT GEOENVIRONMENTAL STATUS OF THE RUSSIAN ARCTIC AND ANTHROPOGENIC IMPACT ON THE ARCTIC ECOSYSTEMS

3.1. Geoenvironmental approach

While developing the mineral resources in some regions, mankind has broken the interaction between the society and nature leading to the coining of the term «global environmental problem». A great number of scientists are actively engaged in the development of this issue. The term «geoecology» was first proposed in 1939 by the German scientist C. Trolle (Trolle, 1970) in relation to studying natural unaltered landscapes.

Geoecology as a scientific field was officially approved during the XXVI International Geological Congress in 1980. The wide term «geoecology» includes many multi-disciplinary scientific theories and practical issues. Until now interpretation of geoecology as a term has not been generally determined (Osipov, 1997, Trofimov, Zilling, 2000, Concepts…, 2000, Aybulatov, Artyukhin, 1993, Aybulatov, 1993, Geoecology…, 2001, etc.). In this section the term is applied to morpholithodynamic, geochemical and other types of Arctic seas coastal belt analysis. It is determined as a scientific field studying the abiotic lithospheric component of ecosystems which affect the properties and functions of the biota. From this point of view the main task of geoecology is to study the properties and changes in subsurface lithospheric interfaces in order to assess their environmental functions (Trofimov, Zilling, 2000).

3.2. Geoenvironmental status of the coastal belt

The Geoenvironmental status of the sea coastal belt (SCB) of the Russian Arctic directly affects the marine biota and chemical pollution assimilating properties of the marine environment.

Conditions of pollution transport and formation of persistent buildup are identified based on the results of geoenvironmental zoning of the Russian Arctic sea area. Based on this factor Russian Arctic seas are classified as highly susceptible to pollution buildup (specific parts of the Barents Sea), well-suited (Kara Sea), relatively suited (Chukchi Sea) and unsuited (East-Siberian and Laptev Sea).

Assimilating properties of the marine environment are caused by the morphodynamic and lithogeochemical factors of persistent pollution buildup formation (proposed formation), the sorptive capacity of sediments, the barrier function of the coastal belt (different types of coasts) and internal mechanisms related to the rate of microbiological and biochemical pollutant destruction processes. Based on the assimilating properties of the coastal belt, the Russian Arctic seas are divided into 3 classes: seas with high, average and low assimilating properties. The Chukchi Sea, characterized by wide development of lagoonal coasts, is assigned to the 1st class. The East-Siberian Sea, with mainly drain coasts and the Laptev Sea with typically spit, abrasion, abrasion-spit, drain and deltaic coasts may be referred as class 2 seas. The Barents Sea has the least resistive properties and expanded abrasion coastal belt.

According to the anthropogenic pollution capacity of the Russian Arctic, all seas are divided into 4 groups:

- fragile (Kara Sea, as the related key issues are connected with the low river, air and diffuse pollution capacity as well as low assimilating properties of the marine environment);
- low capacity (Laptev and Barents Seas: the first is characterised by a low potential exposure capacity and the latter by the high level of air pollution and low assimilating properties);
- relative capacity (East-Siberian Sea with balanced factors);
- steady (Chukchi Sea characterised by high level of potential anthropogenic impact capacity).

Thus, the anthropogenic pollution capacity line of the Russian Arctic seas may be shown as follows: Chukchi Sea > East-Siberian Sea > Barents Sea = Laptev Sea > Kara Sea. Based on this conclusion we shall pay special attention mainly to the Kara and Barents Seas as their ecosystems are at the highest risk due to the proposed development of the hydrocarbon production industry.

3.3. Coastal belt dynamic properties

There are 4 types of coasts in the Russian Arctic: mountain and highland terrain with different roughness levels; lowland spit plains with regional glaciers, fluvial and lagoonal spits; alluvial-lacrustrine-windborne spit plains and alluvial-deltaic plains.

The total estimated length of the coastal belt within the Arctic Ocean is 40,000 km and the length of the continental coastal belt of the Russian Arctic seas is approximately 27,000 km (Kalinina et al., 1992).

SCB is defined as the sea and shore interface territory within which spits and abrasive sea coasts are formed as a result of *direct* energy and mass transport between the sea area and adjacent coast due to the dominating effect of windborne sea waves.

Abrasion coasts represent a little more than 15,000 km or 38% of the total coastal belt. The least part (13% of 1,730 km) of abrasion coasts lies in the Murmansk Region, the highest (87% of approximately 3,000 km) is on Franz Joseph Land. In the Russian Arctic there are mainly lowland coasts with poorly roughed marine plains terrain with dominating loam soils, gravel sands and sandy materials in the West sector, and alluvial, lacrustrine-marsh, fluvial-glacier deposits in the West (mainly permafrost or permacooled) forming cryogenic coasts (thermoabrasion, thermodenundation, abrasive-solifluxion, etc.) and representing approximately 60% of the coastal belt. Coasts of the Russian Arctic seas differ from other coasts of the Global Ocean as they are mainly formed by frozen soils, including underground ice. Such coastal structures bring about the occurrence of wide abrasion processes. It is thought that during the recent period of 5–6,000 years the shore streak was cut off up to 10–30 km as a result of thermoabrasion and in some places up to 50 km. Different abrasion rates are caused by the geological structures of coasts, gradients of the initial surface, height above sea level and cryolithogenous factors such as composition and ice content of sediments forming the sea cliffs, climatic factors (sea wave energy, sea ice conditions and air temperature) and related hydrodynamic factors and neotectonics, i.e. mainly by natural factors. But anthropogenic and combined natural and anthropogenic factors currently also play a role. Their negative effect occurs as a result of the activation of destructive processes, increasing the rate of retreat of the coastal belt, pollution and degradation of coastal ecosystems.

The highest degree of abrasion was recorded in the Arkhangelsk Region, Republic of Sakha (Yakutia), in the East-Siberian Sea area. The highest abrasion rate occurs within the Yamal-Gydan area of the Kara Sea where the coasts are formed by icy particulate layers which contain pool-forming subsurface ice, and the area from Khatanga river estuary in the Laptev Sea to the Gulf of Chaun in the East-Siberian Sea where the coasts are highly unstable due to exposure of thin particulate layers with high ice content containing thick layers of cavern-load ice.

The prevalence of abrasion processes on the coasts is more than 50% on the White Sea coasts, in the Nenets Autonomous District, on Franz Joseph Land and on Lyakhovsky and New Siberian Islands. Not all of them require protection activities based on these values. For example, the protection of coasts of the Laptev Sea is irrelevant and unprofitable as the abrasion rate there may reach 30 and even 55 m/year (based on some research results) and due to the fact that during recent decades Figurin, Diomide and Mercury Islands have disappeared from the date of monitoring their boundaries. The key areas subject to protection are oil and gas industrial development regions in West Siberia. Due to the effects of global warming during the next 50 years, it is expected that the ocean level will increase and permafrost area in Yakutia and West Siberia will decrease by 15–20%, thus resulting in a rapid increase in the abrasion rate (by an order of magnitude).

Within the SCB the most active processes with environmental effects occur in lythodynamic and geochemical barrier areas which primarily include estuary areas and river deltas. Potential environmental stress is also related to negative neotectonic structures accumulating adsorbents in the form of pulverized precipitations which accumulate pollutants. Environmentally safe area are abrasion areas and sediments transit areas with high level of wave energy and varying currents (Mezen Bay, the Neck and Sink of the White Sea, etc.). Fast ice is an important pollution transport factor and in this respect the most environmentally safe are SCB areas in the East-Arctic sector as ice conditions there have a high self-cleaning potential.

The Geoenvironmental background of the Russian Arctic SCB is generally favorable. But still there are SCB areas in the most industrially developed regions (especially in the coastal marine transportation, oil and gas industry and utilities framework development areas where geoenvironmental stress occurs thus requiring regular monitoring of the coastal dynamic development and marine environment quality.

3.4. Anthropogenic impact on natural landscapes

Russian Arctic landscapes are formed in low temperature conditions and characterised by very short vegetation periods, virtually widespread permafrost and water saturation. The most important **landscape features** of the Russian Arctic are:

- A high degree of susceptibility to planetary and space impacts;
- Increased zonal contrast and gradient mediums;
- Young landscapes with multiple relict components;
- High level of natural disasters;
- Simplified organic species diversity;
- Negative thermal balance and ice in the lithogenous landscape base.

These geographical features make the Russian Arctic landscapes highly sensitive to anthropogenic exposure.

The key negative changes in the Arctic landscapes are caused by the following:

Industrial development not corresponding to the natural environmental capacity and lack of adequate reclamation actions;

Limited industrial application of natural resources;

Unmatched land use types.

Recent research in the Russian Arctic has revealed territories with strong changes and disruption of the landscape environment. These negative effects are caused by the pollution of terrestrial and coastal marine and river ecosystems by heavy metals, oil products, different organic compounds, nitrogen and sulfur compounds, mechanical disturbance of soils and ground, and overexploitation of reindeer pastures.

The stable functioning of permafrost landscapes is determined by the degree of their congealed lithogenous base stability. Key factors determining the Russian Arctic landscapes stable functioning are thermal conditions of frozen layers, quantity, genotype and position of subsurface ice as well as the rate of denudation processes. The key stability characteristic of the Arctic terrestrial landscapes (based on the results of ice analysis as a mineral and rock) is subsurface ice formation. Greater ice content in frozen layers and proximity to the surface of the subsurface ice (or icy rock) results in reduced stability of the overlying landscape. The maximum ice content is recorded in the upper layer of syncryogenesis within high-latitude coastal regions of the Russian Arctic. The general principle of preserving the landscape environment functions and prevention of destructive processes in the industrial development territories of the Russian Arctic is ensuring the stable thermal turnover in the permafrost roof within a negative thermal range through the reduction of anthropogenic thermal flows to frozen soils.

The key factors causing land degradation in the Arctic region include fragmentation of the soil and vegetative cover and increased rate of destructive freeze – thaw processes which result in irreversible environmental consequences.

The total area of lands transformed as a result of anthropogenic impact in the tundra area is up to 3% of the total terrestrial part of the Russian Arctic. It is important to note that in some regions (areas adjacent to Norilsk, Monchegorsk and Zapolyarnoe copper and nickel plants) the soil mantle is disrupted within dozens of kilometers around them and there are signs of natural landscape transformation.

The annual increase of the unrehabilitated disrupted land area is 5–6,000 ha in oil industry, 2.5–3,000 ha in gas industry and 400–500 ha under pipelines construction.

Destructive cryolithomorphogenesis processes are deformation and mechanical disruption of the frozen roof, tabetisol and ground surface of the Russian Arctic caused by thermal and mass transfer between the frozen lithospheric area and atmosphere.

The amount of thermo erosion terrain in the forest-tundra and southern tundra is 0.01–0.1 m^3/km^2. The density of thermo erosion terrain types is 6 per 1 km^2, the average length is 100–400 m, the erosion depth is 2–6 m. The amount of thermo erosion terrain in representative tundra areas located to the North fluctuates within the range of 0.1–1.0 m^3/km^2, with an average length of 300–400 m and a depth of 10–12 m. The Arctic tundra is characterised by the maximum amount of terrain affected by thermo erosion: from 0.5 to 2–3 m^3/km^2, a gulley density of 10 per 1 km^2, length of 800–1 600 m and a depth of 15–18 m.

The rate of thermokarst terrain development is mainly caused by the position of pool-forming subsurface ice and icy layers in the frozen roof. In some Arctic regions a cause for concern is soil erosion which occurs as a result of natural vegetative cover disturbance and pollution. Such erosion is a result of permafrost thawing, ground cover degradation and deforestation.

The anthropogenic transformation of arctic vegetative cover is characterised by a decrease in lichen areas and an increase in the amount of grass plants in the tundra geosystems. Biodiversity falls and some species (primarily lichens) drop out of the natural communities. Anthropogenic habitats stocked by native species amounts to 40–60% of local flora.

Degradation of vegetative cover in territories of the Arctic is caused by the following key factors: pollution, logging of forests adjacent to tundra areas, exploitation of reindeer pastures, mechanical disturbances, etc. Primitive groups playing a major role in tundra vegetation cover (weeds, lichen, liverwort and leafy moss; multiple representative phanerogam Arctic species, inhabitants of specific tundra and Arctic eremic habitats) are extremely sensitive to chemical pollution, and typical Arctic animals are more sensitive in this respect.

One potential solution to degradation of the Arctic ecosystem requires the implementation of two major tasks: upgrading the protected natural areas system and expansion of the scope of environmental restoration works (including initial stages of biological recultivation) with simultaneous changes to the current land use structure. It is important to create a single environmental protection framework, i.e. a network of protected natural areas. It is still a requirement to create a regionally-based, environmentally-friendly use of natural resources, transportation and construction.

3.5. Anthropogenic impact effect

The anthropogenic impact on the Russian Arctic seas which impacts on the environment and commercial fishing is characterised by multiple factors, diversified sources and extreme irregularity of special distribution patterns. Environmental consequences mean alteration of sea water bodies causing disturbances in natural habitat composition (namely the habitat of aquatic organisms) and the structure and function of ecosystems. Effects on commercial fishing include a reduction in reserves of commercial species, depletion of reproduction and market condition, migration disturbances and other negative changes in fishery resources, as well as hindering the fishing and marine aquaculture. The strongest impact and negative consequences are concentrated within the narrow sea and land coastal belt where the adverse effect resulting from availability of pathogenic microorganisms in urban and utility sewages is also recorded.

Expert opinions on the nature, range and degree of risks associated with consequences of different types of activities and impact factors are shown in Table 1.

Table 1

Environmental consequences of anthropogenic impact on the Arctic marine environment

Types of activities and impact factors	Nature, range and degree of associated risks					
	Environmental			Commercial fishing		
	L	R (SR)	G	L	R (SR)	G
Industrial						
Waste discharge*	+++	++	–	++	+	–
Soild waste discharge*	+	–	–	+	–	–
Air emissions*	++	++	+	+	+	–
Water consumption	+	–	–	+	–	–
Emergencies*	++	+	–	++	+	–
Agriculture						
Fertilizers and biogene removal*	++	+	–	+	+	–
Pesticide removal*	++	+	–	+	+	–
Urban growth, construction and sea coast development						
Municipal sewage discharge*	+++	++	–	++	+	–
Coastal destruction	+++	+	–	++	+	–
Water consumption	+	–	–	+	–	–
Heat power						
Air emissions*	++	+	+?	+	–	–
Water consumption	+	–	–	+	–	–
Thermal pollution	+	–	–	–	–	–
Offshore oil and gas production						
Seismic survey	+++	+	–	+++	+	–
Drilling and field operation waste discharge*	++	–	–	+	–	–
Platform, terminal and pipeline construction	+++	+	–	+	+	–
Construction disposal	+	–	–	+	–	–
Emergencies*	+++	++	–	++	+	–
Onshore oil and gas production						
Oil ingress to water bodies*	+++	++	–	++	++	
Pipe reducers over rivers	++	–	–	+	–	–
Pipeline-related emergencies*	+++	++	–	++	+	–

table 1 (end)

Introduction and acclimatization of invaders						
Ecosystem alteration	+++	+++	–	++	++	–
Habitat disturbance	+++	++	–	++	++	–
Bottom dredging						
Coastal and bottom destruction	+++	++	–	+++	+	–
Increased sediment concentration	+++	+	–	+	–	–
Fluid circuits construction						
River runoff disturbance	+++	++?	–	+	?	–
Sea dumping (waste discharge)						
Bottom disturbances, increased sediment concentration*	++	+	–	+	–	–
Shipping						
Shipboard waste discharge*	++	+	–	+	+	–
Physical impact	+	+	–	++	–	–
Oil transportation by sea						
Ballast and bilge water discharge*	++	+	–	+	–	–
Tanker accidents*	+++	++	–	+++	+	–
Invasion of immigrant organisms	++	?	–	?	?	–
Fishing						
Selective biomas withdrawal, ecosystem structural disturbances	+++	+++	+	+++	+++	+
Bycatch discharge*	++	+	–	–	–	–
Bottom and benthos disturbances during over-trawling	+++	+?	–	++	+?	–
Forestry						
Coastal erosion and airborne dust intake balance disturbances	+++	+	–	+	–	–

Notes: 1. Impact range: L – local, R (SR) – regional (subregional), G – global. 2. Degree of environmental risk: +++ high, ++ average, + low, – negligible, ? – uncertain; * – types of activities associated with pollution.

The strongest anthropogenic impact on the Arctic seas is concentrated on related coasts, in bays, gulfs and coastal waters. Impact areas with high a level of environmental risk due to the river runoff effect, air pollution and industrial activities on the sea coasts and within coastal waters are shown in the Figure 3:

Anthropogenic stress level is falling in the transit area from the western part of the Arctic shelf (Barents, White and Kara Seas) to its eastern edges (Chukchi and Bering Seas).

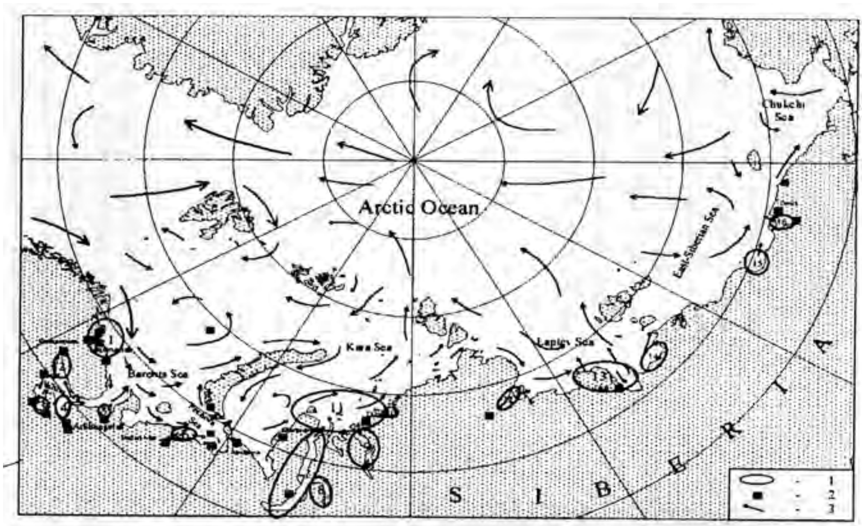

Fig. 3. Impact areas on the Arctic sea coasts [Evseev et all., 2000]

1 – river runoff impact areas; 2 – sources of local pollution (hot spots); 3 – ice drift directions

Strong and moderate negative effects of anthropogenic impact on coastal marine ecosystems of the Arctic are mainly limited locally. Regional and subregional levels are featured by an average, low or negligible degree of environmental risk.

Pollution is associated with most types of onshore and offshore activities and is the most wide-spread environmental risk factor in the Arctic marine environment. Effects on the environment and on commercial fishing occur only in relatively localized marine zones adjacent to regions of direct anthropogenic impact. It is estimated that the total area of such zones is less than 1% of the total coastal area of the Arctic seas amounting, in turn, to less than 10% of the total Arctic shelf area.

The maximum possible damage to commercial fishing resulting from the current pollution of the Arctic is less than 0.01% of lost commercial species biomass inhabiting the Russian Arctic seas. This value cannot be recorded with a view to high natural variability of reserves and the number and catches of commercial organisms.

The effect of pollution on marine fish and invertebrates inhabiting the open waters of the Arctic seas beyond the coastal (neritic) area (the basis of commercial catches in the Arctic) is negligible.

Virtually all types of anthropogenic impact on marine ecosystems by their nature do not differ from natural disturbances. Anthropogenic effects only change the range, frequency and rate of disturbances affecting the status of marine organisms, population and communities.

Fishing has the strongest and most wide-spread impact on the deep-sea ecosystem of the Western part of the Russian Arctic seas (especially the Barents and White Seas). The key factor of such impact is overfishing, resulting in critical (often crisis level) status of commercial populations and related catch reduction. Moreover, unsustainable fishing is associated with disturbances of marine ecosystems trophic structure, elimination of noncommercial species, discharge of by-catches into the sea and depletion of the benthic biocenosis as a result of trawling.

When making plans for the protection of the future marine environment and bioresources in the Arctic, it is necessary to consider that the most possible negative environmental effects may occur as a result of:

- Exploration and operation of offshore oil and gas fields (mainly in the Kara, Pechora and Barents Seas);
- tanker hydrocarbon transportation along the Kola Peninsula coast and by the Northern Sea Route;
- further unsustainable fishing, especially overfishing of mass fish and invertebrate species in the Western seas of the Russian Arctic;
- the increasing extent of invasion of immigrant organisms having been acclimatized in the Arctic seas (primarily the Kamchatka crab in the Barents and Norwegian Seas) and possible new invasions (especially as a result of tanker operations related to ballast waters).

Chapter 4

ENVIRONMENTAL POLLUTION OF THE RUSSIAN ARCTIC, REPUBLIC OF KOMI AND KHANTY-MANSIYSK AUTONOMOUS DISTRICT (YUGRA)

4.1. General information

Compared to other regions of the planet and highly populated areas of the Russian Federation, the Arctic remains relatively clean. But the Arctic is closely linked with other parts of the world, and pollutants are found from sources located far from the Arctic region (through long-distance pollution transport by air, sea and rivers). Moreover, some regions of the Russian Arctic have been actively developing during past decades. The development of the natural resources of the Arctic, including continental shelf hydrocarbons, is set to continue in the coming years in order to make the Russian Arctic a Russian Federation strategic resource base providing the implementation of social and economic development tasks.

The combination of long-range transboundary transport, the development of natural resources and defense-related activities resulted in the creation of multiple Russian Arctic hot spots and impact areas with polluted air, soils, surface and ground waters as well as degraded ecosystems. Pollutants are accumulated in food and conventional forage thus creating health risks for the population, including the small populations of indigenous peoples of the North.

Specific features of the Arctic cause regional and circumpolar distribution of local pollutions under particular conditions. For this reason, the issue of Arctic environmental pollution is a key concern of all Arctic states. This issue may be resolved only by international cooperation, mutual effort and support of all stakeholders.

The most hazardous and wide-spread environmental pollutants in the Russian Arctic are heavy metals, oil hydrocarbons, persistent organic pollutants, acidifying substances and radionuclides.

A description of the environmental status of the Russian Arctic, and the adjacent Subarctic regions, plus key sources of priority pollutants is given below.

4.2. Sources of pollution and migration ways

The key sources of pollution (hereinafter referred to as pollutants) transport to the Arctic sea areas are subdivided into three types:

– exogenous (river runoff, eolian destruction, wave abrasion, glacial, ice and iceberg quarries);

– endogenous (substances moved from the interior, e.g. oil hydrocarbons and methane discharge from sedimentation mass, gas hydrate discharges, etc.);

– aquatic polyanthropogenic (waste dumping, oil and toxic substances transportation, offshore fields development, pollutants transported by the global ocean current system).

The most important exogenous source of sediments, including pollutants, is river runoff**.** Specific data (Mikhailov, 1997; Gordeev, Rachold, 2003) specify that the total water runoff of all Russian Arctic rivers amounts to 2,932 km^3/year. Rivers collect their waters with diluted and weighted load from a wide catchment basin (approximately 13,000,000 sq. km) located in different climatic zones. Total runoff of solid substances to the Arctic is 103,000,000 tons annually. Rivers discharge 19,400,000 tons of diluted and 3,800,000 tons of weighted organic carbon to the Arctic.

The river and sea water mixing area is exceptionally important. This area is a very effective trap for substances discharged by rivers. It is estimated (Gordeev, 1983; Lisitsin, 1994) that in this area, up to 90–95% of diluted and 20–40% of weighted substances (including pollutants) which drop out from further transport to the ocean settle.

A particular role is played by ground water runoff which discharges one tenth of the river runoff to the Arctic and undercuts the coastal belt (approximately 4 times more than solid river runoff). Sea ice transports approximately 14,000,000 tons of solid substance and eolic discharge of the

Arctic basin amounts to approximately 3,000,000 tons. Despite the relatively low amount of eolic precipitation, air dust transports a large amount of pollutants.

Endogenous sources in the Arctic are limited and segmentary. For example, research results of the All-Russia Scientific Research Institute for Geology and Mineral Resources of the Ocean (Saint-Petersburg) showed the presence of migrating gas in the Stockman field, which may wash different substances over from the sedimentation mass, especially PAH (Petrova, 1999).

The most important multi-anthropogenic source is oil and oil products transportated by the sea. Operational waste amounts to up to 50% of the total oil ingress into the marine environment. The increasing rate of oil field development may materially increase the amount of oil hydrocarbon discharges into the sea. Other important sources of this type are ocean currents. It's worth nothing that the Gulf Stream system transports up to 1–1,500,000 tons of oil products annually (Simonov et al., 1974). Sea currents also transport to the Arctic such substances as PCB, heavy metals (e.g. cadmium) and artificial radionuclides from the United Kingdom (Sellafield) and France (La Hague).

According to research results of the All-Russia Scientific Research Institute for Geology and Mineral Resources of the Ocean (Andreeva et al., 2004) possible pollutant accumulation on the Russian Arctic sea shelves is determined by granulometric and mineral composition features of modern bottom deposits. Shelf areas where bed-load transport controlled by currents and bottom terrain is interrupted are of special interest from an environmental point of view as they form geomorphic traps accumulating natural sediments and pollutants.

Different pollutants may exist in different states: diluted in natural waters, as fine particles, colloid, gaseous and other states. The physical state of particular pollutants determines the route and means of transfer thereof from sources to depositing and accumulation areas.

4.3. Effect of hydrometeorological factors

The Arctic is a region to which atmospheric flow from the South often transports suspended pollutants.

Analysis of the background circulation characteristics observed above open water and coastal areas of the Russian Arctic seas shows that in winter and spring:

– north-westerly and westerly air flows prevail over the open water areas of the Barents and Kara seas, which is the main reason behind relatively low organic pollutant accumulation rates in the snow cover, and insignificant meridional transfers from industrial pollution sources located in adjacent European Russia, Ural and Siberian areas;

– it is characteristic of the Laptev Sea to have south-westerly and southerly air flows, which is why primarily Ural and Western Siberian industrial areas contribute a significant amount of pollutants here;

– it is south-westerly, south-easterly and southerly air flows that prevail in the East Siberian and Chukchi seas in this period, therefore it is the Far East areas, including China and Japan, that are the main pollution contributors here.

In winter, meridional air flows transport pollutants from sources located thousands of kilometers far from the Arctic region. In summer there is a growing contribution of meridional transfers from mid-distant and local sources to the pollution of open water and coastal areas in the Arctic seas.

Pollutants transported in marine areas by water flow are mainly related to pollutants transport by surface wind currents.

The function of flood currents is limited to participation in the formation of short-term (daily and average-range) fluctuations in the concentration in particular local sea areas together with physical and chemical processes.

4.4. Main types of pollutants

Heavy metals

Heavy metals (HM) are discharged to the atmosphere, water and terrestrial ecosystems as a result of natural and anthropogenic processes carried out both on the earth's surface and interior. Natural processes include volcanic activity, rock weathering, plant destruction. Anthropogenic processes include industrial production, mineral extraction, combustion of different types of fuels, i.e. processes caused by and related to anthropogenic activities.

There are three main ways of heavy metal transport to the Arctic seas: by air, by land and river (river runoff, ice), and by ocean (ocean currents).

According to recent research, it is evident that air transport of mercury is the main method of transport to the Arctic. Amounts of cadmium and lead are similar, but the highest quantities of zinc are transported by river runoff. Surface waters of the Atlantic and Pacific Oceans are richer in HM than those of the Arctic Ocean, thus the first are sources of HM transport by ocean currents through the Fram Strait to the Barents Sea and through the Bering Strait to the Chukchi Sea. The rate of pollution transport by the ocean is very low and may take from a year to a decade. The highest concentrations of mercury, cadmium and lead are recorded in fish of the Western sector of the Barents Sea where the Gulf Stream effect occurs.

Transport level of HM by river waters is relatively low as all major Siberian rivers are very long (4–5,500 km) and they are able to self-clean, taking HM in the high and middle course. Therefore, HM concentration level in estuaries of the Ob, Enisey and Lena rivers is nearly background, i.e. less than MPC, but there are local areas above estuaries where the HM concentration level may be many times higher than MPC. Based on the results of analysis of different data, it may be concluded that the main sources of HM that ingress into the Arctic Ocean are related to runoff of small and medium rivers (not more than 200 km long) which are not able to completely self-clean. In the Lola Peninsula and Norilsk industrial district, with large discharge sources of waters contaminated by heavy metals, they accumulate mainly in closed water bodies and are not discharged into the Arctic Ocean.

The majority of heavy metals are toxic substances being highly hazardous for biological systems. The Arctic region, and especially the Arctic coastal area, is increasingly affected by the anthropogenic impact both of the long-range transboundary transport of heavy metals and activities of local industrial centres. It is well-known that the Arctic environment is highly sensitive to impact of pollution due to low level of mass and energy transfer, slow self-cleaning processes, and short food chains causing fast transfer of heavy metals to end consumers.

During the 20^{th} century the transfer of heavy metals to the environment has continued as the level of consumption thereof increased. The highest amount of HM transferred to the environment is of lead and zinc. The most hazardous confirmed health risk factor is high concentrations of such highly toxic substances as mercury, cadmium and lead. As a result of transboundary air transfer, European Russia imports the three elements in the following import/export ratios: mercury and cadmium: 2.2/1, lead:

5.6/1. A set amount of these pollutants is transported to the western region of the Russian Arctic in winter. The total amount of emissions in European Russia exceeds that of the Asian territories, and the contribution of motor vehicles in European Russia increased from 38.8% in 1990 to 62.3% in 2007. During a 17-year period from 1990 to 2007, the emissions of solid substances in Russia (by indirect monitoring of HM) have reduced by 4,600,000 tons, i.e. reduced by a factor of 2.6.

The key sources of HM emissions in the Russian Arctic are major copper and nickel plants in the Kola Peninsula (Murmansk Region) and the Norilsk industrial district (Krasnoyarsk Region). As a rule, emissions of metallurgic and thermal power industries are associated with emissions of acidifying substances over wide areas which indirectly affect water systems by acid leaching of unstable elements (especially aluminium, cadmium and zinc). Other sources of HM emissions (thermal energy plants using fossil fuels, transport, waste recycling, etc.) have regional or local impact. This is due to the fact that the industries of the Kola Peninsula and the eastern sector of the Arctic are provided with green power produced by the Kola and Bilibino nuclear power plants and the Norilsk industrial district uses environmentally-friendly natural gas. In addition, there are very few motorcars.

Mercury is one of the most toxic substances. Mercury ingress into the environment related mainly to mining activities and the combustion of different fuels during the previous century has increased from 2 to 20 times due to local, regional and global anthropogenic emissions. Recent research results showed that air transport of mercury is the key factor in its transfer to the Arctic. A constantly high level of gaseous mercury in the air (1.5–1.8 ng/m^3) is recorded in the European region of the Russian Arctic far from urban communities (on land and in the coastal area). To the North of the Ural, the concentration level over the sea area is reduced by 50%. Within urban areas, the concentration of mercury is higher. In spring, the average concentration of 2.2 ng/m^3 in Murmansk (the so called mercury stress relief period) is 1.5 times higher than the average Arctic concentration, in winter this value may be significantly higher. In the Russian Arctic seas, the concentration of Mercury is lower over the surface of the sea than over the land. The average concentration of mercury in the air over the Barents and Kara Seas is 0.76 ng/m^3 falling to 0.32 ng/m^3 to the East.

The main source of cadmium is nonferrous metallurgy. Emissions from this industry are 1.5 times higher than natural values. Cadmium exists in natural waters mainly in its elemental form. Global ingress of lead to the environment has increased greatly in line with its production. Generally, the Russian Arctic is characterised by a low concentration of metals in the air compared to southern regions of Europe and Asia. It is not related to the Norilsk industrial district and Kola Peninsula due to emissions of copper and nickel plants. Based on spacial distribution of components in the snow cover, the Murmansk coastal area is affected by regional anthropogenic emission sources of Cu, Zn and Ni. As to Pb, Cr, Cd and Hg, impact of regional sources is quite low and their transport to the Arctic is related to long-range, transboundary transport of air pollution.

Within the period 1983 to 2001, the concentration of Pb and Cd in the air over the open waters of the Barents Sea fell. The concentration of Pb fell by more than 10 times and that of Cd by approximately 2 times. This conclusion was based on monitoring results of the Spitsbergen Archipelago and results of this research may also reflect global processes in the Russian Arctic. It seems that the reduction in concentration is mainly connected with a global decrease in anthropogenic emission levels of these metals. Reduction in concentrations over the open waters of the Barents Sea is recorded from coasts to its central areas. Mercury concentration surges in spring with wet precipitation and this is caused by washing of reactive and pulverized mercury forms out of the air.

The main source of pollution of the Russian Arctic terrestrial ecosystems with heavy metals is related to emissions of plants located in the Norilsk industrial region, Murmansk and Arkhangelsk Regions where major nonferrous processing plants, mining and power facilities are concentrated. In pollution impact areas adjacent to nonferrous processing plants, there are industrial wastelands (covering areas of up to 10 km) with high concentrations of heavy metals in soils, mainly nickel and copper. Within the area from 10 to 100 km from such areas, forest degradation processes caused by heavy metals and effects of acid precipitation are increasing. In the forests affected by melting plants emissions in the North Kola and Norilsk industrial region, there are high concentrations of metals in soils resulting in disturbances in forest nutrition conditions. As a result of heavy metals impact, lichens and muscoids able to accumulate fertilizer elements from air die; microbial communities are suppressed and the rate of organic matter decomposition decreases due to inhibition of microorganisms (mainly fungi). Deficits in elements such as calcium, magnesium (up to deficiency levels) and manganese have shown nutrition disorders in spruce and pine.

The concentration of heavy metals in the soils of the remote Arctic regions (on the main territory) is within, or close to, the average concentrations of the Earth's crust and any increases in this concentration are caused by geochemical processes.

Heavy metals are transferred to surface waters with industrial wastewaters, fumes and as a result of acid leaching of the surrounding rock. Most instances of pollution of major rivers by heavy metal sources are concentrated in the European Arctic and Western Siberia. In estuary areas of major rivers, the concentration of metals in water and weighted material is close to background values due to dilution and self-cleaning processes. Despite the fact that the concentration of metals in estuarine areas of major rivers is relatively low, there are high concentrations of heavy metals in water and bottom deposits in local runoff discharge areas, and in this case, water and bottom deposits reflect the particular type of impact in the catchment area. Major issues related to water environment status are recorded in the Republic of Sakha (Yakutia), in the Kolyma river basin, the Chukchi Autonomous District and other regions of the Eastern Arctic. But the situation in these regions is not critical.

High concentrations of nickel and copper in lake waters significantly exceeding MPC are recorded around metallurgical plants (30–50 km from the plant depending on wind direction). During recent years, heavy metal emissions and dropout in catchment areas have tended to decrease. This has resulted in a decrease in the nickel and copper concentration of terrestrial water bodies on the Kola Peninsula (especially compared to 1990). Average nickel concentrations (midpoint) recorded during the recent decade are within 1 mkg/l range and lower, thus conforming to the regional level. The average copper content has also decreased but at the same time the level of water pollution by these metals is still high (nickel and copper concentration being more than 10 mkg/l). The concentration of nickel has increased from 2,005 as compared to 2,000 and this may be caused by the operation of active melting plants after a stagnation period and long-range dissemination of substances.

The negative environmental effects of water pollution by metals depend on the concentration level, existing state and behavior, combinations and additional factors (acidifying or eutrophication). The concentration of unstable (ionic) forms of metals in northern waters is significantly higher than bound and complex compounds due to the extremely low complex-forming properties of Arctic waters. The environmental risks for eutrophic lakes, or lakes enriched with humic substance during the subglacial period, are greatly increasing. Metal desorption in winter, together with organic matter and metals deposited on the bottom, play a major role in contributing to the impact of metals in relation to the bottom fauna of Arctic regions. Acid precipitation causes leaching of exchange bases and toxic metals out of the catchment area thus resulting in alteration of salt runoff to seas and increased discharge of particular toxic metals to coastal sea areas. The most hazardous situation is seen in the snow melting period when accumulated metals in melt water are quickly discharged into catchment areas: up to 75% of metals are discharged from the catchment area to small rivers during spring flood-time creating the toxic "shock wave" affecting water inhabitants of littoral areas.

The operation of major metallurgical plants results in the formation of technogenic, geochemical provinces on the bottom of lakes. In these regions extracted, and industrially processed metals, become toxic. Metals accumulated in bottom sediments may become sources of secondary water pollution.

In lakes located far from industrial centers (shown on Chuna-tundra lakes), the concentration of metals tends to increase. This trend is related to both long-range transboundary transport of metals and local metal emission sources. Looking back, we can see that the accumulation of Pb, Cd and other substances in the Arctic region started in the late 19th century, at the same time as the industrial development of Europe. This is confirmed by global air pollution of the Northern hemisphere since this period. In the middle of the 20th century, metal accumulation level increased due to the development of local industry in the Arctic region as a result of related enrichment of the upper atmosphere. Heavy metal concentration in fish reflects the pollution level of natural waters. The highest concentration of mercury, cadmium and lead is recorded in lakes affected by anthropogenic air pollution by heavy metals and acid precipitation.

Acceptance of international treaties on further reduction of heavy metals emissions, especially lead, mercury and cadmium transferred to the

Arctic with transboundary flows may reduce the environmental pollution level of the Russian Arctic. Key Russian environmental protection tasks shall include reduction of heavy metal emissions via fumes as a result of upgrading of copper and nickel plants, primarily Norilsk Nickel MMC JSC and the Pechenganickel plant as well as cleaning up the Kola Bay bottom sediments. Recultivation of disturbed territories may be carried out following the implementation of the above tasks and reduction of industrial load up to the level which allows self-restoration processes within the disturbed territories adjacent to mining and smelting plants to occur.

Oil pollution

River runoff materially contributes to the aggregate amount of oil hydrocarbons discharged into the Eastern Arctic seas. This is primarily referred to the Ob and Enisey rivers characterised by maximum river runoff and increased oil pollution. Exploration, production and methods of oil transportation represent a particular risk of pollution and strong environmental risk for the Arctic environment. International cleanup practice shows that only 10–15% of oil can be collected and disposed of in the Arctic region. The most hazardous source of oil pollution is oil and transportation of oil products.

When discharged into the natural water environment, oil and oil products undergo different physical, chemical and biogeochemical processes. The most important are: evaporation, emulsification, dilution, acidification, aggregation development, sedimentation, biodegradation, including microbial destruction and assimilation by planktonic and benthos organisms. As a result oil film disperses from the sea surface and oil aggregate disappears from the sea coast. During oil transformation, air temperature and the presence of biogenic substances are of key importance.

Ice cover at all stages of its formation slows down the processes of oil transformation, contributes to the formation of stable emulsions, accumulates large amounts of oil and completely blocks its transfer under the ice layer. Transformation of oil products in the snow and ice cover is determined by the weather conditions in the disaster area, the temperature gradient in the water-ice-air system, the structure of ice and the properties of the oil. Hydrophobic properties of aliphatic hyrocarbons determine their high weighted content in snow and ice. The transfer of oil in the ice depends on its age, structure, porosity, density, snow content and other properties. At the same time sorption of oil products by ice and their filtering through the ice layer may occur in capillary and drain channels. During transformation of oil hydrocarbons in the old ice, the main factor is wind processes, and in fast and porous ice the major role is played by filtering through capillaries and drain channels caused by convection-diffusion mechanisms.

Snow cover has properties which make it a good indicator of ecosystem conditions as it functions as a «table» absorbing «fresh» not only atmospheric and air precipitation, but also water pollutants. Ice functioning as a pump accumulates organic compounds from snow and water. That is the cause of increased snow and upper ice layer concentrations of hydrocarbons in impact areas, and in the ice-water boundary in background areas.

Hydrocarbons may be transported by snow and ice for long distances in both lateral and vertical directions. Hydrocarbon distribution in the ice layer is affected not only by its age, but also formation conditions and drift.

Analysis of the levels of hydrocarbons (content and composition of aliphatic hyrocarbons (AH) and polycyclic aromatic hydrocarbons (PAH)) in waters and bottom sediments of the Kara, Barents, White and other seas showed that the current environmental status of the Russian Arctic seas is very diversified with a view to conditions and factors of anthropogenic impact. Increased levels of oil pollution are typical for shallow coastal areas near cities, ports and bays.

Pollutants discharged by rivers are deposited in the river and sea water mixing areas (margin filter area) due to transformation and drop out of both anthropogenic and natural compounds (mainly high-molecular), particularly benzapyrene and other cancerogenic homologous compounds. The quantity of pollutants decreases with increasing distance from such areas to open water (up to values that cannot be recorded on the background of natural process dynamics). The hydrocarbon concentration gradient within these areas is mainly determined by the amount of river runoff, the salinity of sea water, and the hydrological properties of estuary areas. This is the reason why pollutants carried by river runoff are not transferred to open sea waters.

Generally, AH background concentration in bottom sediments is less than 10–20 mkg/g for sandy and 100 mkg/g for silt deposits and their amount in organic carbon (C_{org}) is ≈1%. Increased AH concentration (in dry weight equivalent and in C_{org}) is recorded in sediments contaminated by oil products, especially in showery sedimentation areas. Sediments in the White and Kara Seas in the river margin filter field are characterized by domination of the most stable natural high-molecular AH (terrigenous, allochthonous).

Analysis of available data shows that since 1990 there have been no material changes in concentration and composition of hydrocarbons present in bottom sediments of the Russian Arctic seas. The level of unsubstituted PAH in sediments decreases from west to east as follows (ng/y): Barents Sea (Spitsbergen: 2144), Pechora Sea (156), Kara Sea (66–129), Laptev Sea (13–40). The quantity of petrogenic and oil polyarenes in their composition decreases in a similar order, i.e. a higher concentration of anthropogenic compounds is characteristic of the Barents Sea sediments. PAH concentration values in the Beaufort Sea (597 ng/g), in the Mackenzie river delta (748 ng/g), and in the North-West area of the Barents Sea (607 ng/g) and the adjacent Western area of the Arctic Ocean (664 ng/g) may be considered close (AMAP, 2007). Pertogenic polyarenes dominate.

The effect on the ecosystem of the pollution-affected area is exacerbated by the negative effect on fishery sources with the main population of commercial fish and invertebrate species (commercial bioresources) and economic damage (losses in and disturbances to fishing as a type of business activity). The majority of fish and invertebrates studied show a high sensitivity to oil at early life stages. Toxic concentrations (with lethal effect on organisms or irreversible damage to vital functions) affecting embryos, larvae and young marine organisms are generally significantly lower than those affecting imago, and may reach maximum levels of approximately 10–2 mg/l during relatively long-term (persistent) impact of diluted oil hydrocarbons.

Concentrations of PAH and other oil components in organisms is determined not only by its concentration in the environment but also the proportion of the intake rate, the enzymolysis rate in organs and tissues and the elimination rate. As a rule, benthos invertebrates (especially hard clam) due to their poorly developed enzyme and metabolic systems as compared to fish, their high filtration activity and bottom inhabitation, have a high capacity for oil compound accumulation. In the process of oil "weathering" (evaporation, dispersion, oxidation, etc.) and elimination of the most soluble mono-aroma compounds (benzene, toluene, xylain, etc.), the contribution of high-molecular PAH ultimately means that the long-term (persistent) oil toxicity level will increase.

Targeted research of the consequences of oil spills, including in the Northern and Arctic seas, has not revealed direct confirmation of mass fish mortality or decrease in reserves and catches. Such loss (even in most pessimistic scenarios) amounts to potentially hundreds of tons of biomass and cannot be seen on the population level on the background of natural mortality and fishing.

Based on the results of multiple research related to the consequences of oil spills in different regions (including Arctic and Subarctic seas), it may be stated that the impact range in the coastal area of the Arctic seas may vary from local to subregional depending on the type and particular conditions of spills. Environmental effects mainly take the form of reversible or low-reversible stresses for sea birds, mammals and benthic organisms. Their restoration requires a period from one season to some years. In case of deep-sea spills (without oil carryover to the coast) evident long-term effects on the deep-sea community is actually impossible.

Today all pelagic zones of the Arctic seas and the main part of coastal waters are located in soft oil concentration area. Sublethal effects (decreased growth and reproduction rate, etc.) and acute oil intoxication may occur only in limited sectors of the coastal belt with strong and persistent pollution factors (oil terminals, ports, etc.). This conclusion is supported by all available data on oil pollution of the Russian Arctic seas.

Persistent organic pollutants (POPs)

POPs represent a specific group of organic substances acknowledged by the international community as highly hazardous for health and the environment. The general properties of POPs are high toxicity level, ability to accumulate in living tissues, persistence in the environment for long periods of time and slowly break up under the influence of natural environmental factors.

The presence of POPs on the main territory of the Arctic, including the Russian Arctic, cannot be linked with any current established use of these substances and/or emission from sources located in the Arctic, but it can be only explained by transport from lower latitudes. POPs are transported over long distances by atmospheric transfer to regions significantly far away from the initial sources. It is a well-known fact that arctic regions of the Earth are sinks for POPs as well as suffering from the negative impact of these substances on all natural objects (from water organisms to animals and humans). Atmospheric transport of POPs to the Arctic from pollution sources in low latitudes may take from several days to some weeks. Apart from atmospheric transport, another source of pollution transport to the

Russian Arctic is via the northern rivers (the Northern Dvina, Ob, Enisey and others), especially during flooding. Specific climatic conditions attributable to Arctic regions (low temperature, lack of daylight, etc.) cause the extension of natural POP breakup and conservation period in environmental objects.

The effect of POPs on animals and humans is significantly stronger in the Arctic as compared to lower latitudes. All POPs are toxic for water organisms and cause long-term changes in water ecosystems. POPs accumulate in living organisms through biological accumulation processes and thus fish, birds, mammals and human beings on the top of food chains are at the strongest risk. Accumulation of POPs in the fatty tissues and the blood of animals included in the food pattern of the indigenous population of the Arctic is one of the methods of transport to northern population. POPs cause diseases of all immune systems of the organism even if the intake level is extremely low.

Within the problem of POP pollution of the northern regions (apart from pollution transport from external sources), a significant contribution is made by the industrial activities of the Russian Arctic where large environmental pollution sources are located (Norilsk MMC, West-Siberian oil and gas companies, etc.) as well as Russian industrial centers located along rivers flowing into the Russian Arctic seas.

POP usage is governed by the Stockholm Convention on Persistent Organic Pollutants (hereinafter referred to as the Stockholm Convention) effective from May 17, 2004. Member states committed to withdraw super toxicants from production and usage and further dispose of all accumulated stock thereof. Russia signed this Convention, but it has not yet been ratified (as of 2010). Today Russia is implementing the preliminary activities required for ratification.

Initially, the group of POPs prohibited by the Stockholm Convention included 12 chlorine-containing organic substances: *pesticides* (aldrin, dieldrin, chlordan, endrine, mirex, heptachlorine, hexacholbenzene, toxafene, DDT); *industrial chemicals* (polychlorinated biphenyls) and *by-products* (polychlorinated dibenzo-p-dioxines and polychlorinated dibenzofurans). In May 2009, during the 4th conference of the Stockholm Convention, the list of POPs was extended up to 21 halogenorganic substances, including (together with the «dirty dozen») alpha- and beta- hexachlorcyclohexane, lindane, bromine-containing atipyrenes and perfluorooctane sulfonic acid and its derivatives.

Polychlorinated biphenyls (PCB) are included in the POPs list and may be the source of more toxic polychlorinated dibenzodioxines (PCDD) and polychlorinated dibenzofurans (PCDF). Background concentrations of PCB are found in all Arctic environmental objects (soils, bottom sediments, air). It is necessary to note that the highest PCB background levels in the global Arctic air were recorded in 2008 (at the Valkarkay station on the Chukchi Peninsula). Distribution of PCB in the Valkarkay air actually matched the composition of sovol (a commercial PCB mix used in the USSR).

Today it has been confirmed that PCB have an embryotoxic and potentially cancerogenic effect but the most hazardous is a mutagenic effect. PCB are characterized by an ability to be transferred in the food chain and accumulate in blood and fat-containing organs of fish and animals even if low PCB concentration is available in natural objects. The amount of fat in the traditional diet of the indigenous people of the north causes an excess concentration of PCB and other POPs in the human body. A specific risk of adverse effect occurs for pregnant women as PCB, like other POPs, are easily transferred through the transplacental barrier and transported to the organism during prenatal development.

PCB were produced mainly as dielectrics for transformers and condensers as well as for other applications such as varnishes, paints, finishes and thermal liquids. In the Russian Federation, PCB production was abandoned in 1990–1993, but they are still used in electrical equipment.

Huge stocks of PCB in PCB-containing equipment are located directly in the Russian Arctic (4 regions), namely the Murmansk Region, the Yamalo-Nenets Autonomous District, the Krasnoyarsk Region and the Republic of Sakha (Yakutia). According to available data in 2009, approximately 1269 tons of PCB are concentrated in these regions (644 transformers and 3422 condensers).

The largest amount of PCB is concentrated in the Krasnoyarsk Region (approximately 990 tons) and the Yamalo-Nenets Autonomous District (approximately 235 tons). In Krasnoyarsk (Krasnoyarsk Paper Mill), 290 tons of PCB are contained in 151 transformers and 242 condensers out of total of 396 tons. In Norilsk (Norilsk MMC) there are approximately 461 tons of PCB in 223 transformers and 397 condensers. In the Yamalo-Nenets Autonomous District the highest amount of PCB and PCB-containing equipment are concentrated in Novy Urengoy (118 tons of PCB in

67 transformers) and Noyabrsk (114 tons PCB in 75 transformers and 41 condensers).

Aldrin, dieldrin, chlordane, endrin and mirex were not produced, imported and used in the former USSR. Toxaphene was produced under the name of polychloropinene and polychlorocamphene and used in agriculture up to the late 1980s. DDT was manufactured up to 1988 and was the most widely-used insecticide in the former USSR. Hexachlorobenzene (HCB) was permitted for use as a component up to 1990–1996. Sources of HCB as a by-product include chemical production of organochlorine synthetic products, combustion of industrial and household waste.

Pentachlorobenzene was used as a pesticide and antipyrene, and in dielectric fluids in electrical equipment together with PCB, as well as a by-product for production of pentachloronitrobenzene (quintozene). Pentachlorobenzene may exist as an additive in some organochlorine solvents and pesticides (quintozene, endosulfane, chloropyrphos-methyl, athrasin). Pentachlorobenzene has not been manufactured in Russia. This substance may be unintentionally produced during the manufacture of organochlorine synthetic products and the combustion of domestic and industrial waste. Pentachlorobenzene was found on Russian Hydrometeorological Service (Roshydromet) stations in the Russian Arctic: in Amderma (Arkhangelsk Region): approximately 2 pg/m^3 and Valkarkay (Chukchi Autonomous District): approximately 1 pg/m^3.

In the Roshydromet network, DDT and HCB are included in a pesticide soil pollution monitoring plan, DDT in a sea pollution monitoring plan and background air pollution monitoring programme. Despite the fact that DDT has not been used in Russia for a long time, background concentrations of DDT and its metabolite DDE are recorded in all environmental objects of the Russian Arctic, such as soils, bottom sediments and air.

In 2003, a detailed research project (within ACAP of the Arctic Council) on the composition and amount of prohibited pesticides stored in four Russian Arctic and six Siberian and Far Eastern regions adjacent to the Russian Arctic was conducted. According to its results, four Arctic and Subarctic regions (the Arkhangelsk Region, the Republic of Komi, the Krasnoyarsk Region and the Murmansk Region) had a stock of approximately 27 tons of chlorine-containing prohibited pesticides. POP-containing pesticides were found in the Arkhangelsk Region (polychlorocamfene: 570 l; HCCH (hexachlorane): 0.7 tons) and in the Krasnoyarsk Region

The Siberian and Far Eastern regions (Altay and Kamchatka regions, Kurgan, Magadan, Omsk and Tyumen regions) directly affect the Arctic environment and may significantly affect the Russian Arctic environmental status. Rivers of these regions (such as the Ob and the Enisey) are sources of pesticides and other pollutant transport to the Russian Arctic, especially during floodings. An inventory inspection of prohibited pesticides conducted in 2003 in these territories showed that there are large stocks of these substances with POPs-containing pesticides among them. Major risks are posed by both inadequate storage and the availability of unidentified substances and mixes.

Polychlorinated dibenzo-p-dioxines and dibenzofurans (dioxins, PCDD/PCDF), being the most toxic POPs, are never produced intentionally. They are created as a result of incomplete combustion of chlorine-containing products and production of particular chlorine-containing pesticides and other chemicals. Dioxin emissions may be caused by some types of metal recycling and paper production. Dioxins are contained in motor vehicle emissions and fumes created by combustion of wood and coal.

The major sources of air pollution, including dioxin pollution, in the Russian Arctic and adjacent territories are: the Vorkuta Cement Plant and Syktyvkar Forestry in the Republic of Komi; the Kotlas Paper Mill, the Arkhangelsk Paper Mill, the Solombalsk Paper Mill in the Arkhangelsk Region; Apatite JSC, Kovdor MMC JSC and Kola MMC JSC in the Murmansk Region; Norilsk Nickel MMC JSC, the Achinsk Alumina Plant JSC and the Krasnoyarsk Aluminium Plant JSC.

Environmental pollution monitoring in Russia is performed by Roshydromet, but the concentration of the most toxic POPs (PCDD/PCDF) is not monitored. Implementation of complex analytical methods of POPs identification (especially dioxins and furan) within its network is still too costly. Monitoring of the concentrations of dioxins and furan is performed within particular international and regional projects.

The transboundary component of the total amount of precipitation of PCDD/PCDF in anthropogenic emissions in 2006 in the territory of European Russia was 39%, and Russian sources amounted to 61% (EMEP report, 2008). Transboundary dioxin transport in the Russian Arctic is becoming dominant (up to more than 97% of total precipitation amount) with the major sources located in the USA and Canada. PCDD/A fallout density in the Russian Arctic is 0.1–0.3 DE/m^2 annually (excluding the southern part of the Murmansk Region). This is considerably lower than in European Russia. The average annual PCDD/A concentration in the surface air of European Russia is estimated to be within the range of 0.3 to 3 fg DE/m^3, and less than 0.3 fg DE/m^3 in the Russian Arctic.

Lindane (gamma-hexachlorocyclohexane, gamma-HCCH) is an insecticide widely used to control the population of multiple phytivorous and terricolous infestants. At the present time, the application of HCCH-containing substances is prohibited in Russia. Lindane was an industrial by-product created during extrication of hexachlorocyclohexane isomers (alpha, beta, gamma, etc.) via additional benzene chloration.

Alpha- and beta-hexachlorocyclohexanes (alpha-HCCH and beta-HCCH) are stereomers of hexachlorocyclohexane created as by-products of lindane production. Each ton of lindane created produces up to eight tons of these isomers. These substances are mainly referred to as toxic waste and may be more toxic than lindane. Alpha-HCCH and beta-HCCH are included in technical and concentrated HCCH.

Background concentrations of HCCH isomers are found in all environmental objects of the Arctic (soils, bottom sediments, air) but they differ in particular parts of the Arctic. The concentration of these substances in the waters of the Barents Sea is considerably lower than in the Canadian Arctic seas. Alpha- and gamma-HCCH were found in other organochlorine pesticides in the air on Roshydromet stations in the Russian Arctic: in Amderma (Arkhangelsk Region) and Valkarkay (Chukchi Autonomous District). The average concentration of HCCH isomers near Valkarkay Weather Station within the period from April to September 2008 was approximately 27 and 1.2 pg/m^3 for alpha-HCCH and gamma-HCCH respectively. The maximum concentration of HCCH isomers was recorded in the first three months of this period, and in June-September, the concentration of these substances in the air dropped off and was lower than detection levels.

In 2003, in the Russian Arctic, there were approximately 11 tons of pesticides containing HCCH (data provided by the Ministry of Agriculture of Russia) in the Arkhangelsk Region (0.7 tons) and the Krasnoyarsk Region (10.3). In particular, quantities of HCCH substances in the Siberian and Far Eastern regions may be transferred to the Russian Arctic and Arctic Ocean due to their adjacent positions. In 2003, there were approximately 213 tons of different pesticides containing HCCH isomers in the Altay, Kurgan, Magadan, Omsk and Tyumen regions.

Hexabromobiphenyl (GBB) had been used since 1970 as antipyrene in the production of thermal plastics, the construction industry, industrial and electrical products as well as the polyurethane foam used for internal decoration of cars. In Russia, GBB was not produced, but imported as a component of GBB-containing items.

Pentabromodiphenyl ether (penta BDE**)** is a polybromodiphenyl ether (PBDE) used as antipyrene. Commercial penta BDE may contain 3–6 atoms of bromine (main compounds are tetra BDE, penta BDE and hexa BDE). This substance is found in the human body in all regions of the Earth. Research has shown that it affects the reproductive system and hormones produced by the thyroid gland. It is extremely stable in the environment and has bioaccumulation and long-range transport capacity. In Russia penta BDE was not produced, but imported as antipyrenes and as a component of industrial items. Within the period 2000 to 2004, Russia imported approximately 21.3 tons of penta BDE (data provided by the Federal Customs Service of Russia).

Octabromodiphenyl ether (octa BDE) is a polybromodiphenyl ether used as antipyrene. Commercial octa BDE may contain 6–8 atoms of bromine (main compounds are hexa BDE, hepta BDE and octa BDE). In Russia the sole enterprise producing bromine-containing antipyrenes is Altaykhimprom JSC, but octa BDE is not produced there. Within the period 2000 to 2004, Russia imported approximately 75 tons of octa BDE (data provided by the Federal Customs Service of Russia).

Bromine antipyrenes (BA) are found both throughout the environment (including the Arctic), in animals and in the human body. Recycling and combustion of waste containing antipyrenes is a highly probable potential source of emissions of these substances. In early 1990s it was confirmed that particular bromine-containing antipyrenes may cause the creation of halogenated dibenzodioxins and dibenzofurans at high temperature.

In the Russian Arctic, PBDE (from di- to hepta-bromine derivates) were found in air samples at the Dunay station (1994–1995, Laptev Sea) with an average concentration of 14 pg/m^3. Within the same period, average air concentration in the Canadian Arctic was 10 times higher (240–420 pg/m^3). In 2007–2008, RPA Typhoon (for the first time in Russia) analyzed the PBDE concentration in the air and inside premises, as well as the PBDE concentration gradient in the air from Central Russia to the Russian Arctic. Air sampling has been conducted for two years in 6 geographic locations: in cities and towns (Moscow, Obninsk (Kaluga Region), Arkhangelsk), and in villages such as Amderma (Nenets Autonomous District), Pevek and Valkarkay (Chukchi Peninsula). It was found out that PBDE are widespread and found in high amounts in air samples both in central cities (Moscow, Obninsk) and remote locations in the Arctic and Subarctic (Arkhangelsk, Amderma, Valkarkay). The comparative concentration of PBDE in the air was found to be Moscow > Obninsk > Arkhangelsk > polar meteorological stations, thus showing the high concentration gradient from the central to Arctic region. In 2004-2006, a high amount of PBDE was found in bottom sediment samples taken from lakes on Novaya Zemlya, lakes and the Pasquick river on the Kola Peninsula. The concentration of PBDE materially exceeds the level of other POPs in fish and mussel samples taken in 2007 in the Pechora Sea.

Perfluoroctane sulfonate (perfluorooctane sulfonic acid; its salts and perfluorooctane sulfonyl fluoride (PFOS)) is used in the production of items such as fire foam, carpets, leather clothes, textile, upholstery, paper and packages, coatings and detergents. PFOS was imported to Russia as a component of industrial and consumer products. The issue of PFOS application in Russia required detailed toxicological and feasibility studies. PFOS is very stable and does not deteriorate in the environment. PFOS may be transferred to the environment as a result of industrial processes or by consumers as well as due to waste treatment. High concentrations of PFOS are found in Arctic animals far from anthropogenic sources, and monitoring results show high PFOS levels in different regions of the Northern hemisphere.

Polychlorobiphenyls and organochlorine pesticides are the most volumetric and widely spread POPs present in the Russian Arctic. Their long-term application and storage cause a constant risk of environmental pollution as there is a threat of their transport into the air, soils and also to surface and ground waters. Availability of POPs in the Arctic environment may have long-term adverse effects both on flora, fauna and the health of the local population including the indigenous peoples of the north.

Acid Pollution

Large amounts of active gases (SO_2, NO_X, NH_3) able to transform into acids and cause anthropogenic acidification of soils and waters are emitted into the atmosphere. The main sources of acidifying substances are long-range transcontinental transportation and local sources of SO_2 emissions (copper and nickel production in the Northern Kola regions and Norilsk industrial region, as well as lesser thermal plants in industrial and urban centers such as Pechora, Vorkuta, Nadym, Norilsk, Deputatsky, Valkumey and Anadyr). It is expected that the planned industrial development of Southern Russian and Asian regions such as Kazakhstan, Mongolia and China will also be the source of transboundary transport of acidifying agents to the Arctic which causes soil and water acidification. For this reason, acid precipitation in the Arctic region may be seen in locations far from pollution sources.

Arctic smoke is another effect of transboundary pollution transport from southern regions to the Arctic. Arctic smoke is a mix of sulfates and organic matter with lower levels of ammonia, nitrates, dust, ash particles and concentrated heavy metals. It occurs irregularly in winter and spring in different Arctic regions.

Acid precipitation with high sulfur concentration is local. It may amount to 3000–4000 kg/км^2/year on the Kola Peninsula and in the Norilsk industrial region where copper and nickel mills operate. The amount of precipitation in background areas amounts to less than 100 to 150 kg/km^2/year. But at the same time it was confirmed that in other regions of the Russian Arctic, remote from acid precipitation, high anthropogenic sulfur and nitrogen content occur as a result of transboundary transport of acid-forming substances from southern regions. CHPP and local boilers also make a particular contribution to precipitation acidification in the Arctic.

Detail research related to soil and water acidification was conducted on the Northern Kola Region including the continental part and Peninsula. This research explained the development of soil and water acidification processes and adverse environmental effects in the Arctic and Subarctic regions. For other Russian Arctic regions the dada is limited or absent, especially for regions at high-latitude.

As a result of anthropogenic succession of the Northern taiga forests caused by industrial air pollution (ie copper and nickel production), there is increased acidity of waters, an increased concentration of organic matter, active leaching of aluminium and ferrous compounds with organic matter, as well as key cations and anions of mineral acids thus causing a low level of the exchange base and development of toxic properties. Soil acidification resulting from sulfur and nitrogen fallout has an indirect effect through: a) leaching of main cations from soils causing deficits of these nutrients (especially magnesium) in forest wood; b) migration of diluted toxic aluminium affecting the growth of new roots and inhibiting the absorption of main cations; c) reduction of pH level affecting the mineralization and, correspondingly, the availability of nutrients. It is expected that damage to forests is related to acidification of soils as $A1^{3+}$ has a toxic effect on plants (damage to new roots).

Wide-ranging research of small lakes that are more sensitive to acidification conducted in 2005 showed that the amount of highly acidified lakes with a pH level of less than 5 (and color index of less than 30°Pt-Co) in tundra and taiga regions of the Northern Kola area was 3.9%. Generally, today 10.6% of lakes may be deemed acidified due to anthropogenic impact, and in 1995 this level was higher – lakes with pH<6 amounted to 26% and 11% had pH<5. Reduction of the level of acidified lakes is caused by reduction of SO_2 emissions by copper and nickel industries in the Northern Kola region. Fast short-term pH level reduction in ponds during rain and spring flooding may have severe environmental effects as acidifying agents accumulated in catchment areas during long Arctic winter are rapidly transferred to water basins. This phenomenon was called pH-stress due to severe adverse effect on water fauna.

Diatomic analysis of bottom sediments of mountain tundra lakes in the Northern Kola region showed that anthropogenic acidification of Arctic waters first occurred between the end of the 19th the beginning of the 20th century when the active utilization of fossil fuel in Europe started and polluted air was transported to the Arctic regions. Due to a reduction in emissions of acidifying agents during the last 20 years, the Northern Kola water quality has been restored to some extent (a reduction in the concentration of sulfates and an increase in water acid neutralizing capacity (ANC)). But this process develops irregularly in different lakes under similar conditions of acid load reduction in catchment areas as a result of root modification of the catchment system for a period of more than 50-year stress load on the catchment areas. Water acidification results in a reduction of biodiversity and fish population degradation. Mixing areas of acid river water with sea waters is a strong risk factor for anadromous fish as the diluted aluminium coagulates on gills, causing imago mortality of commercial salmon.

During recent years, the global scientific community has applied the critical load (CL) concept as a scientific method of determining the permissible impact of acidifying agents on catchment areas. The most widely-spread method of CL level calculation in ground waters is the steady-state water chemistry method widely recognized in Europe. This method is based on the determination of the strong acid neutralizing capacity of the catchment area. Acidifying critical loads (CL) are determined as the amount of acidifying agents transferred to the catchment area (mEq/m^2 per year) which does not cause the reduction of acid neutralizing capacity of soils and water up to the level less than critical (ANC_{limit}). The critical level of water buffer properties is a minimum acid neutralizing capacity value (ANC, mEq/l) preventing degradation of the water and terrestrial ecosystems. The excess level of critical load (CL_{ex}) is calculated as the difference between the buffer capacity of the catchment area (determined as CL) and strong acid fallout on the geological substrate.

To calculate these properties, it is required to conduct a territorial study of the key chemical indices of soil and water status. Such studies were conducted in the Russian Arctic in relation to surface waters of the Northern Kola area. Territorial distribution analysis of critical loads in the Northern Kola area showed that low CL values, i.e. catchment areas sensitive to acidification, relate to North-Eastern areas characterized by acidic rock denudations. Over the last 20 years, increased values of critical loads (CL_{ex}) have reduced as a result of material reduction of SO_2 emissions by the copper and nickel industries.

Available data confirm that more than half of the Russian Arctic region is affected by local and transboundary flows of acidifying agents but detailed information on the effects of acid precipitation is available for the Northern Kola region only. It is necessary to study other Russian Arctic regions in detail. The issue of acid pollution of the Russian Arctic may be finally resolved only through cooperation with other states, especially Kazakhstan, Mongolia and China.

Radiation pollution

The Russian Arctic, like other regions of the Earth, has been affected by global anthropogenic sources of radionuclides created via nuclear energy. The main source of radiation pollution, which will continue to have impacts for hundreds and thousands of years to come (as long-lived radionuclides decay), is the nuclear weapons testing carried out by the USA, USSR, China, United Kingdom and France in 1945–90. One of the two USSR atomic testing grounds was located in the Arctic (Novaya Zemlya). About 12% of radioactive debris fell out close to the test location on Novaya Zemlya, 10% fell out in the territory of concentric circumpolar ring along the latitude of Novaya Zemlya, and 78% fell out as fine products and replenished the global stratospheric radionuclides reserve which further continued to fall out (AMAP, 1998). A significant amount of atmospheric radioactive cesium and strontium fell out within the period 1955 to 1966.

There were seventeen underground nuclear explosions in the USSR made near the Polar Circle from 1971 to 1988 for economic purposes. The majority of explosions did not cause material radionuclide pollution near the place of explosion.

The application of nuclear fission for power generation was also a source of global air emission and water discharge of radioactive isotopes, especially as a result of large scale accidents. Special attention shall be paid to the Chernobyl incident of April–May, 1986. A significant quantity of redionuclides emitted as a result of this incident fell out in the Arctic regions and regions directly adjacent to it. A relatively high cesium-137 fallout level was recorded in the Murmansk Region. However, the Chernobyl incident was not the major source of radioactive pollution in the Russian Arctic. Its contribution to cesium-137 contamination of the Arctic region is at least 20 times lower than those contributed by nuclear weapons testing.

There are two nuclear power plants in the territories of the Russian Polar Circle to the west and east, Kola and Bilibino. Kola NPP includes 4 PWR-440 units. The thermal capacity of each unit is 1,375 MW and the power capacity is 411 MW. All units are operated by pressurized water reactors. There are two units with expired initial service lives which have been extended as a result of special maintenance activities.

At Bilibino (Chukchi Peninsula), NPP light-water cooled, graphite-moderated reactors are used. Each EHC-6 unit has an installed thermal capacity of 62 MW and a power capacity of 12 MW. Thus, the aggregate power output of this NPP is 48 MW. The initial service lives of the units have also expired. The relatively low capacity of Bilibino NPP (more than 20 times smaller than Kola NPP), and its remoteness from highly populated regions, make the potential risk assessment irrelevant. But for Kola NPP, such assessment is of high importance. Based on initial assessments made by the IAEA in relation to Kola NPP unit, the potential accident frequency is $5.5 \cdot 10^{-3}$ per year. It is assumed that this index for modern power reactors shall be within the range from 10^{-4} and 10^{-5} per year.

European radiochemical plants in Sellafield (UK) and La Hague Cape (France) have also played a particular role in radionuclide pollution of the Barents and Kara Seas. Since the sea water radioactive level from nuclear tests started to decrease in the 1960s and 1970s, the key contamination factor for the Arctic seas (Norwegian, Barents and Kara) is radionuclide discharges from these plants. In the 1980s, the discharge level of cesium-137, strontium-90, plutonium-241, ruthenium-106 dropped off due to changes in waste treatment and storage methods. But in the 1990s, discharges of long-life radioactive technetium-99 and Iodium-129 isotopes significantly increased.

Major Russian radiochemical plants are Mayak plant in Chelyabinsk Region (Ob basin), Siberian chemical plant (Tomsk-7) in Tomsk Region (Ob basin), Krasnoyarsk Mining and Chemical Complex in Krasnoyarsk Region (Enisey basin). These plants have a large stock of radioactive waste, but still they actually do not affect the Arctic region.

The use of nuclear energy on military and civilian ships and vessels has seriously affected the Russian Arctic. The nuclear fleet, and its maintenance facilities, is mainly located in the bays of the Kola Peninsula and Severodvinsk dock harbour in the White Sea. Current issues of decommissioning of the nuclear fleet and its related framework are among the highest priority radiation security issues regarding the North-Western region of Russia. Decommissioned nuclear submarines have been disposed of in Severodvinsk, including disposal activities carried out under bilateral and multilateral treaties.

The problems of spent fuel originating from the nuclear fleet and solid radioactive waste disposal in the North-Western and Far-Eastern regions require immediate solutions. In the 1960s, the USSR started to construct a framework of radioactive waste (RW) disposal, but construction of related buildings and facilities was abandoned in the early 1970s as it was decided to dump liquid and solid RW (LRW and SRW) in the sea.

The framework that is in place to ensure maintenance of the existing nuclear fleet requires enhancement and further development. It consists of onshore and offshore maintenance facilities, shops, radiation monitoring facilities and special liquid tankers that are sometimes included in a single category (nuclear maintenance vessels). The assessment of risks associated with operating and decommissioning these facilities, and primarily nuclear submarines with unloaded fuel, shows that they reach the highest level in relation to particular facilities containing spent fuel.

Within the period 1993 to 1996, the IAEA implemented the International Russian Arctic Seas Analysis Project. Results of these, and other studies, showed that the radionuclide content in facilities dumped in the

Kara Sea in the late 1990s was as follows (numbers taken from the IAEA Report and 2000 White Paper):

Fission products – 4.1 pBq[1] (cesium-137 – approximately 1 pBq; strontium-90 – approximately 0.9 pBq);

Activation products – 0.5 pBq (nickel-63 – 0.3 pBq; cobalt-60 – 0.1 pBq);

Actinides – 0.1 pBq (main contribution of plutonium-241 – 0.08 pBq);

Total: 4.7 pBq.

The data show a significant increase over previous assessment results. Regular inspections are conducted in order to monitor the status of facilities containing RW. Their results make it possible to conclude that there is no current risk of increased radioactive contamination. However, there are some uncertainties relating to the largest radioactive facility (the Lenin ice breaker containing spent fuel) as it was not found in the proposed dumping place.

A special source of possible radioactive contamination is the so-called radioisotopic thermo-electric generators (RITEGs) used as long-term standalone power supplies for beacons and marine lights. The service lives of all RITEGs have expired. Most of them have been dismantled and transported to storage places or disposal. There are no RITEGs in the territory of the Murmansk and Arkhangelsk regions. As of July 2010, there were 43 RITEGs in the Chukchi Autonomous District. RITEGs available in the Chukchi Autonomous District and the Republic of Sakha (Yakutia) are planned for removal and disposal before 2013. Items lost as a result of destruction of navigation equipment are of major concern as there is a possible related terrorist threat.

Release of ntural radionuclides around oil and gas production facilities on the continental shelf also need to be taken into account.

During recent years, material radionuclide emissions have not been recorded. Anthropogenic radionuclide pollution of the Arctic region by sea currents is related both to substances directly discharged into the marine environment and secondary pollution by bottom sediments. The level of radionuclide pollution from river runoff is negligible.

Monitoring of radioactive pollution of the Russian environment is performed by the permanent radiation monitoring facilities (Hydro and Me-

[1] pBq means peta-Becquerel, i.e. 10^{15} Becquerel

teorological Stations and monitoring units) of Roshydromet, which are integrated into its radiation monitoring network (RMN). This RMN ensures the reliable and effective radiation monitoring both in normal conditions and in case of radiation incidents and accidents.

4.5. Water quality in the Russian Arctic

As there has been an adequate level of water supply in the northern regions, the issue of the condition and use thereof has not been a priority. But the active development of rich Arctic mineral deposits and Subarctic regions together with transboundary pollution transport has caused a disturbance in the fragile environmental balance in many urban areas, thus resulting in a rapid decrease of water quality in the industrial centres and villages of the Russian Arctic. The results of analysis of scientific data related to ground and subsurface water quality assessment showed that this issue requires further investigation. Research activities are mainly concentrated in the higher and middle courses of rivers. As a rule, water quality monitoring in the Russian Arctic is performed on water basins as these are both recipients of sewage waters and limited to measurements of the content of different pollution components not considering the complete range of physical, chemical and biological processes in northern water basins. The effective pollution assessment and regulation systems are based on maximum permissible concentration (MPC) levels which have been established for water basins of the moderate climatic zone, thus they do not consider the specific nature and high vulnerability level of water in the northern environment. At the same time, such northern countries as Canada apply stricter toxic metals MPC for low-mineralized waters.

Analysis of public reports on the status and protection of the environment provide information on the rate of excess MPC in different water bodies receiving sewage waters. The following classes and level of water quality were used: relatively clean, slightly polluted, polluted, very polluted, dirty, very dirty and extremely dirty. Today almost all the major rivers of the Arctic Basin near the settlements and industrial zones (such as the Pechora, Northern Dvina, Ob, Lena and Enisey) are highly polluted by heavy metals, oils, weighted substances and organic toxic compounds. Absorbing various types of wastewater discharged by industrial facilities located along the river, polluted water flows to the Arctic regions where the mechanisms of migration and behaviour of pollutants have their own specific behaviour and their toxic effects are more significant. Catchment areas are polluted by air through local and global anthropogenic sources. However, monitoring data on assessment of the pollution levels of Arctic rivers and their tributaries at the point of pollution can not be extrapolated to all land waters of the Arctic Basin. Generally, water resources in the vast area of the Russian Arctic preserve their natural characteristics.

Among the Subarctic Regions the most significant wastewater discharge and emission level is typical for industrial centers (the Kola and Norilsk regions) where land waters are the most contaminated. Research of the Northern Kola region has shown that both surface and groundwaters are contaminated with metals in the copper-nickel production area. There are cases of groundwater pollution in Murmansk and Arkhangelsk. For other areas, groundwater contamination has not been identified, and for permafrost regions this problem is not relevant.

The poor water quality of the Northern Dvina is mainly associated with sewage discharge from the forest, from the pulp and paper industries into the Sukhona and Vychegda basins, and directly into the Northern Dvina River estuary. The water pollution in the lower course of the Pechora river is associated with the activities of the gas, oil and petrochemical industries, oil products, phenols, copper and other metals ingress into the river, and the concentration of these metals substantially exceeds standard MPC. Typical pollutants of the Ob estuary are phenols, ammonia, nitrogen, copper, iron and zinc compounds. At the Yenisei River estuary, increased concentrations of almost all trace elements is recorded (as compared to the Ob), but it does not exceed the regional geochemical background, as well as their global average concentration level in river runoff in the dissolved and weighted state. Water pollution of the River Lena has a negligible effect on the river water quality as its self-cleaning capacity (due to its extremely high water content) is sufficiently high. For rivers of the Russian Arctic with estuaries located to the East of the River Lena, the main sources of pollutants are wastewater discharged by the mining industry and utilities, as well as surface runoff from undeveloped urban areas and agricultural land.

The majority of water for cities and villages located in the Russian Arctic is supplied from surface water sources which are often recipients of sewage or affected by anthropogenic air pollution. Bioindication in pollution impact areas confirms the poor quality of water in the main drinking water intakes. A study of the environmental effects caused by surface water pollution in the Russian Arctic clearly shows the need to adjust MPC and reduce the values for most components by a factor of three. Studies of cities and towns of the Murmansk Region prove that water quality does not improve after water treatment. Even if the water meets sanitary standards, pollution of drinking water (in particular, by metals) in the anthropogenic impact area by air pollution from the copper and nickel industry remains a cause of disease in populations living in industrial centres.

The interaction of anthropogenic factors with the environment in the Arctic region has the most evident adverse effect. At the same time, water basins are of particular importance here as there are large reserves of high quality fresh water and commercial fish products (eg salmon and whitefish). Of the integrated use of water resources in the Arctic and Subarctic regions, the highest priority shall be given to clean water supporting fish stocks. The issue of protection of water resources from pollution by industrial waste water shall be resolved based on the preventive action principle. All types of activity of the water industry will be properly managed, only if the water resources are protected during their use.

4.6. Environmental status in the regional context

Environmental analysis of the Russian Arctic has shown that some regions are still areas of environmental concern due to a high level of environmental pollution, including results of significant anthropogenic stress together with the vulnerability of the harsh arctic environment. The result of uncontrolled, or poorly controlled, environmental impact was the development of chemical pollution that has engulfed an area of approximately 10% of the total land area (600 km^2). Mechanical soil and ground disturbance amounted to approximately 0.5% of the reclaimed area (approximately 30000 km^2). However, we shall consider that the actual disturbance distribution area may be larger.

From year to year, the level of pollutant emissions to the atmosphere increases. For example in the year 2000, the amount of such emissions in this region amounted to 3,408.9 tons (or 18.1% of total emissions in the Russian Federation), and in 2008 this value had increased by approximately 15 times (amounting to 49,162,000 tons or 24.5% of nationwide emissions). The key pollution issues are related to areas adjacent to major urban areas and industrial hubs. These include the mining and metallurgical complexes (MMC) in Norilsk and Monchegorsk, the oil and gas complex in northern European Russia and western Siberia, and the gold industry in Yakutia among others. In the Norilsk industrial, area Norilsk MMC enterprises annually emit approximately 10% of all pollutants emitted by stationary sources in the Russian Federation. Dynamic analysis of the environmental pollution for the period from 2000 to 2008 shows a wide-spread increase in pollutant emissions. In 2008, emissions in the Khanty-Mansiysk Autonomous District (Yugra) increased almost twice compared to 2000 (in 2004–2006 this increase amounted to 2.5 times), and this increase is associated with the development of the oil and gas industry. The same can be said in relation to the increase in emissions in the Yamalo-Nenets Autonomous District. In this region, emissions over the same period increased by almost 7 times. However, as a result of air protection activities, the emissions level in the Murmansk Region has fallen by 25%. Some decrease in emissions has also been observed in the Republic of Komi and the Arkhangelsk Region.

The 2005–2008 Priority list of cities with the highest level of air pollution in the Russian Federation (integrated air pollution index (API) is equal to or above 14) included Norilsk in the Krasnoyarsk Region (high level of air pollution caused by benzapyrene, formaldehyde, phenol and sulfur dioxide emissions) and Neryungri in the Republic of Sakha (Yakutia) (benzapyrene, formaldehyde and nitrogen dioxide), and two cities in the Khanty-Mansiysk Autonomous District (Yugra) namely Raduzhny (2005) and Beloyarsky (2007, 2008) (high concentration of formaldehyde in the air).

Data on pollution of water bodies show a decrease in discharges of polluted wastewater in the region within the period 2000 to 2008 (from 1,363.8 to 1,138.1 M m^3). The decrease in the total waste water amount discharged into water bodies is caused by objective factors such as a decrease in the number of water users due to their reorganization, conversion, bankruptcy or liquidation. However, the level of this category of wastewater discharge increased in the Republic of Sakha (Yakutia), Khanty-Mansiysk, Yamalo-Nenets and the Nenets Autonomous Districts.

According to official statistics, the annual amount of industrial and domestic waste also tends to increase year upon year. According to data reported in 2008, the amount of waste in the Republic of Sakha (Yakutia) was 40 times higher than in 2000. Over the same period, the Murmansk

Region and Chukchi Autonomous District showed an increase of 30 times, the Arkhangelsk Region an increase of 20 times and in the Nenets Autonomous District, an increase of 10 times. Such an increase was mainly caused by the inclusion of Hazard Class V Waste (non-hazardous, bulky) in the waste classification system (2002). However, it should be noted that the number of reports and the level of reporting also significantly increased in this period. Analysis of information on Arctic regions shows that there is an accumulation of waste on unauthorized landfills located around settlements and industrial centers.

Different-scale negative changes in the natural landscapes of the Arctic result in the creation of «hot spots». A «hot spot» is a limited area where anthropogenic pollution sources have an adverse impact on the environment. In these areas, the environmental pollution, ecosystem degradation, population health depletion, biodiversity loss and disturbance to life-support systems are many times higher than permissible. The following types of economic activity characterise the typical sources of adverse environmental impact:

mining and processing, pulp and paper, and steel industries;

construction of hydraulic structures;

construction and operation of linear structures (oil and gas pipelines, railways and roads, power lines, etc.);

mining companies, including oil and gas producing and transporting companies;

fuel and energy industry (boilers, CHPPs);

military facilities;

transportation (sea, pipeline);

housing and utility industry (HU);

agricultural production;

marine resources use.

Over 100 hot spots (with 30 priority locations) have been identified in the Russian Arctic.

In the Murmansk Region, the major pollution sources are the mining and metallurgical enterprises, and utilities and transport. There are 12 hot spots identified in the region, located in Nickel, Apatite, Zapolyarny, Murmansk and Kovdor.

Lovozero; Kola, Polyuarniye Zori; Pechenga and Terek regions; Zaozersk and adjacent marine areas (the Gulfs of Nerpichye, Bolshaya Lopatkina, Malaya Lopatkina, Andreev Bay), Ostrovnoy (closed city, Murmansk

Region) and the Barents Sea coast near Yokanga islands and the Svyatoy Nos Peninsula, Snezhnogorsk (closed city, Murmansk Region) and Kut Bay of the Gulf of Olenya.

Extremely polluted areas in the Murmansk Region are located near Monchegorsk and Nickel and cover a total area of approximately 3,200 km^2. From an environmental point of view, they are anthropogenic wastelands with an almost totally destroyed vegetative structure, disturbed soil mantle and extremely polluted surface water. Pechenganickel (Zapolyarny and Nickel) and Severonickel (Monchegorsk) MMC discharge 86% of the regional total of sulfur dioxide emissions. They also emit up to 3,000 tons of Ni, 2,000 tons of Cu and 100 tons of Co annually. The copper concentration in the snow cover near Severonickel MMC (Monchegorsk) reaches 2154 mkg/l. The major source of environmental impact in the Khibiny mountain range is the processing plants of Apatite JSC which emits up to 70,000 tons of pollutants annually. More than 30 million tons of waste rock containing strontium are annually stockpiled near Apatite JSC covering an area of approximately 3,000 km^2. A vast area to the south of Revda is polluted by strontium as a result of the Lovozero Mining Plant operation as it produces rare earth metal ores. The most polluted water bodies in the region are the River Rosta and Varnichny brook (Murmansk), Khauki-lampi-yoki river (Nickel) and Nyuduay river (Monchegorsk). Based on water quality properties, these rivers are classified as dirty – very dirty (due to critical concentrations of copper, nickel, manganese, organic matter, ammonia, nitrogen and petroleum products). The Kolos-yoki river receives wastewaters discharged by the Pechenganickel plant and it displays persistent water and sediment pollution by nickel compounds. The industry's share in the total amount of water pollution is 64% and municipal utilities pollute 34% of water. Analysis of the water environment in the Murmansk Region showed a high level of pollution of the Barents and White Sea coastal waters. The water is polluted by wastewater discharged by fleets and onshore enterprises of transport, construction, defense and associated agencies, Rosagrokhim JSC and Rostsvetmet Corporation.

The existing situation on the Kola Peninsula regarding waste creation, use, disposal, storage and dumping causes dangerous environmental pollution and is a real and current threat to public health, biodiversity and ecosystems. The accumulation of waste in dumps and toxic waste landfills, including waste containing carcinogenic substances, is of special concern. Major sources of waste are Apatite JSC (approximately 50%), Kovdorsky

MMC JSC (Kovdor, approximately 30%), Kola MMC JSC, Pechenganickel plant (Zapolyarny), Olenegorsk MMC JSC (Olenegorsk).

One of the major environmental issues in the Murmansk Region is the safe management of radioactive waste and spent fuel. The region is characterized by a large number of hazardous radioactive facilities. The region has accumulated approximately 10 million Ci of radioactive waste in a raw state and temporary storage areas for solid radioactive waste are at 90–100% capacity.

The environmental status of the Arkhangelsk Region is affected by the pulp and paper industry, forestry and wood processing, mining, thermal power and transport (both river and sea), facilities of the Ministry of Defense of the Russian Federation and utilities. There are more than 160 potentially hazardous facilities in the region, including more than 100 due to explosive substances and approximately 50 due to chemically hazardous materials. The following hot spots are identified in the region: Arkhangelsk, Severodvinsk, Novodvinsk, Koryazhma and Dvina Bay in the White Sea. The main types of environmental impact in the region are: air pollution (from benzapyrene and other PAH, mercury and other heavy metals, sulfur and nitrogen oxides, carbon disulfide, formaldehyde, methyl mercaptan and suspended solids); discharge of untreated sewage and pollution of ground and surface water (including sea water, pollution of coastal waters by ships and port facilities operation); pollution of land (abandoned vehicles, illegal dumps), uncontrolled deforestation, draining and cluttering of forests. Water pollution in the estuaries of the Northern Dvina and Vychegda rivers have reached a critical level.

The supply of clean drinking water to the population of industrial centres is extremely neglected. The low quality of drinking water is a result of low capacities, inadequate municipal wastewater treatment plants and water intakes located in the area of industrial and domestic wastewater discharge.

One of the major environmental problems of the region is the recycling of solid industrial and domestic waste. Most solid waste storage reservoirs, landfills and dumps do not meet current environmental requirements. Soils under landfill sites are contaminated by heavy metals. The issue of recycling and disposal of solid and liquid radioactive waste at the military and industrial complex in Severodvinsk has not been resolved. Nuclear testing conducted on Novaya Zemlya before 1995 has had a negative impact on the environmental quality of the district. The highest levels of pollution were observed on Vaigach island near Amderma and Karatayka, and in the Kara tundra. Launches of spacecraft from the Plesetsk launch site (the most northern in the world) have also had a negative environmental impact.

Major sources of pollutant emissions to the atmosphere in the industrial centers and settlements of the Arkhangelsk Region are the Arkhangelsk Paper Mill JSC (Novodvinsk), the Kotlas Paper Mill JSC (Koryazhma), the Solombalsk Paper Mill JSC (Arkhangelsk), the thermal power industry, the PO Northern Machine-Building Enterprise (State Unitary Enterprise (SUE)), the Zvezdochka Machine-Building Enterprise Federal State Unitary Enterprise (FSUE) and the Arkhangelsk Hydrolysis Plant JSC. They emit 53% of the total amount of pollution in the region. The Estuary of Northern Dvina River is polluted by specific substances (namely lignin substances, methanol and formaldehyde) as a result of wastewater discharges from pulp and paper plants. Major sources of water pollution are the Kotlas Paper Mill JSC (Koryazhma, 36% of the total amount of polluted wastewater discharged); Arkhangelsk Paper Mill JSC (Novodvinsk, 27%); Solombalsk Paper Mill JSC (Arkhangelsk, 11%) and PO Sevmashpredpriyatiye SUE (Severodvinsk, 6%).

All the territories of the Nenets Autonomous District are included in the Russian Arctic. Hot spots include the coastal areas of the Pechora Sea, Naryan-Mar and Amderma. There are many pockets of oil pollution in the Bolshezemelskaya tundra and on Kolguev Island caused by the intensive development of oil and gas drilling works during the last decade.

The major types of environmental impact in the district are air pollution (oil, carbon, strontium, radionuclides and oxides of sulfur and nitrogen), land contamination by illegal dumping of solid domestic waste (SDW), separating rocket stages launched from the Plesetsk launch site, pollution of coastal waters by ships and waste from port facilities, soil and ground pollution by oil products, rocket fuel and water pollution from sewage discharges.

The River Pechora and the Pechora Sea coastal zone are the main sources of negative environmental impact in the region as they have been polluted since the middle of the 20th century when active development of oil fields in the district and in the Komi Republic began.

The main source of air pollution in the district is the open combustion of associated gas in flare devices which amounts to 70% of the total volume of pollutant emissions. Emissions from flares (carbon monoxide, nitrogen dioxide, methane, methanol, carbon black) are typical for this region. Major sources of land water pollution in the district are municipal utilities which discharge approximately 80% of polluted wastewater. Industrial wastewaters discharged into water bodies amount to approximately 14% of wastewater discharges. In most cases the quality of water in drinking water supplies of the Nenets Autonomous District does not correspond to hygienic standards. Waste discharge by utilities amounts to approximately 80% of the total generated waste, oil and gas companies discharge approximately 20%. The most dangerous and widespread waste substances are mercury-containing fluorescent lamps, used batteries and motor oil.

The environmental status of the Republic of Komi is mainly affected by coal mining and the oil and gas industries. High levels of pollution are observed in the Vorkuta municipal region, as well as in the Intinsk region and Syktyvkar. The combustion of gas during oil production and the associated air pollution is an environmental issue in the republic. The cutting down of indigenous forests and boreal forest fires also damage the environment. Significant damage to the environment of the republic is caused by anthropogenic accidents on oil pipelines (mainly in the Usinsk region) and gas pipelines (mainly caused by depressurization of the pipelines). In the cities, there are high levels of air pollution from specific impurities such as formaldehyde and benzo(a)pyrene.

The major industries in the republic contribute more than 600 tons to the total amount of pollutant emissions. The proportion from the coal-mining industry amounts to approximately 30%, the gas industry 10–12%, the oil industry 12–14%, the energy industry 15%, the construction industry 5%, oil refining 6%, and timber, woodworking, pulp and paper industries 10%.

The main sources of air pollution are major industries, namely CHPP-2, CHPP-1 (Vorkuta, accounting for 9% of total emissions); the Sosnogorsk Gas Processing Plant (GPP) (6%); the Sosnogorsk Main Gas Pipelines Line Production Administration (LPUMG) (Ukhta, 5%); Neusiedler Syktyvkar JSC (Syktyvkar Forestry, 4%); the Vorkuta Cement Plant JSC (2%). Up to 50% of emissions are discharged in Vorkuta, which is the largest industrial centre in the republic.

The soil mantle near Vorkuta is characterized by a high capacity for accumulation of mobile metal compounds such as Zn, Mn, Pb and Fe. Virtually all regularly monitored water bodies of the republic have pollution levels exceeding established standards. The increasing microbiological contamination of water bodies remains a constant health hazard. Ground water pollution of water intakes is primarily caused by the inflow (coning) of sub-standard underground water. Solid domestic waste is a significant problem in the republic as there are no existing SDW landfills.

The environmental status of the Khanty-Mansiysk Autonomous District (Yugra) is affected by the booming regional oil production and transportation of oil products. Leaks in damaged pipelines, accidental blowouts on exploratory wells, dumping of waste mud and raw sewage into water bodies and in soils, and open combustion of associated gas in flares result in air and surface water pollution. According to surveys, the amount of residual oil ingressed in soils due to the poor quality of oil collected in ground spills amounts to tens of tons per hectare of contaminated land. Forest fires have a negative impact on forests. During the construction of fields, roads, power lines and pipelines many areas are deforested and large amounts of timber are not exported thus disturbing the sanitary condition of forests.

In 2008, Beloyarsky was included in the priority list of cities with the highest air pollution level in the Russian Federation. Uncontrolled associated gas emissions on oil fields play a major role in air pollution in the district. Though the district emits the largest amount of pollutants in the Russian Federation, the recovery level is still one of the lowest. The water quality of the Ob and Irtysh river basins is estimated as «dirty». The main sources of surface water pollution in the district are the oil industry (80%) and the utilities of Nizhnevartovsk, Khanty-Mansiysk, Kogalym and Nefteyugansk (16%). In the Khanty-Mansiysk Autonomous District (Yugra), the water factor plays a great role in the somatic population case rate thus increasing the priority of the problem of providing the population with high quality drinking water among other important social and economic problems. Regular accidents in the oil industry of the Autonomous District are a major environmental threat as they result in pollution of the soil mantle, groundwater and surface water, as well as destruction of vegetation. In 2008, the oil industry of the Autonomous District reported 4817 accidental spills associated with the production of hydrocarbons, resulting in significant environmental pollution (5500 tons of pollutants emitted). The total polluted area was 287.4 ha. The main cause of accidents (99%) is corrosion of internal and external pipelines.

The environment of the Yamalo-Nenets Autonomous District has recently begun to experience an extreme anthropogenic impact and the pace and extent of this impact is currently increasing. One of major issues in the district is disturbance of the soil and vegetation cover, freeze – thaw processes and the associated degradation of the tundra landscape. The greatest negative impact on the environment of the Yamalo-Nenets Autonomous District is due to anthropogenic stress in the developed oil and gas areas. Significant environmental changes are recorded in exploration areas as a result of the impact of powerful vehicles in permafrost and the creation of impassable road conditions.

Spills are reported on oil production facilities and oil pipelines annually. The main types of violations with a view to land resource use are land contamination by oil products and the cluttering of land by industrial and domestic waste. In this case, soil contamination by oil in areas of oil production, processing, transportation and distribution is up to 10 times higher than background regional values. Emissions from oil and gas production facilities are more than 80% of the total amount of air pollution. The increase in pollutant emissions from stationary sources (which doubled over the period 2000 to 2008) is associated with increased hydrocarbon production and combustion of natural and associated gas in flares. The main sources of pollution in the district are oil and gas companies, namely Rosneft-Purneftegaz JSC, Nadymgazprom LLC, Sibneft-Noyabrskneftegaz JSC, Urengoygazprom, Tyumentransgaz and utilities of Urengoy, Gubkino Purovsk, Nadym. The level of water pollution is increasing. In 2004, the amount of polluted wastewater in the total amount discharged to water basins was 46%, and in 2008 this value reached 98%.

The Norilsk industrial region (Krasnoyarsk Region) is the largest in the Russian Arctic in terms of the total area of contaminated land and amount of emissions. The Norilsk industrial region is characterized by a significant impact on natural geosystems which resulted in changes in vegetation associated with severe air pollution and mechanical disturbances. Signs of damage occur in sparse coniferous taiga located up to 200 km from Norilsk in the direction of the prevailing winds. There is an anthropogenic desert area located close to the non-ferrous processing plant (up to 80 km away in the direction of the prevailing winds).

Norilsk has been included in the priority list of cities with the highest level of air pollution in the Russian Federation for many years. It was included in this list as a result of the significant pollutant emissions (chiefly sulfur dioxide) by Norilsk MMC which contributes approximately two million tons, or 10%, of the total pollutants emitted from stationary sources in the Russian Federation. In the lower course of the Enisey river (Igarka), the water is affected by significant anthropogenic stresses associated with a significant excess of average annual concentrations of oil products, copper ions, zinc and other pollutants MPC. The production activities of Norilsk MMC are characterized by an accumulation of large amounts of mining waste, including overburden and final tailings.

The Republic of Sakha (Yakutia) is one of the cleanest in Northern Russia, with the exception of eight hot spots of critical environmental status. These are industrial centres where non-ferrous metallurgy, mining, coal, food processing, forestry and wood processing, power, and construction material industries are located. The following enterprises are the main sources of environmental pollution in the republic:

Deputatsky MMC (tin deposits in the Yana basin);

energy facilities, transportation, landfills in Tiksi;

gold mining companies around Kulari, Vlasovo and Entuziastov villages;

Yuakutsk utilities;

Ayhalsky MMC of AC Alrosa Joint Stock Company (JSC), Aikhal;

Nyurbinsky MMC of AC ALROSA, Mirny;

Udachninsky MMC, Udachny;

Mirny MMC of AC ALROSA, Mirny,

HC Yakutugol JSC, Neryungri.

In Yakutsk, the pollution level is estimated to be high, while it is very high in Mirny and Neryungri. Indeed, Neryungri has been included in the priority list of Russian cities with the highest level of air pollution since 2006. The main sources of water pollution are the Aldanzoloto Joint Stock Company and housing facilities. Almost 55% of sewage waters are discharged untreated and the supply of drinking water in the Republic of Sakha (Yakutia) is still unsatisfactory. The centralized water supply covers only 12.2% of settlements. The area of land disturbed during mining and exploration is growing. While the level of annual waste generation in the republic is significant, the level of use, disposal and recycling is still very low.

The Chukchi Autonomous District is one of the most environmentally clean regions of the Russian Federation and the least affected by the anthropogenic load. The environmental status of the District is affected by mining, power, engineering, transport (including heavy plant) and housing industries. The district is characterised by the occurrence of mechanical environmental disturbances, especially around Pevek and Valkumey, Iultin, Polar and Leningradsky settlements. The Pevek, Bilibino, Anadyr and Cape Schmidt settlements are also susceptible to pollution. Degradation of permafrost soils and spring flooding of settlement areas are major factors affecting public safety and water in open water sources does not meet hygienic standards. There are environmentally hazardous facilities in the district such as the waste repository of Bilibino nuclear power plant and the processing plant in the Chaun region (which was decommissioned in the early 1950s) that contain radioactive waste accumulated in tailings.

Chapter 5

ENVIRONMENTAL STATUS OF THE NATIVE HABITAT OF THE INDIGENOUS POPULATION OF THE RUSSIAN ARCTIC

According to archaeological data, Arctic Eurasia has been developed by humans since the Pleistocene era. Palaeolithic implements, mammoth bones, woolly rhinoceros, and mammoth images on tusks (radiocarbon dating to 12–13,000 years) were found in the Berelekh site (left tributary of Indigirka, 71°N) (Mochanov, 1977). A few sites, together with tools of ancient man and mammoth bones, were also found in the north of Western Siberia. Tribes of hunters, fishermen, marine mammal hunters and gatherers lived in this territory in ancient times. Reindeer breeding dates back to the turn of I-II millennia BC.

The current population of the Russian Arctic numbers approximately 1 million people, including more than 150,000 representatives of 17 indigenous peoples. Among the non-indigenous population (which came to the Russian Arctic in the twentieth century) the proportion of city dwellers was approximately 80%. The amount of the urban population among the indigenous population is less than 25%, i.e. more than 75% of the indigenous peoples are concentrated in rural areas and lead a traditional lifestyle.

The ethnic composition of the indigenous population of the Russian Arctic includes the Sami, Nenets, Khanty, Mansi, Selkup, Ket, Enets, Nganasans, Dolgans, Evenki, Even, Yukaghir, Chukchi, Eskimos, Kerek, Chuvans and Komi-Izhma. Upon consideration of issues related to resettlement, ethnic composition and headcount of the indigenous population of the Russian Arctic, we should note that the majority of the indigenous peoples are nomadic and semi-nomadic and annually migrate from Arctic areas to the Subarctic and back.

According to official statistics (2002 census) births in the indigenous population of the North have declined by 69% as compared to 1995, and mortality rates have increased by 35.5%. The average life expectancy among the indigenous population is 10–20 years less than the average in Russia. A positive increase in the headcount of the indigenous peoples recorded by the 2002 census reflects the pattern of uneven development of ethnic identification across regions and change in ethnic identification of these peoples. When considering reasons of the high mortality rate among indigenous peoples, we see a high proportion of working-age mortality caused by external factors such as unintentional injuries, suicide and homicide (36%). Given the small population size of all indigenous peoples of the north, such a demographic state can lead to depopulation of the ethnic minority and the current demographic state of indigenous peoples is defined as critical.

Existing environmental factors which affect the original habitat of the indigenous people of the Arctic are processes associated with climate change. Principal among these is the leading industry of unconventional land use – large-scale tundra reindeer breeding which already suffers from frequent ice-covering of the ground resulting in famine and death among the herds. Other types of conventional land use (hunting, fishing, hunting of marine mammals) are also impacted by the effects of climate change. The negative impact on the health of indigenous people (as a result of the forced change of lifestyle) may be minimized through implementation of preventive measures with a view to public health, education reform based on features of the indigenous peoples, and selection of areas suitable for conservation and development of traditional lifestyles. It is also of value to identify and support the adaptive capabilities of traditional use which were developed during periods of global climate change in previous epochs.

Anthropogenic factors affecting the original habitat of the indigenous population of the Russian Arctic include stress impact of industrial facilities on reindeer pastures and hunting grounds covering up to 40% of the traditional land use areas. The main areas of anthropogenic impact on the territory of traditional land use are the Kola, Timan-Pechora, Novaya Zemlya, Vorkuta, Per-Nadymsky, Yamal, Middle Ob, Norilsk, Anabarsky, Yano-Mndigirsky, Valkumeysky and Bilibinskiy regions.

The negative impact on health and demographic indicators of the indigenous population of the Russian Arctic has increased as a result of environmental degradation due to industrial development as well as ill-conceived management decisions (forced sedentism of nomadic populations, wide-spread large-herd reindeer breeding based on collective and state management, forced implementation of the average nutrition pattern of «mainland people» in northern indigenous population).

A specific form of chronic arctic stress, caused by the decreased tolerance of the body in harsh polar conditions, is typical for inhabitants of the Arctic and Subarctic regions. The main causes of death are circulatory diseases (33%), external causes (36%) and neoplasms (8%). There are also high suicide rates in northern regions. According to the WHO, the critical level of suicides is 20 cases per 100,000 people. The territories with the highest suicide rates in the Arctic region include the Nenets, Koryak and Kamchatka regions (the latter having the highest rate of all of 133.6 cases per 100,000 people). The suicide rate among the indigenous peoples is more than three times higher than the Russian average. The rate of mortality caused by infectious diseases (mostly tuberculosis) among indigenous people is 60 per 100,000 inhabitants (the average value in Russia being 23). Such an extremely high mortality rate of the indigenous peoples of the north allows us to judge the health level of the indigenous population to be critical.

The issue of improving the native habitats of the indigenous population of the Russian Arctic is currently solved within the framework of Federal Law No. 49-FZ «On Territories of Traditional Land use of Indigenous Peoples of the North, Siberia and the Russian Far East». The law provides a general description and typology of traditional economic activities of the indigenous peoples of the Russian Arctic.

Sustainable development is impossible without preservation of the Arctic environment for the development of traditional land use of indigenous peoples. The conservation level of these conditions indicates the environmental status of the Russian Arctic.

Today, it is difficult for indigenous peoples to obtain rights to use natural resources as well as being affected by depletion of the resource potential in virtually all sectors of traditional land use. These difficulties can be divided into legal and environmental, and both are caused by anthropogenic impact. The existing legal insecurity of the indigenous peoples' access to necessary land and renewable natural resources reduces the capability of sustainable development of traditional land use. The negative effects that accumulated over the previous period of industrial development (which led to degradation and pollution of approximately 40% of territories) significantly reduced the possibility of development of traditional land use in the Arctic. Further expansion of subsoil resources and industrial development in the Arctic and Subarctic regions may be implemented only by considering the interests of indigenous peoples and establishing a legal framework which ensures the preservation of traditional land use and life support of those indigenous peoples. The establishment of traditional land use territories (TLT) is still the best scenario of conservation of natural resources and a traditional life support framework of the indigenous peoples. The creation of TLT as a special protected area with specific goals and objectives should contribute to the preservation of natural diversity and the creation of conditions for the survival of indigenous peoples as well as the development of indigenous participation in TLT natural resource management.

The issue of historical and cultural heritage preservation of the indigenous people still needs further investigation and has both legal and practical aspects. Based on the example of the mapping of sacred sites in the Yamalo-Nenets Autonomous District, it was discovered that there were certain difficulties in the legal registration of the status of such objects. The best recommended way of protecting the historical and cultural heritage is their inclusion in the territory of traditional land use of indigenous peoples and transfer of their protection, registration and use powers to indigenous peoples.

It is evident that anthropogenic and environmental factors impact on traditional land use territories and the socio-economic, demographic and medical aspects of the life of indigenous peoples. A description of the adaptive capacity of traditional land use in conjunction with the accumulated empirical traditional knowledge should be considered when developing programmes for sustainable development of the Russian Arctic.

Chapter 6

BIOLOGICAL DIVERSITY OF THE RUSSIAN ARCTIC

6.1. Arctic biota species diversity

The formation of unique arctic biota is based on the exceptional variety of marine and land ecosystems of the Russian Arctic. By estimates of Yu.I.Chernov (2004), based on research findings of experts in the Russian flora and fauna, about 25,000–26,000 species are present in the Arctic Region, which is approximately 1.5% of the total species currently described on Earth (Table 2). However, of that total, only 0.6–0.7% are unique to the Arctic. Such disproportion between area (the Arctic area occupies about 4% of the total Earth area) and species richness results from the overall reduction of biota diversity from the tropics to the poles due to the reduction in heat quantity as well as factors related to Arctic biota genesis.

Animals comprise about half of the total number of species in the Arctic biota. Of this amount, 6,000–7,000 species are terrestrial animals although division into marine and terrestrial, as well as into marine and freshwater, is rather subjective. The Arctic flora includes approximately 2,300 species of tracheophytes (0.8% of the global amount), 900 species of muscoids (3.6%), and 1660 species of lichens (10.7%). This range positively demonstrates the increasing effect of protomorph nonresponsiveness to the thermal climatic pessimum, and corresponds with an understanding of the resistant adaptive strategy advantages in polar latitudes, as well as reduction in the Arctic biota of the most potentially successful taxons which represent the base of the Earth's biological diversity.

Economic activity in the Russian Arctic has expanded notably in recent years, threatening environmental pollution, considerable extension of disturbed lands areas and fragmentation of natural ecosystems. The negative trend of tradition-bound farming of the indigenous population of the Rus-

Table 2

Global Earth biological diversity and percentage of the Russian Arctic biota groups

Kingdom	Type (phyla)	Number of described species: on Earth/in the Russian Arctic	Estimate of the Russian Arctic biota rate (%)
Vertebrate animal	Mammals	4 630/75	1.6
	Birds	9 946/240	2.8
	Reptiles	7 400/1	0.01
	Amphibians	4 950/2	0.04
	Fish and cyclostomes *	25 000/430	2.0
Invertebrate animals	Insects	963 000/400	0.3
Mushrooms		72 000/3 000	0.4
Plants	Angiosperms	270 000/2 300	0.8
	Lichens	17 000/2 000	11.7
	Muscoids	16 100/900	5.6
TOTAL		**1 750 000/(25 000 – 26 000 species)**	**1.3–1.4**

sian Arctic is supported and maintained. All of the above impose a separate responsibility on Russia concerning the execution of requirements of the Convention of Biological Diversity, the Programmes of the Arctic Council, the European Union, the Northern Forum, large environmental institutions and funds (such as the WWF, IUCN, GEF) in the Arctic regions.

6.2. Threats to biological diversity and Arctic Sea biological resources

The main threats to biological diversity and Arctic Sea biological resources are:

1. Transport, accumulation, transfer in the food chain and the prolonged effect of persistent pollutants which are able to accumulate in organisms and migrate in food chains. Such pollutants include groups such as heavy metals, persistent organic pollutants, radioactive isotopes and hydrocarbons (especially polynucleated).

POPs concentration in the marine ecosystem is considerably variable in water, precipitation, and living organisms. However, high concentrations of polychlorbiphenyls (exceeding 1 ng/g of sediment) occur in the coastal area of the Svalbard archipelago, Franz Josef Land, and northern, north-west and south-west costs of Novaya Zemlya. A similar pattern is observed with dichlorodiphenyltrichloroethane although the values are slightly lower.

Migrant birds may accumulate organic pollutants in wintering areas, which, in turn, may lead to very high concentrations of persistent organic pollutants in the predaceous organisms that preying upon them.

Persistent growth of POPs content in the fat tissue of Greenland seals has been observed in the last 10 years. POPs content in eared seals and Greenland seals in the White Sea is now greater than corresponding values for Canada. The PCB concentration in polar bears of Franz Josef Land and the Kara Sea regions exceeds the concentration in the tissue of polar bears on Svalbard. It is known that the effect of POPs, together with the lasting effect of oil pollution transferred by rivers, may lead to a decrease in the viability and population level of animals, particularly whitefish and salmonid fish, semi-aquatic birds and Pinnipeds.

A considerable hazard for Arctic Sea ecosystems is posed by oil and phenol pollution transferred by the main rivers to the basin. Chronic exposure of oil pollution may lead to intoxication and development of pathologies of semi-anadromous and fresh-water fish wintering in gulfs. A likely increase in the heavy fractions of oil products in silt deposits may lead to significant structural changes in benthic cenosis, which, in turn, exerts a notable influence on fish and bird populations.

2. Biological diversity threats caused by exploration, production and transportation of hydrocarbons are connected with both an increase in drilling waste and hydrocarbon pollution, and with development of marine and coastal infrastructure. A potential hazard may be created by drilling mud fluids primarily due to the content of stable suspensions and secondary pollution of the environment as a result of sedimentation and secondary stirring. Chronic pollution caused by loss of oil products during transportation, scheduled or emergency discharges, as well as drilling mud fluids and drilling wastewater leakages, results in a decreased in the survivorship rate of benthic crustaceans and mollusks as well as suppression of the imago reproductive capacity. Drilling mud fluids based on ammonia are known to be particularly toxic. Long-term exposure to comparatively inconsiderable drilling mud fluid among codfish young may lead to chronic intoxication in platform regions and to a decrease in adaptive capacity.

For example, gas condensate is important for the development of the Shtokmanovskoye gas condensate field in the Barents Sea. Ingress of this gas condensate into the marine environment in concentrations currently accepted as admissible limits for oil and oil products (less than 0.1 mg/l for algae and crustaceans, and less than 1mg/l for mollusca) exerts a toxic effect on benthic organisms. It is obvious that commercial production of hydrocarbon material on the Arctic shelf (gas in the first instance) increases the risk of disruption of the ecological balance in the marine and geological environment, as well as in coastal ecosystems in the locale and on the transportation routes of oil products. The risk of uncontrolled emissions on offshore wells is: 0.48 per 10 000 wells for production drilling; 1.2 per 10 000 wells for development and 0.23 per 10 000 well-years for operation.

The most hazardous exposure is in the form of oil spills approaching the coast (with possible beaching of the spill) as well as exposure of marine organisms to sunken and submerged hydrocarbons. Emergency situations related to the destruction of offshore pipelines are unlikely (estimates of frequency range from $1.0 \cdot 10^{-5}$ to $1.0 \cdot 10^{-4}$). However, the risk of breakdown of marine transport supporting liquefied gas and oil products, and of platforms increases considerably in conditions of ice flow.

Transportation of oil produced on the Vankorskoye field via Dickson port at a volume of up to 100–140 passages of large-capacity tankers per year poses a risk of tanker breakdown in severe navigating conditions such as ice and adverse meteorological conditions. Emergency pollution and oil spills will be especially hazardous in the marshy, coastal regions of the Yamal and Gydansky peninsula, where the adverse impact on the coastal ecosystem, young fish and marine birds is potentially disastrous (the shores of the Pechora Sea). Spills in polynya regions in icy conditions will exert a negative influence on the production properties of the Kara Sea ecosystem, and, furthermore, will lead to the demise of marine birds and intoxication of marine mammals.

Coastal biological diversity is directly or indirectly influenced to a great extent by the development of marine and coastal oil and gas infrastructure. A significant part of the coastline is occupied by export terminals and liquefied natural gas plants, which may include important wetlands, marshlands, migratory areas of whitefish and salmonid fish, bird nesting and resting grounds, and herds. The location of these coastal infrastructure facilities adjacent to wildlife habitats important for the preservation of biological diversity will have an adverse effect on the condition of biotopes and communities due to the presence of large groups of people who do not respect the rules of behaviour relating to care of the environment. The very presence of large numbers of people and machinery, apart from an increased risk of illegal hunting and poaching (gathering of migratory birds eggs, for instance), will have an adverse effect on semi-aquatic birds and marine mammals.

3. Intensification of maritime traffic. Considerable threat to biological diversity is posed by and emergency situations related to spills of oil products and leakage to the environment during shipping and transportation. Global experience suggests that non-standard situations, clerical mistakes, and even criminal negligence resulting in oil leakages and spills cannot be anticipated completely even in conditions of increased requirements for oil transportation safety. The volume of traffic just in the Western sector of the Russian Arctic from Prirazlomnoye field, Dickson port and other locations has already reached approximately 20 million tons per year, which is equivalent to approximately 300–350 trips of loaded tankers. In the case of explosive growth in oil transportation, the adverse effect of biological diversity will be defined by the proximity of spill and leakage areas to exposed wildlife habitats (marshes widespread in tidal and/or built up areas on shores, shallow waters and areas of high concentrations of marine birds and mammals). Several such areas in the Russian Arctic have been granted the status of wetlands of global importance protected by the Ramsar Convention.

Reduction of ice cover in Arctic Regions may result in increasing through traffic in the Kara Sea along the Northern Sea Route. Difficult ice conditions, as well as possible increases in the frequency of storms, may result in breakdowns and oil and LNG spills in spite of the experience accumulated over the years of safe navigation the Northern Sea Route and Kara Sea. Usage of polynyas for navigation deserves special consideration as polynyas play a key role in marine mammal life, and it is not improbable that heavy traffic in polynya regions will lead to increases in anxiety of wildlife and disturb normal usage of polynyas by pinnipeds and cetaceans. However, estimates of possible navigation effects on polynya biota require additional observation and analysis.

4. The effect of undermanaged fishing**.** Fishing is a powerful and large-scale anthropogenic factor which greatly affects biological diversity.

The problem of present day ecosystem transformation under the influence of fishing concerns the Barents Sea in the first instance. The White

Sea ecosystem apparently suffered a massive influence from fishing in the first half of the 20th century, when the herring yield reached several thousand tons. Currently the total yield of fisheries in the White Sea does not exceed 2 thousand tons and apparently does not exert any significant influence on the ecosystem. However, available official data on yields are incomplete inasmuch as figures do not consider bycatch and data related to spills and illegal fishing. The last three factors explain the inaccuracy of predicting usable stock sizes, especially with reference to cod and haddock (prediction is conducted based on virtual analysis of populations), as prediction exaggerates results 15–30% due to underestimates of fish mortality (bycatch, spills and illegal fishing). Bycatch of rockfish, wolffish and halibut may reach 40–50% of the official yield.

Intense fishing regions are mostly influenced by trawl fishing. Intense benthal trawling leads to a reduction in the benthic community biomass.

Fisheries may have a direct impact on the death rate of marine birds. Even though fisheries have a direct effect on marine birds, fishing fleet activity in the Barents Sea affects the environment of nidicolous marine birds and reproductive properties mainly indirectly, through changes in food potential. A drastic reduction of lode stock, partly caused by overfishing, resulted in a reduction of the overall population, and population of young, kittiwake and other gulls.

5. Undermanaged fishing, aquaculture development and poaching**.** One of the most essential elements of biological diversity is the salmon population in the Barents Sea and White Sea basins with their complex gene pool. In the 20th and the beginning of the 21st centuries, salmon populations were exposed to the adverse combinatorial effects of the following different factors, which are difficult to evaluate separately: pollution caused by timber drift floating, waterworks construction, abuse of fish counting quotas and poaching. This situation has led to considerable reductions in population, especially in the Arkhangelsk Region.

The effects of illegal fishing on the most valuable fish species of the lower reaches of the Western Siberia rivers and the Kara Sea bays, mainly whitefish and sturgeon, has increased in the last 20 years due to the demand for delicatessen production of whitefish and sturgeon in the regional centers of oil and gas recovery. Poaching has become easier due to the existing oil and gas infrastructure. The development of new infrastructure on the Yamal gas fields will inevitably result in increased effects of poaching on whitefish and sturgeon in the Gulf of Ob. In combination with gulf pollution added by rivers, this may result in an almost total loss of the commercial importance of those fish populations within the next 5–10 years.

Widespread poaching on the Pechora River, once the habitat of the largest salmon populations in the Barents Sea basin, is largely a result of fishing mismanagement (quota reductions resulted in the development of poaching and an introduction of a year-round salmon fishing season in the river Pechora for 7 years from 1989). This has led to the transformation of salmon spawning and wintering conditions in the most exposed regions and resulted in a five-fold fall in the salmon population. The invasion of Atlantic salmon parasites infecting salmon young living in the river to the Barents Sea – White Sea basin is also considered to be a serious threat.

In the Chukchi Sea basin, fishing is concentrated in the inlets and lagoons and mainly takes the form of harvesting by indigenous and local populations without posing a serious threat to the marine ecosystem. Trawl fishing has developed in recent years due to the vast stock of humpy shrimp and flounder in adjacent waters washing the Chukotka Peninsula, particularly in the Gulf of Anadyr. The high intensity of trawl fishing and lack of regulation may lead to a range of negative consequences for the preservation of biological diversity. Thus, the effect of trawl fishing on benthic cenoses may have negative consequences for the food reserve of walruses wintering in the Gulf of Anadyr.

Aquaculture development in the Russian Arctic and in the Barents and White Seas is just beginning. Cage culture breeding of Atlantic salmon is unlikely to reach the level found in Norway in the near future. However, the adverse effect of Norwegian aquaculture on the natural population of salmon in the White Sea and Kola Peninsula in the next decade should not be ruled out.

Unregulated hunting of marine mammals, including the polar bear, is considered to be another threat to marine biological diversity. Hunting polar bear, an entry in the Red Book of Endangered Species of the Russian Federation, has been prohibited until recently. It is however known that hunting had been occurring and was sometimes offered, even illegally, to the rich hunters from overseas. Polar bears are sometimes shot as a result of a conflict between human and animal, most notably in cases where bears visit scrap-heaps in villages. The Russian-American Agreement on Polar Bears grants the right of the indigenous population to hunt polar bears, as a traditional prey, up to a certain limit. As any excess hunting in the current climatic conditions (disadvantageous for polar bears) may be fatal for the species population in the Eastern Arctic, it is essential that this limit is not exceeded. However, administrative and educational background for hunting control within the specified limits is almost absent.

6. Alien species in the Russian Arctic seas. Polar latitude conditions, such as low water temperature and extended periods of ice cover, limit the number of donor regions, which may be sources of alien species. Ship passage through ice floe practically eliminates vessel fouling, on which introduced species may spread. At the same time, in the case of the scenario of warming of the Arctic regions, the transportation of hydrocarbons and the development of intense end-to end boat traffic along the Northern Sea Route may lead to the introduction of species from the northern part of the Atlantic and Pacific Oceans to the seas of the Arctic Ocean. In the case of species introduction, the degree of natural ecosystem transformation, especially in estuarine areas such as the Gulf of Ob which are currently under stress due to river pollutants, may appear quite considerable.

King crab, which naturalized in the waters of the Barents Sea in the 1960s, has become a subject of scientific, political, and social discussions. The eastern boundary of the king crab expansion stretches to the Gusinaya Bank, the Kolguev Island region and Cape Svyatoy Nos. The western boundary lies in the Norwegian Sea and in the south to the Lofoten Islands. Possible consequences of crab immigration are structural changes in the benthic biocenosis due to crab feeding preferences and the direct influence of crabs as carnivores on populations of commercial clams. The king crab is likely to exert a negative influence on populations of local species from the same Lithodidae line due to direct competition.

In addition to king crab, the Barents Sea and the White Sea were populated at the end of the 1950s by the Far Eastern humpback. The local populations that formed became an object for amateur, sport and coastal commercial fisheries. There is lack of information on the influence of humpback populations on other components of the biological diversity of the Barents Sea and the White Sea ecosystems. The Chinese mitten crab has become the subject of unintended immigration as it was imported from the north-western part of the Pacific Ocean and spread in the inlets and rivers of the North Sea and Baltic Sea basin. Another case of crustacean introduction may turn out to be the presence of the opilio crab in the Barents Sea. This species seems to have entered the Barents Sea both from the Far East and from the north-west Atlantic, but the mechanism of immigration is unknown.

The hazard of carrying and introducing alien species from ballast water or ship fouling into an ecosystem is likely to increase considerably in line with the development of marine transportation of hydrocarbons. The northern part of the Pacific Ocean is a region with similar climatic and oceanographic conditions and with higher biological diversity, which may be a donor of alien species for the Russian Arctic seas. Such a situation may have occurred in the case of the humpback and king crab acclimatization. The potential effect of immigration of alien species on the ecosystems of the Barents Sea and White Sea remains difficult to predict.

7. Climatic change and its effect on biological diversity and biological resources of the Russian Arctic. All the above factors influencing biological diversity will remain in place despite significant climatic changes in the Russian Arctic. The cumulative effect will clearly appear on the back of such changes. The *Arctic Climate Impact Assessment* (ACIA, 2004) operates with a moderate temperature increase scenario and considers general characteristics of Arctic ecosystems. Regional scenarios were developed in less detail. In accordance with predictive estimates, winter season warming on the Kola Peninsula will be the greatest in Europe up to the middle of the century, approximately 3–4ºC higher relative to the average level of the period 1961–1990. The summer temperature rise in the peninsula will be minor (2–3 times less than that of winter temperatures) and as obvious as in adjacent regions. The negative consequences will be most apparent in the cold seasons, as many species of marine mammals and birds depend on the winter-spring ice conditions. A change of direction and intensity of the North-Atlantic current may dramatically change the climate of the Barents and White Seas, which may be the main problem in that case. Warming may lead to an increase in spawning of capelin, which is favorable for marine birds and predatory fish. Milder winters, with a great number of polynyas, represent a positive factor for eider and other ducks. However, the Greenland seal may face severe problems in the case of changes in ice cover dynamics in the White Sea: young seals will be forced to search throughout the White Sea basin, which usually leads to the death of the majority of animals. A reduction in ice cover, and a decrease in the White Sea ice area and thickness, may severely affect the ringed seal and bearded seal, limiting the reproductive capacity of these species. Ice cover reduction may also result in migration of two more marine species, the white whale and narwhale, to the East. These animals usually dwell near the edge of, and among, the ice. The narwhale reaches up to 80°N, which is nearer

to the pole than any other whale. The problem facing the white whale is that its primary food source (polar cod) has a lower reproductive rate if the May temperature increases.

Warming in the Kara Sea and the coast of the Taimyr Peninsula is slower. For the next 10–15 years, the peninsula will remain an “oasis of climatic well-being”. It is Taimyr that remains a cradle of annual migration. Hundreds of thousands of anseriformes and greybacks, representatives of rare and common species of birds, raise nestlings in Taimyr. The remaining time is spent in wintering quarters and areas of rest along the flight to Europe, Africa and Asia. Climatic changes in those places (floods, droughts, changes in land-use management and agriculture) adversely affect bird populations, mostly the species with small rations of food (such as the red-breasted goose, brant goose, robin sandpiper). As it will be difficult for these species to change regular wintering areas, climatic changes in Europe may actually overlap climatic changes in Taimyr.

The warming will affect the polar bear populations. The amplitude of seasonal ice edge fluctuations is currently increasing, not to tens, but to hundreds of kilometers. But for the «local» bears it will be completely unusual, more so because the bear population on the continental part of the shore is relatively low. In the case of ice coverage reduction, earlier destruction and later shore ice formation, it cannot be ruled out that polar bears will become extinct in the area.

In the Chukchi Sea, as in the Kara Sea, warming processes develop more slowly than in other Arctic Regions. However, predictive estimates confirm the general trend of warming for this region too. In spite of some seemingly positive points relating to the possible future «softening» of climatic conditions for human economic activity, the warming will have an adverse effect on species and landscape diversity of the coast. Rising sea levels will also make their own «contribution». Nesting conditions of marine birds will be disturbed due to sea cliff erosion (dumping of sanderling and robin snipe nesting on Wrangel Island, for instance) as well as walrus and seal rookeries. However, climatic changes are mostly dangerous for such rare species as whales, walruses, marine birds and especially polar bears, whose life is inseparably connected to the sea. The adverse effects of increased temperatures will also be expressed indirectly. As a result of changes in ice edge dynamics, composition and structure of benthic biocenosis – the basic food for gray whale and walrus – will be altered as well. The consequences of such processes require further in-depth study.

Changes in marine ecosystems under the influence of climate warming will affect the structure and size of populations of marine birds. The effect will be especially powerful in subpolar front regions, where increases in bottom water temperature, by only tenths of one degree, may lead to rearrangement both of the pelagic and benthic cenosis including valuable fish species. The greatest influence here will be exerted by secondary effects, as population size and allocation are mainly defined not by the direct influence of higher temperatures, but rather by dynamic physical processes such as currents and winds. Warming will result in decreases in longitudinal temperature gradient on the sea surface, the intensity of ocean currents and the ocean circulation as a whole.

It should be noted that large carnivores may act as an indicator of ecosystem health. The cumulative effect of climate warming in Arctic Regions may be estimated by the condition of populations of polar bear (being on the top of the food chain). Decreases in ice area and thickness, reduction in the maximum development period of floe-ice, and changes in floe-ice dynamics and structure have an adverse effect on the conditions required for reproductive behavior of polar bears and their victims. Earlier breakage of the floe-ice southern boundary as a result of warming observed in spring, and later boundary setting in autumn lead to a reduction of the bears' active hunting period. A two-week reduction results in an 8% loss of animal weight and a one-week shift in the spring ice melting means a 10 kg loss. Insufficient weight gain leads to an excess death rate among animals, especially bear cubs, due to a lack of milk for winter breeding. The negative consequences of anticipated increases in precipitations should also be predicted. Rains at the end of the winter may destroy bear lairs before females with young could leave, which is an increased hazard for the infant bear cubs (the same is also true for the young of mink and ringed seal). Moreover, enhanced winds and ice drift is expected to lead to increased metabolic costs and stresses among bears which spend most of their lives on the ice. All the above circumstances will fundamentally complicate the life of bears, possibly forcing them to migrate to more suitable regions.

Reduction in ice coverage will have an adverse effect on walrus populations as well. Walruses feeding on shallow waters of the Kara Sea and the Chukchi Sea require floes for rest. If no ice is present along the shore, animals are forced to head for floes in deeper regions which are less suitable for feeding. With the disappearance of ice, autumn migration of walrus to the Bering Strait region becomes metabolic cost-plus and more difficult. All the above factors lead to increases in animal.

All these above threats and factors, including accessibility of previously remote regions, have increased in recent years. They have a trans-border component which concerns persistent pollutants and hydrocarbon contaminating factors most of all. However, even factors which appear to be acting locally are caused by processes taking place beyond the Russian Arctic and may also have a cross-border effect.

6.3. Main factors affecting the condition of biological diversity of land territory

Landscape and biological diversity of the territory of the Russian Arctic is considerably better preserved in comparison to Western and Central Europe and Southeast Asia. However, in spite of the cellular nature of anthropogenic disturbances, dynamic degradation is occurring resulting in land cover erosion, thermal erosion, fragmentation of the habitat of Arctic fauna, substitution of natural flora by its derivatives, and decreases in populations of rare species. All of the above occurs on the back of quite pervasive natural changes caused by global and regional climatic reorganization, changes in atmospheric circulation leading to changes in size and allocation of arctic biota along with the development of new properties and dynamic regularities.

The following main factors affecting the current condition of the Russian Arctic biota and ecosystems may be emphasized at the present moment:

Natural factors

– Global and regional climatic change in the Arctic, expressed in increased growing season length (for plants), nesting period (for birds), warm season (for invertebrates), movement of the forest boundary northwards, to areal expansion of some species of plants, mammals and birds, changes in migration routes, and the introduction of alien species.

– Transformation of climatic conditions of terrestrial biota due to changes in atmospheric circulation and oceanic currents (increased frequency of climatic anomalies such as winter thaws, summer freezing, enhanced precipitation) resulting in mass animal mortality (reindeers or waterbirds, for instance), or, on the contrary, in favorable conditions for arctic territories for the invasion by boreal species such as brown bears.

– Active neotectonic processes expressed in some cases in elevation of land and formation of new areas for biota stocking (such as the formation of new islands, growth and joining of old islands, marine terraces, marshy surfaces)

anthropogenic factors

– Global, regional and local environmental pollution (such as tropospheric transfer, emissions from impact sources, emergency blowouts and spills of oil) which are capable of transforming vegetation and fauna in some territories. Pollutants in the food chain, leading to pollutant accumulation in carnivorous mammals, birds and fish

– Mechanical disturbance of land cover caused by unregulated traffic, construction and geological exploration, leading to ecosystem fragmentation, formation of semi-natural and artificial habitats and contamination of existing habitats by undesirable plants

– Plant cover depletion caused by domestic deer overexploitation and violation of conventional regulations and places of pasture

– Poaching and unregulated usage of biological resources leading to reduction in stock particularly within ethno-economic areas.

– Introduction of opportunistic plant species, exploitation of new habitats, prevention of original vegetation recovery; deliberate and unintended introduction of alien species in ecosystems of the Russian Arctic.

6.4. Estimation of the main biome stability of the Russian Arctic

Estimates of the stability of biota and main biome ecosystems of the Arctic Regions, along with their population carrying capacity status, are based on the probability of irreversible or long-recoverable changes. Biome estimation of the Russian Arctic terrestrial biota and ecosystems with reference to specific natural (climatic) and anthropogenic changes is as follows (Table 3).

The total Arctic biome has average to weak stability regarding climatic changes and associated changes in other abiotic factors of the environment, and primarily permafrost. Integral estimation allows us to distinguish typi-

Table 3

Estimation of the Main Biome Stability of the Russian Arctic regarding climatic changes (according to forecasts for 2025 with respect to a scenario approved by ACIA, CO_2 emission will increase 2 times, CO_2 content in atmosphere will increase to 100 ppm, seasonal tabetisol depth will increase by 25–50%)

Direct-Action Factors Biome	Increase in Air-Ground Interface Temperature (1–2°C)	Rise in Sea Level (10–20 cm)	Increase in Seasonal Tabetisol Depth (25–50%)	Increase in amount of precipi-tation (20%)	Stability index (from 0 to 12)
Arctic deserts (shores/inland regions)	+	–/+++	++	++	8
Alpine polar deserts	+	+++	++	+	7
Alpine tundra	–	+++	+	+	5
Arctic tundra (shores/inland regions)	++	+/+++	+	++	9
Subarctic southern tundra (shores/ inland regions)	–	–/++	–	+	3
Subarctic typical tundra (shores/inland regions)	+	–/++	+	+	5
European and Siberian forest tundra	++	++	+	+	6
Far East typical and southern tundra (shores/inland regions)	–	+/++	–	+	4
Far East forest tundra	++	++	+	+	6
Far East elfin woodland	++	++	++	++	8

cal and southern tundra as less stable. Other biomes are relatively stable, though responses to climatic changes have zonal and provincial differences.

Unlike human intervention (pollution, mechanical effect on vegetation, etc.), the stability of natural ecosystems of the Arctic in relation to climatic changes (such as temperature, amount of precipitation, defrosting of the seasonally thawed layer) has different vectors and parameters. Arctic deserts and forest tundra are the most stable because deserts require more pervasive climatic changes for transition into another condition while forest tundra compensates for the effect of air warming by growth of moss cover phytomass and intensification of frost preservation. The southern tundra is less stable. Forest invasion in the southern tundra will be comparably quick (change of ecosystem type is a dramatic example of the instability of climatic changes).

International experience, and domestic developments that estimate the warming effect on the Arctic (Anthropogenic Climate Change, 1987; Climatic Change Effects…, 2001; Climatic Changes…, 2003; Chuckchi ecoregion…, 2002; Kola Peninsula ecoregion…, 2003; Revich and Co., 2003; Taimyr ecoregion …, 2004; UNEP: Climatic Changes. 2003, www.unep.ch), shows us that instead of attempting to identify the response of the natural ecosystem (which is predictable), more attention should be given to the consequences of climate change for management and population (as well as the possibility of sustainable use of the environment) in dynamic climatic conditions.

6.5. Potential threats and risks

Potential threats and risks of the degradation of anthropogenically conditioned natural ecosystems, with due consideration of possible climatic changes and permanent frost depreservation, may be divided into direct (pollution, mechanical destruction of vegetation, soils, and frost) and indirect (thermal erosion development, carbon sink enhancement, accumulation of pollutants and their migration through the food chains, incidence rate, increased frequency of technogenic disaster, etc.).

Currently, continuous permafrost in Russia occupies an area of about 6 million sq. kilometers. As a result of reconstruction, it was established that the area of permafrost decreased by a factor of six during the last interglacial period of approximately 125 thousand years ago (a paleoanalogue of 2^{o}C warming), and doubled during the period of maximum cooling, approximately 20–15 thousand years ago (a paleoanalogue of 4°C cooling) compared to the present day.

A prevalent warming trend has been observed in the Arctic Regions in recent decades, though this is not evident everywhere. Warming intensity varies in different regions and seasons prompting suggestions of a "mosaic" effect on the Arctic biota. Inland warming is more noticeable in winter than in summer, but, at the same time, there are frost pockets in Arctic Regions in winter and which are lacking in summer. From a position of possible effects on the frost ground the changes in process are controversial as well. Summer increases in temperature are not so high in the zone of the deepest soil frost, and is more noticeable at lower latitudes. In winter, the range of cryosolic areas is exposed to a slight cooling.

Most research discusses a reduction in sea ice areas (changes in the balance of atmospheric circulation between ocean and land), a rise in sea level, intensification of coastal erosion and melting of permafrost as main natural threats to the Russian Arctic biota and ecosystems. Other effects could generally be considered to be consequences of the above dynamic processes, though the vast Arctic areas have differently directed trends, other responses to higher-priority climatic changes. Such trends may include deglaciation, increased river flow, reduction/enrichment of biological diversity, forest invasion in tundra, swamping/deswamping and drying-out of lakes. The range of risks and threats to the economic infrastructure and human population increases accordingly. The list of the main potential threats and risks of antropogenically conditioned degradation of the Russian Arctic terrestrial biota and natural ecosystems is as follows:

– Modification of the surfaces with different absorbing and reflecting capacity, extension of terrestrial areas without snow and ice cover, solar radiation absorption

– Increased river flow resulting in rising ocean levels; global reorganization of water and atmospheric circulation; changes in coastal biota and ecosystems

– Changes in the rate of greenhouse gas emissions and absorption by soils, plants, and oceanic shallow waters

– Intensification of erosion of rivers, lakes, and sea shores; intensification of gullying and sloping processes, eolation in regions of light soils

– Changes in biological diversity in the Russian Arctic and natural zones where wintering quarters and Arctic biota migration areas are concentrated; northward shifting of invasion boundary of many plants and animal species along with alien species invasions

– Moving of the north and altitude-zonal timberline along with reduction of zonal tundra areas on the continental part of Northern Eurasia

– Increased frequency and extent of forest, grass, peat-bog and tundra fires, as well as disastrous outbreaks of phytophagous insect populations

– Expanded range of some species of infection carrying animals including feral herds that pose a high threat to humans

– Critical reorganization of typical and rare habitats of animal species (polar bear, wild reindeer, swimming birds and marine birds)

– Growth in access to transportation in formerly inaccessible Arctic regions; increased pollution of those regions and transformation risk.

Climatogenic changes of biota and ecosystems in the same manner result in risks and threats to traditional farming in Arctic Regions:

– Increased risk and threat of inevitable population expansion owing to the need to withstand the threat of transformation of terrestrial ecosystems; risk of a large-scale migration from the regions with a retrogressive environment

– Increased risk of economic activity in coastal areas (erosion, floods, swamping, storms)

– Spread of a range of contagions as a result of climate warming leading to overall population morbidity as adaptations to new environmental conditions require longer periods than observed climatic alterations

– Increased risk of changes in the habitats of animals subjected to traditional harvesting by indigenous people (reindeer, polar fox, coarse and migratory fish, swimming birds), along with reduction of their numbers

– Threat of transformation of the traditional pastures of domestic reindeer and routes of their seasonal movement; degradation of deer farms; irreversible changes in freshwater bodies as traditional fisheries (river shallowing, destruction of spawning areas, drying out of lakes), as well as disturbances to the fisheries of indigenous people

Risk of loss of traditional culture and social identification indicators, as well as the existence of some traditional cultures based on the utilization of highly specific biological resources, habitats and harvesting lands.

The joint action of changing natural and anthropogenic factors is capable of leading to a multiplied effect of disturbances, a «cascade effect» of development, accumulation of negative influences, and growth of risks and threats. Therefore, the following integral groups of interconnected consequences, along with risks and threats defined by those consequences, require independent study, additional estimation and separation into individual sections:

– Risk of traditional farming and ecosystem degradation along with enhancement of the agricultural development of northern lands in conditions of climate warming

– Risk of a cumulative and synergistic effect of the influence on population health, environmental pollution, increase of ultraviolet solar radiation and climate warming

– Risk of synergistic effect of the regional climate accelerated transformation along with changes in underlying terrain, vegetation, the hydrological regime of the terrain and atmospheric pollution.

6.6. Main anthropogenic influencing factors

The influence of anthropogenic factors on the Russian Arctic terrestrial biota differs from biome to biome. Polar deserts, except for minor waterside areas near polar stations and military facilities, were not subjected to man-made changes. Up to 20% of the tundra area, primarily on Yamal, is characterized by a decrease in available pasture as a result of the high pasture load of domestic reindeer. Within a radius of tens of kilometers near the copper-nickel plants of Norilsk (on the Taimyr Peninsula) and Monchegorsk (Kola Peninsula), the plant cover is depleted as a result of emissions of sulfur and nitrogen compounds into the atmosphere. 3–8% of forest tundra in various regions is occupied by areas of technogenic disturbance in sites of production of oil, gas, and other mineral resources. Such areas are numerous on the Kola Peninsula, and in the north of West and North-East Siberia. Fires are registered every year over areas of several tens of thousands of square kilometers. The zonal vegetation recovery rate in the north is considerably lower than in southern regions.

Global, regional and local environmental pollution conditioned by tropospheric transfer, emissions from impact sources, emergency blowouts and spills of oil, etc. is capable of transforming vegetation and fauna in some territories. Species on the highest levels of the food chains, which are less multicomponent than in southern regions, are most exposed to the effects of pollution. As pollutants in entering the food chains accumulate in carnivorous animals, these animals should be protected by taking measures to exclude environmental pollution initially.

The following effects of pollution specific to the terrestrial biota of the Arctic Regions may be defined:

– Exclusion of spore plants species (algae, lichen, moss, and liverwort) highly sensitive even to low and medium levels of environmental pollution with sulfur, nitrogen and heavy metals compounds from phytocoenosis composition

– Eggshell thinning of some species of birds of prey due to the effects of persistent organic pollutants

– Decrease in the reproductive capacity and high death rate of embryos (embryo resorption) of arctic swimming birds receiving significant doses of pollution in wintering and migration areas at mid and low latitudes

– Decrease of immune resistance of arctic birds and mammals due to environmental pollution

– Increased risk of contamination by ultraviolet solar radiation of purely arctic species.

Mechanical disturbance of land cover due to unregulated traffic, construction and geological exploration leads to ecosystems fragmentation, formation of semi-natural and artificial habitats and contamination of the those habitats by undesirable plants. Such disturbances may be also caused by plant cover depletion of domestic reindeer pastures and violation of conventional regulations and places of pasture. The Russian Arctic ecosystems fragmentation processes have their own special nature including the following stages:

1. Formation of localized sites of disturbance with a minor zone of natural-anthropogenic transitional communities.

2. Increase of area and construction of linear structures connecting transformation sites.

3. Formation of a system of localized and continuous disturbances with a relatively wide (comparable in size with localized and continuous disturbances) transitional community.

4. Joining of localized and continuous disturbances by means of transitional communities along with formation of disturbance frontal zones.

5. Formation of large-scale (regional) frontal disturbances and expanding towards similar formations (by means of fragmentation of areas between localized disturbances and between frontal disturbances).

The processes described above are specific to the Kola Peninsula, lower course of Pechora River, the countryside surrounding Vorkuta, southern Yamal, and the area between Norilsk and Dudinka.

Poaching and unregulated utilization of biological resources in the form of terrestrial and freshwater fauna (leading to reduced stocks particularly within ethno-economic areas) is the main threat to the Russian Arctic biota at present. It is difficult to estimate the scale of this phenomenon due to lack of the substantial state supervision, departmental dissociation, reduction of commercial fauna populations, research, and public accounting.

For instance, illegal hunting of polar bears (registered in the Red Book) has stabilized at the level of 300–350 specimens over recent years, 800–1,000 specimens in the Laptev Sea region, 3,000 specimens in the north of the Barents Sea, and 2,000 specimens on the Chukchi Peninsula and Alaska.

There is the possible threat of a drastic reduction in the size of the unique Taimyr population of wild reindeer (currently the largest in the world) that roams throughout the whole Taimyr Peninsula and south of the Evenki Autonomous Area. Seasonal migrations occur in that region through 5 natural zones and subzones – form polar tundra to north taiga – within a range of 1,500 km. The threat is one of uncontrolled animal hunting by special teams of poachers using snowmobiles during migration period or on winter pastures.

The introduction of opportunistic plant species and assimilation of new habitats in the Arctic Regions were discovered as far back as the 1960s–1970s. Currently this process is becoming more interesting owing to the practical difficulties of environmental restoration of disturbed lands (the invading plants interfere with initial vegetation restoration in anthropogenic habitats). Moreover, the problem of biotical invasions (deliberate and unintended introduction of alien species in ecosystems of the Russian Arctic) is aggravating due to climate warming, which may cause, to our opinion, a regional environmental crisis.

6.7. Main trends of anthropogenic transformation

The overall level of anthropogenic transformation of the natural ecosystems of the Arctic Regions does not exceed 5–10%, but some regions have a significantly lower level of environmental degradation (up to 1%). In conditions of extremely low population density of 1–2 persons per km^2, which is almost 10 times lower than mean value in Russia, anthropogenic stress in the Russian Arctic is significantly higher than foreign regions of Arctic. In the case of corresponding areas, the population in the Russian Arctic is 4 times higher than the equivalent population in the foreign Arctic, and the overpopulation rate is 20% to 40%. Long-standing and indigenous populations here are dispersed, while alien populations, on the other hand, are concentrated in locations of development which increases the anthropogenic stress on the environment and, more importantly, on biological resources. Trends in the condition of terrestrial biota and ecosystems detected may be generally interpreted as localized and, less frequently, continuous.

Among the natural trends of the Arctic biota, the following changes may be distinguished: climatogenic and trends related to the current dispersal processes of biota assimilating new habitats, and fodder-producing areas, etc. For instance, trends in the population 57 polar greybacks have been detected in the form of size and/or allocation changes. It has become apparent that species with positive trends dominate over numbers of species with negative trends in changes of both habitats and populations size. The habitat size and population of two species (spoon-billed sandpiper and lesser golden plover) have decreased. All other cases of negative trends are only known for separate populations or on species habitats, especially in the western and eastern regions.

Other examples of natural climatogenic trends are demonstrated by the analysis of the current dynamics of the northern boundary of some animals. One of the most important tasks of modern biogeography and ecology is the study of fluctuations of the northern boundary of some species in polar latitudes at the limit of their expansion, along with their determinant factors. These parameters distinctively and reliably indicate the conditions of species population, and dynamic trends in condition of natural and anthropogenic environmental transformation, and characterize the status of the arctic ecosystems as a whole.

Climatogenic and anthropogenic trends in arctic flora can be detected by means of compositional analysis of the local flora. A current local flora inventory allows trends to be traced of natural long-term changes in flora under the effect of both global factors and fluctuations in seral processes. The Arctic sector has been studied quite poorly in this aspect; a complete recurrent inventory has been conducted only for some flora of the Yamal, Taimyr and regions of north-east Siberia.

The trend in transformation of natural ecosystems can be estimated indirectly by the example of a large-scale effect on vegetation during the development of new territories on the Yamal Peninsula. At the same time, it is known that the scope of anthropogenic transformation and tundra fragmentation on this peninsula have been increased so much in the last decade that the question of the development of a critical environmental situation in that region may already be raised.

The presence of rare species of plants and animals in the region may be considered to be another factor in the anthropogenic transformation of the northern biota and ecosystems. Compared with other natural zones, polar deserts, tundra, forest tundra and north boreal forest are not distinguished by the abundance of rare and endemic species.

The habitats of some mammals (polar bear, reindeer, polar fox) and birds in the Russian Arctic have experienced some modification owing to climate warming which has resulted in population reduction. Anthropogenic stress on terrestrial ecosystems in some regions (the lower course of the Pechora River, the Yamal Peninsula, the western part of the Taimyr Peninsula and the Chuckchi Peninsula) have significantly increased, intensifying the fragmentation, degradation and contamination processes, and the introduction of opportunistic plant species. This has resulted, in turn, in a reduction of the population of some species of polar mammals and birds, and dispersal of some species of animals (brown bear, lynx, fox) to the north.

Problems of preservation of biological diversity can be solved by organizing specially protected natural reservations, as described in Chapter 8.

Chapter 7

CLIMATIC CHANGES AND THEIR SOCIOECONOMIC EFFECTS ON ARCTIC REGIONS

The Arctic Regions hold a special position in the climatic system affecting the current global changes. The ongoing increase of the temperature of the Earth's troposphere is a world-wide phenomenon and results in rising sea levels, particularly due to deglaciation, which could spell danger for coastal areas.

The melting of permafrost (notable in some large regions of the Russian Arctic) is a potential source of methane and, therefore, a contributing factor to intensification of the greenhouse effect. At the same time, polar oceans absorb carbon dioxide, which contributes to a reduction of the accumulation of greenhouse gases in the atmosphere.

Polar latitudes possess the driving mechanisms of the global thermohaline circulation which affects regional climatic changes outside polar regions.

At the same time, global changes and their effects are visible in the polar regions. This is especially evident in the Russian Arctic where increases in air temperature, changes in the thermohaline structure of the Arctic Ocean, reduction in ice-flow area, retreat of glacier and permafrost and accelerated disturbance of the icy shores of polar seas are evident. Climate modeling results show a high probability of the development and enhancement of the above processes in the future.

Climatic change in the Arctic Regions is one of the most controversial trends in modern climatic research. The future of marine ice cover of the Arctic Ocean, and the permafrost and glaciers of the Arctic lands, attracts special research attention, as the cryosphere, which they constitute, is considered responsible for climatic changes, and is capable of both acceleration and deceleration of their development.

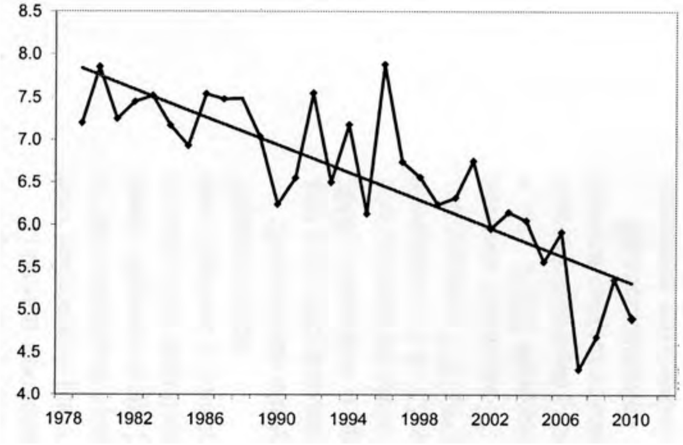

Fig. 4. Polar ice-flow area (millions of square kilometers) in September, 1979-2010 (according to the data from *http://nsidc.org/*)

The area of polar ice-flow at the end of the summer season has gradually decreased since the beginning of satellite monitoring in 1979 and reached an absolute minimum in 2005 (Fig. 4).

Shore (fast) ice makes up approximately 29% of the area of polar seas during winter. Changes in the overall area of fast ice were between 470–800 thousand km^2 over the observed period since the 1930s. The minimum fast ice area was observed in 1995. In the last 20 years, on average, the overall area of fast ice, compared to the same previous period, reduced by 20 thousand km^2 (equivalent to 3% of the average area). Generally, interannual fluctuations in the expansion area and thickness of fast ice do not indicate significant decreasing trends, which proves less sensitivity in the winter season to ice accumulation as a result of changing air temperatures.

Fluctuations of ice expansion areas in the arctic seas during the 20th century and at the beginning of the 21st century took place on the back of a negative trend. Reduction in area during the period 1924–1955 is similar to the reduction in the last three decades (1979–2003) (Fig. 5).

Long-term changes in the Russian Arctic marine area occupied by ice demonstrate cyclical fluctuations of about 60 years. The contribution of the above changes to the overall variability is more than the overall contribution for the period under observation of 23% for Siberian seas of the Russian Arctic.

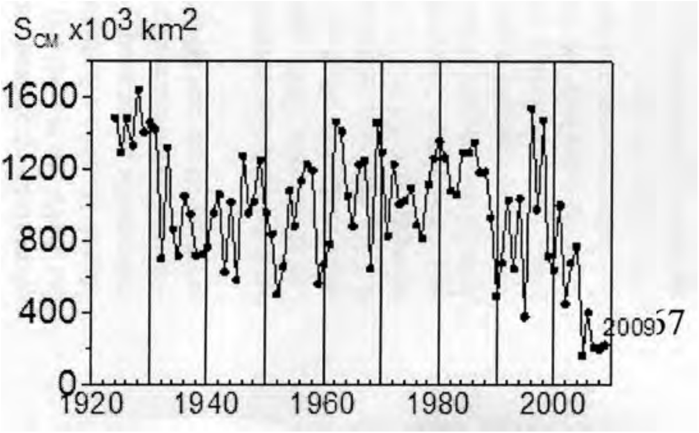

Fig. 5. Ice expansion area in Siberian arctic seas in September, 1924–2009 (according the data provided by the Arctic and Antarctic Research Institute)

Simple extrapolation of this cyclical fluctuation, apparently of natural origin, to the following decades assumes a return of the more severe ice conditions, compared with the present day, by the 2020s. However, according to many experts, rapid reduction of the summer ice area in the last five years and global climate model calculations considering the anthropogenic effect are a noteworthy indication of the summer ice-flow retreat outside the arctic seas forthcoming in the middle of the 21st century. Calculations for the end of the century predict an almost complete disappearance of ice at the end of the summer season.

Considerably less data on the thickness of drifting ice is available. Analysis of information on the distribution of ice settlement in the Arctic basin collected by US and UK submarines shows, in particular, approximately a 42% decrease in average ice thickness (from 3.1 m to 1.8 m) from 1958–76 to 1993–99, and a reduction of almost 32% in the overall volume of ice. However, the above estimations were obtained in conditions of incomplete Arctic basin coverage, so the representativeness of the data can be doubted due to possible movements of old ice outside the coverage of the survey.

Calculations of the future climate of the Russian Arctic, performed using up-to-date global climatic models with due consideration to increases in the concentration of greenhouse gases in the atmosphere, demonstrate continuing warming and significant increases in air temperature in the winter season up to the middle of the 21st century. The observed warming of the Arctic climate, especially its possible future intensification, could lead to the degradation of glaciers and permafrost in the arctic lands.

Increased air temperatures in permafrost regions deepens soil thawing in the summer season, and shallow soil freezing in winter. As a consequence, the depth of the active layer in the soil and the permafrost layer increase. Fluctuations in the depth of the active layer in the basin of the rivers Ob, Yenisei and Lena in the 20th century demonstrate this positive trend.

Climatic changes will affect the type and scope of transfer of pollutants in water systems and the atmosphere. In particular, the following conditions will be significant for transfer of pollutants:

– Enhancement precipitation in the Russian Arctic

– Enhanced atmospheric meridional exchange due to increased cyclonic activity in mid and polar latitudes of the Northern hemisphere

– Increased flow (up to 20%) of arctic rivers

– Increased length of ice-free period in the Russian Arctic seas

– Permafrost thawing, more intense disturbance of the Russian Arctic sea shores

– Increased frequency of ice jamming events on the Lena and other Siberian rivers.

Generally, the above factors will contribute to some increase in the volumes carrying (and resulting in fall out) pollutants. This increase will also contribute to a higher volume of river flow, precipitation enhancement and cyclonic processes in the atmosphere. More intense pollution of the seas of the Russian shelf (owing to prolongation of the ice-free period) is also possible due to the fact that the sea ice present in the Russian Arctic sea basins, for the period exceeding nine months, accumulates pollutants that fall out from the atmosphere and are captured by the superficial layer of the sea. They are then carried out to the central Arctic basin and further to the Strait of Frama, where pollutants are discharged into the marine environment. In the case of a prolonged ice-free period, part of the pollutants previously carried out with ice to the central Arctic basin will be discharged to the coastal shelf marine environment and then, intermixing, to the internal waters of the Arctic Ocean.

Thus, the Arctic Ocean will be exposed to changes in spatial attitude of pollutant salvo emission zones from snow and ice cover to the marine environment.

Degradation of the quality of drinking water is also expected due to permafrost thawing, coastal erosion and other changes in the natural environment.

Climatic changes may have severe socioeconomic effects. The thawing of permafrost soils in the Russian Arctic leads to a negative effect on urban and industrial infrastructure including airports, motor ways and railways, and pipelines.

Multiple examples of destruction of apartment building in Yakutia and other regions of the Far North (Yakutsk, Norilsk, Vorkuta, Amderma, Tiksi) indicate an increased risk to infrastructure and human life. Damage to oil and gas pipelines has been registered in the permafrost zone of the Khanty-Mansi Autonomous Area – Yugra. Permafrost thawing may require great reclamation work resulting in intensive investment. Some disturbances of snow-and-ice roads (winter roads) may also be expected resulting in transportation problems. On the other hand, the volume of fuel required to heat buildings is likely to fall, and this positive effect of climatic change has been observed recently.

Transportation of coal and mineral resources will probably be exposed to both positive and negative effects of climatic changes. Transporting products by sea from Siberian mines will probably benefit from the reduction in sea ice and extension of the navigation season. The mineral resource industry, using arterial roads laid in the permafrost, will probably bear high expenses on road service owing to the thawing permafrost. The effect on the oil and gas industry will probably be similar with eased access from the sea and hindered terrestrial access. Reduction of arctic sea ice areas will undoubtedly serve to accelerate the development of oil and gas resources on the coastal shelf.

Future changes in the extent of snow-cover and condition may have severe adverse effect on reindeer breeding and the related physical, social and cultural aspects of herders' lives. Earlier thawing and later frosting of river ice may lead to a break in the conventional migration routes between winter and summer pastures.

The forest industry (already declining due to economic factors) may face additional problems in relation to warming. Timber quality will be reduced due to insect damage as well as problems with infrastructure and winter transportation due to the thawing of soils.

Forecasts of the development of wild fire conditions in Siberia show that a possible air temperature increase in the summer season from 9.8ºC to 15.3ºC will lead to a doubling of the number of years with catastrophic fires (an increase of 150% in the area of forest fires per year) and to a 10% decrease of the timber resources.

Climatic conditions restraining agricultural development include a short growing season (insufficient period for complete ripeness or for production of crops capable of ripening), heat scarcity (insufficiently warm days during the whole growing season), and long cold winters limiting the capacity of permanent crops for survival. According to the forecast, agricultural opportunities will increase as warming progresses.

Transition to a wetter climate will probably lead to an increase in aquatic resources for the people living in the region. The ground water level in permafrost-free regions will probably rise closer to the surface. According to forecasts, more moisture will be available for the agricultural industry. Enhanced flow and precipitation in the spring season will probably cause a rise in the water level in rivers and an increased flood hazard. According to forecasts, lower water levels will be observed during the summer season, which will probably adversely affect river navigation and hydraulic power engineering, and increase the risk of wild fire.

Climatic change will have an adverse effect on human health in the Arctic Regions.

The human body is the most exposed to violent fluctuations of the main meteorological parameters (air temperature and humidity, atmospheric pressure and precipitation, wind velocity and solar radiation). The frequency of the above parameters notably increases along with climate warming. An increase in the number of extraordinary events, such as floods, storms, landslides and avalanches, as may be expected, will lead to more damage and a higher death rate. In addition to the direct effects of such events, the indirect effects may include an influence on the availability and safety of drinking water. Intensive precipitation events may also cause outbreaks of diseases carried by mosquitoes, as well as floods and water source pollution depending on the current water infrastructure.

Rural residents in the Arctic, living in small isolated communities with underdeveloped social systems, poor infrastructure, and underdeveloped or non-existent public health systems, are the most vulnerable. Indigenous peoples that depend on hunting and fishing, especially using a small number of species, will turn out to be the most vulnerable to the changes severely affecting the above species (for example, reduced sea ice area and its effect on the ringed seal and polar bear). Changes in food ration may have the most negative effect on the health of indigenous peoples.

Age, lifestyle, sex, access to resources and other factors affect the individual and cooperative adaptability. The historical capability for migration as a means of adaptation to changing climatic conditions has decreased, as the majority of the population has switched to a sedentary life.

Changes in the ecosystem of the Russian Arctic seas in global warming conditions may have show rapid and radical modifications. A decisive role among such modifications will be played by the processes affecting ice cover conditions as they define, to a great extent, the overall regime and ecology of the Russian Arctic seas. Large-scale weakening and shifting of ice cover towards the pole (along with simultaneous increases in river flow and rising sea level) may lead to the total actuation of biological productivity processes along the whole shallow and wide shelf of the Arctic Ocean from the Kara Sea to the Chuckchi Sea.

The Kara Sea and Chuckchi Sea ecosystems on the western and eastern flanges are expected to be transformed to a condition close to that of the Barents Sea and Bering Sea respectively. Ice coverage weakening and northward movement of the ice expansion boundary, along with simultaneous increases in river flow (by means of the total precipitation increase and as a result of thawing in permafrost zone) will lead to actuation of the (currently literally) «frozen» biological productivity potential of the Arctic shelf seas and fundamental modification of the ecosystem. Corresponding changes in piscifauna will take place in parallel though with some delay. Such changes will most likely begin on the western and eastern edges of the shelf, as a result of migratory expansion of cold-water species to the Barents Sea and the Bering Sea, with the following extension of their habitat areas to the whole shelf.

The response of the populations of some mass species of fish to temperature changes may be especially clear, rapid and large-scale in situations where habitats of those species overlap the regions with domination of temperature «thresholds» for species. In such cases, areal northern boundaries will be defined by the latitudes of free water allowing to habitation and reproduction of some species i.e. higher than threshold level. Such situations are typical, for instance, in the northern part of the Pacific Ocean with a vast aquatic area with cold «winter» water where the temperature decreases to -1.7^{o}C and therefore stops the invasion of most piscifauna species. At the same time, such regions are usually notable for their high level of biological productivity and good food potential. Even a minor increase in the water mass heat content in such regions, regardless of the cause (climatic, oceanological, seasonal), may make them accessible for feeding and reproduction of various species and thus drastically change the fishery situation in a region.

An especially clear and close connection between the condition of fishery resources, and regional climate and temperature regime is typical for the Barents Sea.

In conditions of climate warming in the Arctic Regions, the formation of commercial piscifauna species will take place both by means of an increase in some local species of the arctic complex (generally, semi-anadromous whitefish, some codfish and flatfish), and as a result of expansion of arctic-boreal species (codfish, walleye pollack, lodde, herring, wolffish, flatfish) during dispersal from the Barents Sea and the White Sea. The intensification of river flow, biogen carry-out and ice retreat must occur simultaneously with the growing importance of wellhead areas and the whole shelf coastal area as a region for migrating and semi-migrating fish. This situation will be the most notable in shallow seas such as the East Siberian Sea and the Chuckchi Sea.

Estimates of possible scenarios and modifications of the ecosystems and piscifauna of the Russian Arctic seas in conditions of climate warming and ice coverage degradation show that the above seas may drastically increase their fish production potential (up to 30–40 million tons by biomass of the main commercial species) and become a place of intensive fishing and effective aquaculture with overall commercial fishery yield reaching 10 million tons per year.

Climatic changes will have an inevitable effect on the Russian Arctic terrestrial ecosystems including:

– Increased growing season length (for plants), nesting period (for birds), warm season (for invertebrates) leading to the northward movement of the forest boundary, to expansion of some species of plants, mammals and birds, changes in migration routes and introduction of alien species;

– Increased frequency of climatic anomalies (winter thaws, summer freezing, enhanced precipitation) will lead to mass mortality of some populations (for instance, reindeers during the period of formation of ice crust in winter or frost return during fawning), or, on the other hand, favorable conditions in arctic territories may lead to invasion by boreal species (brown bear of the forest tundra and southern tundra, for instance).

Chapter 8

SPECIALLY PROTECTED NATURAL RESERVATIONS OF THE RUSSIAN ARCTIC AND SUBARCTIC REGIONS

The Russian Arctic, and adjacent regions, contains a network of 14 federal state reserves, the national park «Russian Arctic» and the federal wildlife reserve «Franz Josef Land». These are considered as Class 1 Specially Protected Natural Reservations (hereinafter referred as SPNR) according to the classification of the International Union for Conservation of Nature and Natural Resources (IUCN). The total area of the above mentioned SPNR is over 15 million hectares. The total area of the northern, arctic and near-arctic SPNR is about 30 million hectares, which is about 5% of the whole territory of the Russian Arctic within the boundaries used for the Arctic Council CAFF and AMAP Programmes.

The network of existing and potential SPNR comprises all the key landscapes of the north including transitional communities, and typical zonal, island, continental, mountain, and delta landscapes. However SPNR density varies from region to region. The Kola Peninsula has 6 SPNR and 12 conservation areas have been formed, or are in the process of forming, in eastern European, western Siberian and central Siberian sectors. The whole Arctic area of Eastern Siberia has only 4 existing and several potential SPNR.

Unfortunately, the current situation with SPNR development (respectively low representativeness, poor efficiency of biota preservation, lack of educational and ecological tourism opportunities) cannot be solved only by means of a mechanical increase of the quantity and area of SPNR included in the schedule of the possible future development of the federal SPNR network. For instance, making a decision to open two large national reservations in the whole Russian Arctic («Russian Arctic» and «Beringiya») is obviously not enough for organization of a large-scale, high-latitude, extreme ecological educational and tourist resort as can be seen in the North American Arctic and the Scandinavia and Svalbard archipelago, where the SPNR network occupies up to 40–50% of the total area. Lack of conservation areas as reference points of the condition of Arctic biota in many large regions of the Russian Arctic does not allow complete estimates to be made of the natural and anthropogenic trends in terrestrial biota dynamics. Development of extensive poaching and an actual decrease of terrestrial fauna reserves in some arctic regions are, in many instances, connected with a lack of wildlife reserves that can offer protection for populations of commercial fauna and protected animals allocated in accordance with seasonal and feeding migrations.

There were only several conservation areas in the Russian Arctic until the 1990s, namely Kandalaksha, Kronotskiy and Wrangel Island. These areas included water areas for preservation of marine ecosystems. The Komandor, Nenets, Koryak, and the Big Arctic conservation areas, which were later added, significantly expanded the size of the protected basins. Some of the conservation areas (Big Arctic, Kandalaksha, Komandor, Koryak, Kronotskiy, Nenets, «Wrangel Island»), the «Russian Arctic» national reservation, and wildlife reserves («Franz Josef Land», «Nenets», «Severnaya Zemlya») have protected marine waters occupying about 10 million hectares in total, which is approximately 2% of the continental shelf area under the responsibility of the Russian Federation. The water area in the «Wrangel Island» and «Komandor» reservations exceeds that of the land area.

Currently, the Russian Arctic federal and regional marine SPNR are absent in many physiographic provinces of the Arctic Ocean, namely the continental slope in the central part of the ocean; on the shelf in the Barents Sea; in the coastal area of the Yuzhniy Island of Novaya Zemlya; in the water area and along the east coast of the Kanin Peninsula in the White Sea; in the Kara Sea, Laptev Sea and East Siberian Sea including the Siberian polynya. All the above regions have no protected SPNR water areas except for the coastal waters of the Taimyr Peninsula and the Wrangel Island.

Such ecosystems as marshes, river inlets, productive shallow bays and lagoons, recurring polynyas, upwellings, underwater banks, large spawning grounds, aquatic mammal rookeries, conglomerations of marine bird nests, and habitats of rare marine species are insufficiently presented in the current marine SPNR.

As opposed to the terrestrial SPNR, the status of the federal wildlife reserve or national reservation is sufficient for the marine SPNR. In some cases, concerning the scheduled SPNR of acting reservations («Kolguev Island», for instance) one can talk about an ecosystem conventional exploitation area with protected waters. Such facilities require the formation or expansion of the present protected water areas (as in the case of the Kandalaksha reservation).

A review of the current SPNR system in the Russian Arctic demonstrated the presence of many gaps in relation to the effectiveness of biological diversity and ecosystem territorial protection, as well as representativeness of the current Russian SPNR system. The arctic tundra of Novaya Zemlya, Yamal, Gydan, and West Taimyr, the tundra and polar desert of the New Siberian Islands, the subarctic tundra of Pakhoy, Timansk, Paykhoy, Polyarnouralsk and Vaygach, the forest tundra along the extension in the North of Eurasia (Novaya Zemlya, West Siberia, Central Siberia, Yakutia, and Chukotka) are the least represented in the modern federal arctic SPNR.

An increase in habitat representativeness of rare species of terrestrial plants and animals in the SPNR of the Russian Arctic requires organization of new conservation areas, national reservations, and federal wildlife reserve on the arctic coast of Yakutia and the Chuckchi Peninsula. Up to 10 rare species registered in the Russian Red List may be presented in the SPNR at the same time.

In accordance with the «Outline of territorial planning of the Russian Federation in relation to the development and allocation of federal specially protected natural reservations for the period until 2020», 3 new conservation areas are scheduled in the Russian Arctic by 2014–2015:

«Bear islands» in the Republic of Sakha (Yakutia), covering an area of 13.99 thousand hectares (including – 7.99 thousand of hectars);

«Khibiny» in Murmansk region, covering an area of 1483 thousand hectares;

«Central Chuckchi» in the Chuckchi Autonomous Area, covering an area of 100 thousand hectares.

Moreover it is planned to expand the marine protected zones around some conservation areas including Kandalaksha (an area of 73 thousand hectares of water), Taimyr peninsula (an area of 500 thousand hectares), and Magadan (600 thousand hectares). Strategic targets of the «Territorial planning of the Russian Federation…» unfortunately do not completely match the priorities of the Russian Arctic natural territorial protection as can be seen from the from a comparison of the plans and propositions and recommendations presented above.

Chapter 9

ROOT CAUSE FAILURE ANALYSIS OF THE RUSSIAN ARCTIC ENVIRONMENTAL PROBLEMS AND CONCERNED PARTIES ESTIMATION REVIEW

9.1. General provisions

The method of the Root Cause Failure Analysis (RCFA) of environmental and socioeconomic problems connected to the utilization and protection of environmental and natural resources has been developed by the Global Environment Facility (GEF). Currently this method is extensively used in transboundary water diagnostic analysis. The purpose of RCFA consists of identifying the most important influencing factors relating to every significant problem relating to the development of adequate measures focused on environmental damage indemnification and mitigation including protective, recovery, and adaptive measures. RCFA procedures provide for identification and prioritization of influencing factors and investigation of direct, industrial and root causes of environmental problems.

The key feature of the RCFA procedure in the Russian Arctic is the discrepancy of territorial boundaries and geographic limits of influencing factors. Air currents transferring pollutants from regions outside the Arctic Ocean catch basin (Western Europe, North America, and South-East Asia) play an important role in background environment pollution of the Russian Arctic. Apart from atmospheric transfer, pollutants ingress to territorial and shelf waters of the Russian Arctic with river flow, as well as ocean and sea currents. Therefore, a methodological approach to RCFA has been proposed for the justification and consideration of all influencing factors affecting the generation of environmental problems. This approach provides identification of three categories of factors and problems: local, regional and cross-border. Identification of the varying scale of environmental factors and problems allows the people responsible for political and economic decisions to foresee risks and threats related to the following: a) spot development of producing operations and their local effect on the natural environment within a settlement, industry, and defense lands; b) impact pollution of adjacent natural sites with a special environmental conservancy regime effective for the purpose of provision of the exploitation of the traditional ecosystem of the Northern Indigenous Peoples, stable functioning of fisheries, supply of quality drinking water, preservation of biological diversity, and resolution of other environment-oriented problems; c) background environment pollution sourced far outside the Russian Arctic.

The following terms are used for analysis and identification of causes of environmental problems in the Russian Arctic within the scope of RCFA:

– *RCFA geographical limits* – include: a) the Russian Arctic territory itself with multiple hot spots of pollutant sources and other technogenic influences on the elements of the natural environment; b) other territories outside the Russian Arctic identified by large river catch basins, air and sea pollutant streams from other regions including Western Europe, North America, and South-East Asia. RCFA action within the Russian Arctic is based on estimation of technogenic effect factors in corresponding hot spots (listed below) located in terrestrial and marine parts of the territorial area. The cross-border aspect (considering the influence of many regions and sources located in the northern hemisphere) assumes the selective character of RCFA. Cross-border influencing factors are subject to detailed analysis upon the following conditions: a) as a result of long-range transfer of air or sea water masses, influencing factors stipulate background pollution of the Russian Arctic subsequently affecting food chains and posing a threat to the health of Arctic regions; b) influencing factors are responsible the formation of impact pollution zones in the arctic sea coastal area due to pollutant ingress from river flow.

– *Hot spot* is a technical or natural-technical facility being a source of environmental pollution, or local natural locality (facility or territory), which is polluted or a source of above-level pollution and environmental quality change.

– *Environmental quality* is the degree of correspondence between the environment and people’s needs.

– *Root causes of environmental problems* are key factors, trends and processes affecting the selection of policy, regime and methods of natural ecosystem utilization along with their ecological-economic functions. The above measures and processes exert an influence on: a) economic and other activity development conditions; b) selection of technology and regimes of functioning of economic sectors and industry; c) level of risk for the natural environment.

– *Direct causes of environmental problems* are physical, biological or chemical parameters of the environment which appear in the hot spots as factors of negative change of environmental quality including changes in the natural ecosystems condition and human living environment.

– *Industrial causes of environmental problems* are the activities of various economic sectors (industries) leading to direct causes of environmental problems including economic solutions directly or indirectly resulting in a change of environmental quality and respective socioeconomic effects.

– *Socioeconomic effects* are harmful influences on environmental health factors and the well-being of the population (for instance, the deterioration of the health of the population along with cost escalation, water treatment expenses due to the deterioration of the water quality of drinking water sources, etc.).

– *Environmental exposure* means the harmful influence on natural ecosystems and components (reduction of biological diversity, deterioration of living environment and habitats of plants and animals etc.).

– *An environmental problem* is a change in the natural environment as a result of anthropogenic influence leading to the disturbance of the natural ecosystem structure and functioning. Environmental problems are classified by spatial coverage (local, regional, cross-border, global etc).

Main materials for the identification of hot spots, and prioritizing the defining factors of technogenic or other harmful influence and related environmental problems, are represented by regional environmental reports for recent years, publications of Arctic Council task groups (AMAP), thematic materials prepared within the scope of the subprogramme «Development and Utilization of the Arctic Regions», the Federal Target Programme «World Ocean», the Ecological Atlas of Russia, regional ecological and complex atlases, as well as literary sources and dedicated internet sites.

9.2. Identification of foreground environmental problems

According to the results of detailed analysis of the current condition and predictions of possible environmental changes in the Russian Arctic hot spots, five foreground environmental problems have been identified for the region: environment pollution; soil degradation and land usage violation; change in the biological diversity and reduction of the reserve of biological resources; deterioration of the habitat of the Russian Arctic indigenous population and conditions of conventional nature management; negative effects and threats of ongoing global climatic changes.

Several ecologically and socioeconomically measurable negative factors have been identified for each foreground environmental problem. Specification of the above factors is provided in the corresponding sections of the diagnostic analysis. Factors having a negative effect are distinguished by an invariant nature and this is clear from the part they play in the development of several environmental problems. Thus, factors of technogenic pollution and global climatic change cause the generation of key environmental problems (technogenic pollution and negative effects of climatic changes). At the same time, the above factors are responsible for generation of indirect environmental problems including soil degradation and land usage violation, deterioration of the habitat of the indigenous population, change in the biological diversity and reduction of the reserve of biological resources etc. Identification and prioritization of indirect environmental problems is connected wit the following: a) the high sensitivity of Arctic landscapes and indigenous populations to technogenic pollution and climatic changes; b) the requirement for consideration of stated problems in strategic planning of the Russian Arctic socioeconomic development along with the key environmental problems.

9.3. Hot spot prioritizing for environmental problems analysis

Hot spot prioritizing has been performed based on a set of parameters specified below. Comparative analysis of various parameters offers weight characteristic as well as selection by means of surveys of the opinions of concerned parties opinions allowing weighting of the contribution of each parameter in the course of the hot spot formation (Table 4).

Table 4

Weighing coefficients applied in prioritizing

Parameter	Weighing Coefficient
Size of population exposed to the negative effect	0.8
Area exposed to the negative effect	0.8
Air pollution concentration	1.0
Open water pollution concentration	1.0
Environmental hazard of extractive industry	0.6
Environmental hazard of long-range pollutants air and water transfer	0.6
Degree of ecosystem degradation	0.8
Hazard of the hot spot current effect	1.0
Hazard of the hot spot potential effect	1.0

Prioritizing results (Table 5) are presented in the form of a matrix, where hot spots are estimated according to the following parameters.

Column 1: hot spot location.

Column 2: distance from sea shore (5 categories): 5 – sea offshore area; 4 – within 10 km; 3 – within 100 km; 2 – 100–1000 km; 1 – >1000 km.

Column 3:population size in affected zone (5 categories): 1 – less than 100 people; 2 – 100–1,000 people; 3 – 1,000–10,000 people; 4 – 10,000 – 50,000 people; 5 – >50,000 people.

The presence of northern indigenous minorities in the affected zone is specified in the notes: index I is for domiciled population, index M is for migratory population.

Column 4:affected zone (5 categories): 1 – <10 sq.km; 2 – 10–100 sq.km; 3 – 100–1,000 sq.km; 4 – 1,000–10,000 sq.km; 5 – >10,000 sq.km.

Column 5: atmospheric pollution level (according to the atmospheric pollution index) (5 categories): 5 – very high; 4 – high; 3 – increased; 2 – moderate; 1 – low.

Column 6: open water pollution (5 categories): 5 – very dirty; 4 – dirty; 3 – polluted; 2 – moderately polluted; 1 – clean.

Column 7: environmental hazard of extractive industry (5 categories): 5 – very high; 4 –high; 3 – increased; 2 – moderate.

Column 8: estimation of the environmental hazard of long-range pollutants air and water transfer (3 categories): 5 – very high; 3 – high; 1 – moderate.

Table 5

Summary table of hot spot prioritizing in the Russian Arctic and adjacent territories

№	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Republic of Karelia														
1	Belomorsk	4	2.4	3	3	3		0.6	3	1	1	21.0	22.0	TR,PF
2	Kem	4	2.4	3	3	3		0.6	2	1	1	20.0	21.0	PF, TR
3	Nadvoitsy	4	2.4	1.6	3	3	–	0.6	2	1	2	19.6	21.6	ME
4	Segezha	4	2.4	1.6	3	4	–	0.6	3	1	2	21.6	23.6	PF
Murmansk Region														
5	Nikel	3	3.2	3.2	5	5	4	1.8	4	4	4	37.2	41.2	ME
6	Zapolyarniy	3	3.2	3.2	5	5	4	1.8	4	4	4	37.2	41.2	ME
7	Pechenga	3	2.4	1.6	2	4	–	–	2	1	1	17	18	TR
8	Murmansk	4	4	2.4	4	5	–	1.8	3	2	3	29.2	32.2	CO
9	Kola	4	4	2.4	3	4		1.8	3	1	1	24.2	25.2	FO(PP)
10	Teriberka	4	0.8	0.8	2	3		0.6	2	1	2	16.2	18.2	TR
11	Apatity	2	4	1.6	2	3		0.6	2	2	2	19.2	21.2	CO
12	Kirovsk	2	3.2	1.6	3	4	4	0.6	3	2	2	25.4	27.4	MI
13	Kovdor	2	3.2	1.6	2	3	4	0.8	2	2	2	22.6	24.6	MI
14	Yena	2	2.4	0.8	1	3	2	0.6	2	1	1	15.8	16.8	MI
15	Polyarniye Zori	3	2.4	0.8	1	1		3	1	2	4	18.2	22.2	PP
16	Kandalaksha	4	2.4	1.6	3	4		1.8	3	2	2	23.8	25.8	ME,TR
17	Beloye More (settl.)	4	1.6	0.8	1	3		0.6	2	1	1	15.0	16.0	TR
18	Umba	4	1.6	0.8	1	2		0.6	2	1	1	14	15	TC TR RE
19	Olenegorsk	2	3.2	1.6	3	4	4	0.6	2	2	2	24.4	26.4	MI, CO
20	Monchegorsk	2	4	2.4	4	5	4	3	4	3	3	31.4	34.4	MI, ME,

№	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Arkhangelsk Region													
21	Mezen and urban settlement Kamenka	4	2.4	1.6	1	3		0.6	2	1	2	15.6	17.6	TR,TC
22	Arkhangelsk	4	4	2.4	4	4		1.8	3	3	3	26.2	29.2	CO
23	Severodvinsk	4	3.2	1.6	4	4		1.8	3	2	2	23.6	25.6	HL(PP)
24	Novodvinsk	4	2.4	1.6	4	4		1.8	2	2	2	22.6	24.8	PF
25	Solombola	4	2.4	1.6	4	5		1.8	3	2	2	23.8	25.8	PF
26	Koryazhma	3	2.4	1.6	4	5		1.8	4	2	2	23.8	25.8	PF
27	Onega	4	2.4	1.6	3	4		1.8	2	2	2	20.8	22.8	PF,FO
28	Nizhnyaya Zolotitsa	4	1.6	0.8	1	2		0.6	1	1	2	12.0	14.0	TR, RE
	Nenets Autonomous Area													
29	Vasilkovskiy oil/gas condensate field	4	0.8	2.4	1	5	–	1.8	3	2	2	22.0	24.0	OG
30	Kumzhinskoye field													
31	Naryan-Mar	2	3.2	1.6	2	3	–	1.8	2	1	1	17.6	18.6	TR CO
32	Amderma	5	1.6	1.6	2	2	–	0.6	2	1	1	16.8	17.8	TR CO
33	Kharyaginskoye field	2	1.6	1.6	2	3	–	1.8	2	2	2	18.0	20.0	OG
34	Toraveyskoye field	4	1.6	1.6	2	2	–	0.6	1	2	2	16.8	18.8	OG
35	Varandeyskoye field	4	1.6	2.4	2	3	–	1.8	2	1	2	19.8	21.8	OG
36	Peschanoozerskoye field	4	1.6	1.6	2	2	–	1.8	2	1	2	18	20	OG
	Komi Republic													
37	Vorkuta	2	4	3.2	3	4	2.4	1.8	3	3	4	30.4	34.4	MI, PF, M
38	Inta	2	3.2	2.4	3	3	1.8	1.8	2	2	2	23.2	25.2	MI, PF

№	1	2	3	4	5	6	7	8	9	10	11	12	13	14
39	Verkhnevozeyskoye field	2	2.4	2.4	2	3	–	1.8	3	2	2	20.6	22.6	OG
40	Vozeyskoye field	2	1.6	2.4	2	4	–	1.8	3	2	2	20.8	22.2	OG
41	Usinskoye field	2	4	2.4	2	4	–	1.8	3	2	2	23.2	25.2	OG
Yamalo-Nenets Autonomous Area														
42	Urengoi field	3	4	3.2	2	3	–	1.8	3	2	2	24.0	26.0	OG
43	Yamburgskoye field	4	2.4	3.2	2	3	–	1.8	3	2	2	23.4	25.4	OG
44	Medvezhye, Yubileynoye, and Yamsoveyskoye fields	3	2.4	3.2	2	3	–	1.8	3	2	2	22.4	24.4	OG
45	Bovanenkovskoye and Kharasaveyskoye fields	4	1.6	3.2	2	3	–	1.8	2	2	2	21.6	23.6	OG
46	Zapolyarnoye field	3	2.4	3.2	2	3	–	1.8	2	2	2	21.4	23.4	OG
47	Nakhodka and Yurkharovskoye fields	4	2.4	3.2	2	3	–	1.8	2	2	2	22.4	24.4	OG
48	Salekhard	2	3.2	1.6	3	4	–	0.6	1	1	1	17.4	18.4	TR (FO)
49	Labytnangi	2	3.2	1.6	3	4	–	0.6	1	1	1	17.4	18.4	TR (CM)
50	Nadym	3	3.2	1.6	3	4	–	0.6	1	1	1	18.4	19.4	TR
51	Noviy Urengoi	2	4	2.4	3	4	–	1.6	1	1	1	20.0	21.0	TR (PP)
North of the Krasnoyarsk Territory														
52	Norilsk	2	4	4	5	5	3	3	4	4	4	38.0	42.0	ME (MI)
53	Talnakh	2	3.2	2.4	5	5	2.4	1.8	4	2	2	27.8	29.8	MI (RE)
54	Kayerkan	2	3.2	2.4	5	5	2.4	3	4	2	2	31.0	33.0	MI
55	Dudinka	2	3.2	1.6	3	4	–	3	3	2	2	23.8	25.8	TR

№	1	2	3	4	5	6	7	8	9	10	11	12	13	14
56	Dickson	4	2.4	1.6	3	3	–	0.6	2	1	1	18.6	19.6	TR
57	Kayak	2	1.6	0.8	2	3	1.2	0.6	1	1	1	14.2	15.2	MI
58	Hatanga	2	2.4	1.6	3	3	–	0.6	2	1	1	16.6	17.6	TR (FO)
	Republic of Sakha (Yakutia)													
59	Tiksi	4	2.4	1.6	3	3	–	1.2	2	1	1	19.2	20.2	TR
60	Kular	2	2.4	1.6	3	3	1.2	–	2	2	2	19.2	21.2	MI
61	Deputatskiy	2	2.4	1.6	3	3	2.4	0.6	2	2	2	21.0	23.0	MI
62	Tenkeli	2	2.4	1.6	2	2	1.2	0.6	2	2	2	17.8	19.8	MI
63	Yese-Haya	2	–	1.6	2	2	1.2	–	2	2	1	13.8	14.8	MI
64	Nizhneyansk	4	2.4	1.6	2	3	–	0.6	1	1	1	16.6	17.6	TR
65	Chokurdakh	2	2.4	1.6	2	3	–	0.6	2	1	1	15.6	16.6	TR (FO)
66	Chersky	3	2.4	2.4	2	3	–	1.8	2	1	2	19.6	21.6	TR (PP)
	Chukot Autonomous Area													
67	Iultin	3	–	1.6	2	2	1.2	1.8	3	1	2	17.6	19.6	MI
68	Bilibin complex	2	3.2	2.4	3	4	2.4	1.8	3	2	2	25.8	27.8	MI
69	Bilibin NPP	2	2.4	1.6	1	3	–	0.6	2	1	5	18.6	23.6	PP
70	Baranikha	3	–	1.6	2	3	1.2	1.2	2	1	1	17.0	18.0	MI
71	Komsomolsky	3	–	1.6	2	2	1.2	1.2	2	1	1	15.0	16.8	MI
72	Pevek	4	2.4	2.4	4	4	0.6	1.8	3	2	2	26.2	28.2	TR (PP)
73	Valkumey	4	–	1.6	3	3	1.2	1.8	2	1	1	19.6	20.6	MI
74	Krasnoarmeyskiy	3	1.6	1.6	2	3	1.2	0.6	2	1	2	18.0	20.0	MI
75	Polyarniy	4	1.6	1.6	3	4	1.2	0.6	2	2	2	22.0	24.0	MI
76	Mys Shmidta	4	2.4	1.6	4	4	–	0.6	3	1	2	22.6	24.6	TR (FO)
77	Anadyr	4	3.2	1.6	2	4	1.8	1.8	3	2	2	25.4	27.4	MI, TR
	Marine Zones and Subjects													
78	Kola Bay	5	4	4	4	4		1.8	4	2	2	26.8	28.8	TR

№	1	2	3	4	5	6	7	8	9	10	11	12	13	14
79	Motovskiy Bay	5	1.6	1.6	2	4		1.8	3	1	2	22.0	24.0	TR
80	Pechora Bay	5	3.2	2.4	2	3		1.8	3	2	2	24.4	26.4	TR
81	Varandey Zone	5	2.4	2.4	2	3		1.8	3	1	2	22.6	24.6	TR
82	Prirazlomnaya Zone	5		2.4	1	2		1.8	1	1	2	16.2	18.2	OG
83	Shtokmanovskaya Zone	5		2.4	1	2		1.8	1	1	2	16.2	18.2	OG
84	Dvina Gulf	5	4	4	4	4		1.8	3	2	2	25.8	27.8	TR, RE
85	Onega Bay	5	3.2	2.4	3	4		1.8	3	1	2	25.4	27.4	TR, RE
86	Kandalaksha Gulf	5	3.2	2.4	3	3		1.8	3	2	2	25.4	27.4	TR, RE
87	Mezensk Bay	5	2.4	2.4	1	2		1.8	2	1	2	19.6	21.6	TR,
88	Novaya Zemlya zone	5	0.8	2.4	1	2		1.8	1	2	3	19.0	22.0	OG
89	Amderminskaya zone	5	0.8	1.6	1	2		0.6	1	1	2	15.0	17.0	TR
90	Baydaratskaya Bay	5	0.8	1.8	1	2		0.6	1	1	2	15.2	17.2	TR
91	Ob Bay	5	3.2	3.2	2	3		1.8	3	2	2	25.2	27.2	TR.
92	Yenisei Bay	5	3.2	3.2	3	2		1.8	3	2	2	25.2	27.2	TR
93	Pyasinskiy Bay	5	0.8	2.4	2	2		0.6	2	1	2	17.8	19.8	TR
94	Tazovskiy Bay	5	3.2	2.4	2	3		1.8	2	1	1	21.4	22.4	TR
95	Khatanga Bay	5	2.4	2.4	1	1		0.6	1	1	1	15.4	16.4	TR
96	Buor-Khaya	5	2.4	2.4	1	2		0.6	2	1	1	17.4	18.4	TR
97	Yanskiy Bay	5	2.4	2.4	1	2		0.6	1	1	1	16.4	17.4	TR
98	Kolyma zone	5	2.4	2.4	1	2		0.6	1	1	1	16.4	17.4	TR
99	Chauna Bay	5	2.4	3.2	1	2		0.6	2	1	2	19.2	21.2	TR
100	Shmidt zone	5	0.8	0.8	1	1		0.6	1	1	1	12.2	13.2	TR

Column 9: ecosystems condition (4 categories): 4 – critical; 3 – stress; 2 – satisfactory; 1 – good.

Column 10: scope of effect (5 categories): 5 – global; 4 – Arctic Regions; 3 – Russian Arctic; 2 – regional; 1 – local.

Column 11: potential effect level (5 categories): 5 – global; 4 – Arctic Regions; 3 – Russian Arctic; 2 – regional; 1 – local.

Column 12: estimate of overall effect.

Column 13: estimate of potential overall effect.

Column 14: type of economic activity causing the formation of the hot spot (13 types). The first code means general effect. The second effect, in order of importance (if any), is specified in the same column in parentheses. FI is for fishery; MA is for marine resources utilization; ME is for metallurgical industry; MI is for mineral resource industry; OG is for oil and gas production; PF is for paper-and-pulp industry; PP is for power production; FO is for food industry; HL is for heavy-duty and light engineering; CM is for construction materials industry; RE is for recreation; TR is for transport; TC is for timber harvesting and lumbering operations; CO is for an integrated effect.

The obtained prioritizing results allowed the identification of 30 main hot spots (Table 6). Higher-priority hot spot data has been applied for identification of industrial and root causes of environmental problems. The hot spots are also subject to the preinvestment studies planning and adoption of targeted measures to decrease the level of cumulative environmental damage and conduct protective and compensatory environmental protection actions.

Table 6

List of higher-priority hot spots of the Russian Arctic and adjacent territories

Hot Spots	Current (ongoing) effect	Potential effect
NORILSK	38.0	42.0
NICKEL	37.2	41.2
ZAPOLYARNIY	37.2	41.2
MONCHEGORSK	31.4	34.4
KAYERKAN	31.0	33.0
VORKUTA	30.4	34.4
MURMANSK	29.2	32.2
TALNAKH	27.8	29.8
KOLA BAY	26.8	28.8

table 6 (end)

ARKHANGELSK	26.2	29.2
PEVEK	26.2	28.2
BILIBIN COMPLEX	25.8	27.8
DVINA GULF	25.8	27.8
ANADYR	25.4	27.4
KIROVSK	25.4	27.4
KANDALAKSHA GULF	25.4	27.4
ONEGA BAY	25.4	27.4
GULF OF OB	25.2	27.2
YENISEI BAY	25.2	27.2
PECHORA BAY	24.4	26.4
OLENEGORSK	24.4	26.4
KOLA	24.2	25.2
URENGOI FIELD	24.0	26.0
KANDALAKSHA	23.8	25.8
SOLOMBALA	23.8	25.8
KORYAZHMA	23.8	25.8
DUDINKA	23.8	25.8
SEVERODVINSK	23.6	25.6
YAMBURGSKOYE FIELD	23.4	25.4
INTA	23.2	25.2

9.4. Key factors of environmental problems identification

A list of key factors of the formation of Russian Arctic high-priority environmental problems in the hot spots has been developed based on the following: a) development of an expert task force Strategic Action Programme for Protection of the Russian Arctic Environment in 2006–2009; b) scientific reports with specification of environmental problems (issued in 2010); c) reports on findings of conducted preinvestment studies in environmentally neglected areas of the Russian Arctic (performed in 2008-2010); d) survey data of the opinions of concerned parties (2008). According to the above, the list of key factors in the identification of environmental problems within the scope of RCFA includes:

- «Environment pollution»
    1. *Chemical pollution (sulfur and nitrogen compounds, persistent organic pollutants, heavy metals)*
    2. *Radioactive contamination*

3. *Oil pollution*
4. *Solid wastes accumulation*

- «Soil degradation and land usage violation»
  1. *Soil degradation caused by mining*
  2. *Mechanical disturbance of soils*
  3. *Mechanical effect on the sea shore*
- «Negative effect and threats of ongoing global climatic changes»
  1. *Ice melting*
  2. *Permafrost retreat*
  3. *Coastal retrogradation*
  4. *Landscape dynamics*
- «Deterioration of the habitat of the indigenous population of the Russian Arctic and conditions of conventional nature management»
  1. *Water pollution*
  2. *Resource potential derogation*
  3. *Disturbance and reduction of traditional activities*
- «Change in biological diversity and reduction of the reserve of biological resources reserve»
  1. *Ecosystems transformation*
  2. *Ecosystems loss*

9.5. Factors affecting level ranking

Each of the factors specified above has three levels of effect on the Arctic environment, population and economics: local, regional and cross-border. The local effect appears within settlement, industry, and defense lands. The legal status of those lands allows wastes generation and utilization as well as performing compensatory, recovery and protective environmental measures and other safety measures, particularly connected to changes in climatic and natural conditions. The regional effect is related to land impact pollution (or disturbance) on environmental territories located outside industrial and defense lands. The legal status of the natural territories does not stipulate persistent and systematic pollution or disturbance and includes a measurement system for natural protection and recovery. Transboundary effects are connected to the consequences of environmental background pollution. Elimination of the transboundary impact is possible only by joint efforts and dedicated measures taken on interregional, national and international levels.

Accumulated knowledge and expert estimates show that the listed factors have a varying effect on local, regional and cross-border levels. This observation has become the base of a priority integrated matrix for the factors of technogenic and other effects on natural sites, population and economics of the Russian Arctic and is presented in Table 7.

The following high-priority factors of technogenic and other effects with the highest score are identified based on the table data:

«Acid forming gases»: caused by emissions of acid forming gases to the atmosphere in the Russian Arctic from commercial sources located in the Russian Arctic. Long-term and intense acid-causing substances affect valuable natural sites (facilities) along with the formation of hot spots and impact zones.

«Persistent organic pollutants»: caused by POP transboundary transfer into the Russian Arctic, where such types of pollutant have never been produced and utilization is limited. Pollutants are characterized by extremely high toxicity and the ability to accumulate in the tissue of living organisms.

«Heavy metals»: caused by ingress of this type of pollutant into the atmosphere, water bodies, ground surface and underground waters from commercial sources located in the Russian Arctic. It is one of the main factors of hot spot and impact zone formation.

«Radioactive contamination»: poses a potential threat to local areas.

«Oil spills»: pose a threat to ecosystems as well as the formation of hot spots and impact zones.

«Production and consumption wastes»: cause degradation of terrestrial ecosystems in local areas posing a threat to aquatic ecosystems.

«Mechanical disturbance of soils»: poses a threat to terrestrial ecosystems as well as the formation of impact zones.

«Permafrost retreat»: appears in thermokarst development characterized by the melting of ground ice and generation of subsiding soil.

«Water pollution»: caused by changes in the surface and underground water quality in coastal areas and deterioration of the drinking water supply.

«Ecosystems loss»: characterized by the presence of potential threats and anthropogenic risks to natural ecosystems considering possible climatic changes and permafrost depreservation.

Table 7

Quantitative estimation and ranking of technogenic factors defining the formation of environmental problems in the Russian Arctic

No.	Factor	Factor Effect Level	Effect on the Environment			Effects on Economics (water, fishery, agricultural)			Effects on Population			Score
			1	2	3	1	2	3	1	2	3	
"Environmental pollution"												
1	Acid forming gases (SO_2,NO_X, NH_3)	Cross-border	1	1	1	0	0	0	1	1	1	6
		Regional	2	2	2	1	1	1	1	1	1	12
		Local	3	3	3	2	2	2	2	2	2	21
2	Persistent organic pollutants (POPs)	Cross-border	2	2	2	1	1	1	2	2	2	15
		Regional	1	1	1	1	1	1	1	1	1	9
		Local (there are no large POP sources in the Russian Arctic)	-	-	?	-	-	-	-	-	?	
3	Heavy metals	Cross-border	1	1	1	1	1	1	1	1	1	9
		Regional	2	2	2	2	2	2	2	2	2	18
		Local	3	3	3	2	2	2	3	3	3	24
4	Radioactive contamination	Cross-border	1	1	1	0	0	0	1	1	1	6
		Local (potentially)	1	1	3	1	1	2	2	1	3	15
5	Oil pollution	Cross-border	2	2	2	1	1	1	1	1	1	12
		Regional	1	1	3	2	2	2	1	1	1	15
		Local	3	3	3	3	3	3	2	2	2	24
6	Solid waste accumulation	Local	3	3	3	2	2	2	2	2	2	21

"Soil degradation and land usage violation"											
7	Soil degradation caused by mining	Local (potentially)	3	2	1	1	1	1	2	1	1	13
8	Mechanical disturbance of soils	Regional	2	2	2	2	2	2	2	2	2	18
9	Mechanical effect on the sea shore	Local	0	1	2	1	1	1	0	0	1	7
"Negative effect and threats of ongoing global climatic changes"											
10	Ice melting	Regional	0	1	1	0	1	1	0	0	0	4
11	Permafrost retreat	Regional	0	1	1	0	1	3	0	1	2	9
12	Coastal retrogradation	Local	0	1	1	1	1	2	0	0	1	6
13	Landscape dynamics	Local	0	1	1	0	1	1	0	0	1	5
"Deterioration of the Russian Arctic indigenous population habitat and conditions of conventional nature management"											
14	Water pollution	Regional	1	2	2	0	1	2	1	2	2	13
15	Resource potential reduction	Local	0	1	1	1	1	1	0	1	1	7
16	Disturbance and reduction of traditional activities	Local	0	0	0	0	1	1	1	2	2	7
"Change in biological diversity and reduction of biological resources reserve"											
17	Ecosystems transformation	Regional	0	1	1	0	1	1	0	0	1	5
18	Ecosystems loss	Local	1	1	1	0	1	1	0	1	1	7

Effects: 1 – last, accumulated; 2 - current; 3 – potential, forecast. Effect estimation (score): 0 – low; 1 – notable, appreciable damage; 2 – significant, substantial damage; 3 – catastrophic, extensive damage.

9.6. Industrial causes of environmental problems

The main industrial causes of local and regional pollution of the environment of the Russian Arctic are connected with production cycles, operation of other facilities, as well as the nature of economic measures taken etc. Three categories of industrial causes of the environmental deterioration of the Russian Arctic may be identified:

1. Technical and technological causes: extensive amortization of environmental constructions; violation of the technological requirements for commissioning environmental constructions; ineffective usage of functional treatment facilities; lack of integrated utilization of raw materials, waste disposal systems and resource saving technology.

2. Economic causes: limited capital expenditure on environmental protection measures, which are not utilized.

3. Administrative-regulatory causes: unauthorized and unregulated accumulation and disposal of waste; poor organization of production and environmental supervision; land utilization within administrative areas that violate land legislation; land allocation for multiple dump pits and sludge collectors in settlement zones; unsatisfactory accomplishment of environmental protection plans and plans of rational utilization of natural resources; regular noncompliance with the current environmental and health legislation.

Industrial causes of the Russian Arctic environment transboundary pollution are: anthropogenic sulfur ingress into the atmosphere as a result of consumption of fossil fuels by large thermal power plants working on residual oil and coal, metal smelting out of sulfur-containing ores, small boiler plant emissions; application of chlorine-containing insecticides, dichlorodiphenyltrichloroethane in the agricultural and forest sector; emergency emission of poly-chlorinated biphenyl (PCB) used in various spheres of industry; radioactive contamination as a result of nuclear weapon tests performed by USA, USSR, China, Great Britain and France, as well as a result of the Chernobyl incident of 1986; marine transfer of radionuclides from western Europe.

Industrial causes of the negative effects of climatic changes are connected with the start of intensive exploitation of the Arctic Regions in the 1930s, when most of the region was exposed to climate warming. However, the peak of industrial development occurred in the 1940s–1980s.

Many large industrial facilities were constructed in this period along with development of transport infrastructure and big cities and settlements. This development had already been performed in conditions of climatic cooling. Many structures and facilities have been constructed without regard to possible sudden climate warming and development of processes modifying geotechnical and other operational conditions. The global warming that has taken place in recent decades poses a threat to the safe operation of infrastructural facilities, and has a range of other negative socioeconomic effects. Permafrost changes lead to the damage of buildings and groundwork structures, malfunction of utility services and other life-supporting communications of inhabited localities. Loads on underwater pipelines increase along with the probability of accidental damage and ruptures. The obstruction of navigation occurs due enhancement of river beds, increased storm activity, and complication of the ice situation at sea. Climate warming also creates conditions facilitating accelerated access to the arctic resources and a considerable increase in the volume of recovered hydrocarbon transportation. These conditions will increase the pollution risks of new territories and water areas. The growth of storm activity and threat of icebergs also increases risks to navigation and offshore operations. Negative effects of climatic changes in the Arctic Regions also include possible considerable appreciation of engineering, design work and field operation in industrial facilities, on transport, and in community facilities.

The above industrial causes are generally constant and lead to the formation of indirect environmental problems including: soil degradation; deterioration of the habitat of the indigenous population and reduction of biological diversity.

9.7. Root causes of environmental problems

Root causes of the deterioration in environmental quality of the Russian Arctic are defined by the combination of economic, technological, demographic, legal, administrative and other factors affecting the functioning conditions of economic sectors and industries, environmental safety and level of technogenic effect on the environment. The most important root causes are: resource and single-profile nature of economies in the constituent entities of the Russian Federation located in the Russian Arctic; the lack of the best available production and consumption waste treatment technology; the high cost of economic activity and survival of populations in extreme natural and climatic conditions; concentration of communities on a limited area; ineffective legislation, lack of legal rules of responsibility for previous environmental damage; and poor environmental supervision by environmental authorities.

The policy on the formation of institutional conditions for mitigation of previous (cumulative) environmental damage and future prevention of environmental threats is of key importance in resolving the problem of hot spots of the Russian Arctic.

Root causes of cross-border problems are: lack of a sufficient base of evidence base for the negative effects of transboundary pollutant transport in the territory of the Russian Arctic; a lack of coordination of national government actions regarding solutions to problems related to the reduction of transboundary pollution, prevention and maintenance of control; lack of effective regulatory mechanisms of environmental activity in relation to solutions to interregional environmental problems.

RCFA results serve as justification for taking environmental protective measures related to solving transboundary, regional and local environmental problems. Considering the retrospective nature of many regional and local problems connected with previous economic activity and previously made mistakes in the strategic planning of the development and utilisation of the Arctic Regions, the general task of all-level executive authorities and business is the development of cooperative environmental plans and programmes along with their co-financing.

One important direction of the work consists of introducing representatives of the indigenous minorities of the Arctic regions as well as business and nongovernmental environmental organizations in the process of development of strategic solutions.

9.8. Concerned parties estimation review

A review of the opinions of concerned parties on the key aspects and causes of the Russian Arctic environmental problems has been conducted within the scope of RCFA in cooperation with regional agencies, enterprises, institutions and public associations. According to the review findings, the greatest effect on the environmental condition of terrestrial and marine areas of the Russian Arctic is posed by:

- Activity of oil and gas and extraction industries; hydrocarbon materials and oil products shipment; heavy machinery application.
- Activity of agencies of the Ministry of Defense of the Russian Federation.
- Environmental pollution as a result of lack of treatment facilities in populated localities, accumulation of production and consumption wastes, transboundary transfer, atmospheric emissions and pollutant discharge into rivers.
- Illegal fishing of marine biological resources (poaching), lack of effective supervision.
- Effects of climatic change.
- Low level of environmental culture among the local population.
- Insufficiently effective environmental legislation and lack of proper regulation on the part of specially authorized government bodies.

According to responses, the most topical questions are:

- Safety issues related to the industrial development of arctic regions and the development of mineral resources.
- The waste utilization problem.
- The lack of motivation and poor culture of compliance with the requirements of environmental legislation.

According to the concerned parties, the following areas of potential environmental cooperation are the most topical:

- Perfection and enhanced efficiency of government regulations concerning environmental protection and nature management
- Provision of environmental safety during production, transportation and shipment of oil and oil products
- Clearing of territory from abandoned and sunken ships and other ownerless property in coastal areas
- Preservation of biological diversity and development of the specially protected natural reservations network
- Reduction of pollutant discharge and emissions; improvement of the treatment system of household and industrial waste
- Increase in radiation safety.

Chapter 10

FINAL PROVISIONS OF THE DIAGNOSTIC ANALYSIS AND PRIORITY ENVIRONMENTAL PROTECTION OBJECTIVES

10.1. General environmental assessment

The increasing number of environmental issues related to the Russian Arctic is caused by an underestimation of the nature and economic / environmental balance in the system of the centralized government of the former USSR and gaps in the existing environmental law of the Russian Federation, primarily with a view to assessment of environmental quality and liability for past environmental damage. A decline in economic activity in the Russian Arctic in the 1990s did not compensate for the severity of the accumulated environmental issues as they had been neglected. The diagnostic analysis shows that the current environmental status of the Russian Arctic requires the development and implementation of urgent actions intended not only to minimize the existing environmental damage, but also to prevent even more potentially harmful environmental threats.

The main result of the DA is the systematization of environmental knowledge about the Russian Arctic and factors affecting it which made it possible to create:

– the list of priority environmental issues of the Russian Arctic and the most environmentally significant direct, industrial and root causes thereof;

– the key action areas, objectives and measures to address the priority environmental issues of the Russian Arctic.

10.2. Industrial development as the main factor of environmental issues

Pollution and other negative effects in the Russian Arctic lead to the creation of hot spots and impact areas characterised by high levels of chemical pollution and alteration of the natural geochemical background, degradation of marine biota, vegetation cover, soils and ground soil erosion, uncontrolled development processes, cryogenic and karst development in vast areas, introduction of pollutants into the food chain, increased morbidity, air pollution by strontium compounds, heavy metals (especially mercury), oils, etc..

The detailed diagnostic analysis of the current situation and forecasting of the potential environmental changes in the Russian Arctic were used to identify the following five priority environmental issues in the region:

– Environmental pollution (transboundary transport of pollutants by water and air, and oil, chemical, and radiation contamination) and deterioration of the quality of surface and ground waters in the coastal areas of the Russian Arctic;

– Land degradation and irresponsible use of land;

– Changes in biodiversity and depletion of biological resources;

– Deterioration of the living conditions and environment of the indigenous population of the Russian Arctic and disruptions of their traditional use of natural resources;

– Negative consequences and threats from ongoing global climate changes.

Based on DA results, the following economic activities performed in the Russian Arctic (and being typical sources of adverse environmental impact) were identified:

mining and processing, pulp and paper and steel industries;

construction of hydraulic structures;

construction and operation of linear structures (oil and gas pipelines, railways and roads, power lines, etc.);

mining companies, including oil and gas producing and transporting companies;

fuel and energy industry (boilers, CHPPs);

military facilities;

transportation (sea, pipeline);

housing and utility industry (HU);
agricultural production;
use of marine resources.

Features of the economic and industrial development of the Russian Arctic determine the creation of impact areas (Table 8).

Over 100 hot spots (with 30 priority locations) have been identified in the Russian Arctic impact areas where the level of pollution by natural components is considerably higher than the maximum permissible level. Natural ecosystems are disturbed resulting in substantial damage to the health of the local population.

Table 8

Industrial pollution impact areas in the Russian Arctic

Impact area	Pollution source	Key pollutants
Western Kola	nonferrous industry, mining	NOx, dust, heavy metals (Cu, Ni, Co), hydrogen fluoride
Central Kola	nonferrous industry, mining, NPP, transportation	SOx and NOx, heavy metals (Cu, Ni, Co, Pb, Cr), dust, strontium, phosphorus, radionuclides
Arkhangelsk	pulp and paper industry, machinery manufacturing, forestry, heat power, transportation	COx, NOx, SOx, heavy metals, lignosulphates, methyl mercaptane, phenols, formaldehyde, PAH, methanol
Timan-Pechora	hydrocarbons production and transportation	oil products, COx, NOx, SOx, heavy metals, PAH
Novozemelsky	military facilities (CIP), dumping of nuclear installations and other radioactive waste	radionuclides, heavy metals
Lower Ob	hydrocarbon production and transportation	hydrocarbons, PAH, heavy metals, radionuclides, soluble salts,
Norilsk	nonferrous industry, mining	SOx and NOx, heavy metals, dust, arsenic, formaldehyde, carbon black
Yano-Indigirsky	mining	dust, heavy metals, mechanical disturbance of geosystems
Western Chukchi Peninsula	mining, NPP	heavy metals, dust, radionuclides
Eastern Chukchi Peninsula	mining	heavy metals, dust, PAH, hydrocarbons, carbon black

10.3. Environmental pollution and deterioration of surface and ground water quality of the coastal areas of the Russian Arctic

In the Arctic region of Earth, including in the Russian Arctic, there are specific mechanisms of planetary pollutant migration (atmospheric transport, river runoff, ocean currents). Thus, the Russian Arctic is one of main recipients[1] of transboundary pollution as a result of transboundary and interregional air and water transport responsible for its transformation into a «global storage» of multiple pollutants. Within the Russian Arctic, or close to it, economic and other activities are (or have been) carried out which are the «internal» source of local pollution causing (under certain circumstances) a regional and transboundary pollution risk.

The sources of environmental pollution in the Russian Arctic are as follows:

– Transboundary atmospheric and aquatic transport of contaminants, including atmospheric transport of the by-products of fuel combustion, the decomposition and emission of petroleum, dust, and heavy metals from industrial activities and transport of pollutants by the Gulf Stream system;

– transport of pollutants by the major rivers, including the spring thawing of snow cover and river ice which, in turn, is contaminated by substances transported through the atmospheric streams from other continents and is being accumulated throughout the winter period;

– emissions to the atmosphere generated by stationary and mobile sources of the Russian Arctic;

– discharges of polluted wastewater by industrial enterprises, municipal facilities, and mobile sources (all types of transport, including marine and river fleets, aircraft, vehicles, and oil pipelines) into the seas and the rivers which flow into the Arctic Ocean;

– Solid waste accumulation from industrial production and consumption; illegal and unsupervised waste disposal;

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[1] With a view to sphericity of the Earth, latitudinal expansion to the pole is sharply decreased, so the total area of the Arctic geophysical zones is relatively very small compared to more southern latitudes. Considering this, in the process of transport of global pollutants by air, rivers, ocean currents and migrating species, pollutants coming from the vast industrial development areas of the Earth are concentrated in a relatively small area of the Arctic region of the Earth, including the Russian Arctic.

– accidental spills of petroleum and petroleum products on land and into the seas;

– natural siphoning sources in oil and gas areas and on the shelf zone of the Arctic seas;

– operation of engineering facilities in the coastal zone of the Arctic seas.

Transport (migration) of pollutants entering the Arctic environment, and their negative effects, are largely dependent on the complex of abiotic and biotic processes occurring in marine, freshwater and terrestrial ecosystems. Mixing processes in the marine environment transfer pollutants from the surface to deep waters which slowly transport the pollutants beyond the Arctic Ocean with partial deposition on the seabed.

Due to specific features of air circulation in the Russian Arctic, the maximum levels of air pollution are observed in the period from February until the first half of April, thus the top layer of snow cover is the most polluted. Snow cover on drifting ice is transported hundreds of kilometers from fallout areas, thereby participating in the global redistribution of pollutants.

The peak discharge of pollutants that accumulated in snow to surface waters during the period of active snow cover melting may have a significant effect on the hydrochemical characteristics of river and lake waters and the upper layer of the ocean.

Microorganisms and higher plants selectively absorb pollutants from water, sediments and soils, in some cases increasing the concentrations of them. The structure and length of food chains affect the transport of pollutants and their redistribution processes. Relatively primitive groups, which play an important role in the tundra vegetation cover (such as algae, lichens, liver and leafy mosses), as well as multiple typical arctic species of flowering plants, inhabitants of specific Arctic and Subarctic habitats, and typical Arctic species of marine and land animals are even more sensitive to chemical pollution. Lichens intensively accumulate pollutants in long-living tissue and are eventually the first to fall out of the ecosystem. In the areas of iron and steel works, and chemical plants, visually intensive (although difficult to record) depletion of ecosystems and degradation processes (e.g. in lichen and moss-lichen tundra and woodland) occur.

Various chemical pollutants rapidly accumulate in the upper trophic links of Arctic terrestrial and aquatic ecosystems and are concentrated in the bodies of long-lived carnivorous mammals, birds and fish whose share is especially high in the Arctic wildlife, thus creating conditions for the occurrence of long-term effects of chemical pollution of ecosystems, including the death of offspring, reduction or extinction of populations and fauna depletion. Current main pollutants of trophic chains of Arctic ecosystems are organochlorine hydrocarbons (DDT, HCH, PCBS) accumulating in organisms due to the global pollution of the ocean, transboundary transport, deposition of aerosols in the Arctic and bird migration.

It was established that the issue of chemical pollution of the Russian Arctic, which usually occurs in land hot spots and impact areas, is mainly associated with heavy metals and persistent organic pollutants creating significant health and environmental risks in the region. This is caused by the high toxicity and resistance to degradation of pollutants, including the ability to accumulate in the tissues of living organisms for a long time, persist in the environment and degrade very slowly under the influence of natural factors.

The group of heavy metals (HM) includes multiple chemical elements (metals and metalloids) with one common feature: they can be biologically active. Accumulating in food chains, HM are eventually transported into the human body with food and can pose a real threat to health and even life. The most toxic HM in the Russian Arctic ecosystems include mercury, lead, cadmium, arsenic, copper, zinc, vanadium, chromium, silver and nickel.

Heavy metals enter the terrestrial and marine ecosystems of the Russian Arctic by transboundary transport from sources located far beyond its borders, and from natural sources involved in the natural geochemical cyclic processes. In many cases the contribution of natural pollution sources is a major factor, and concentration of metals in marine mammals is largely dependent on regional geological and biogeochemical properties.

Anthropogenic sources of HM pollution include primarily high-temperature processes generating metal emissions, namely combustion of coal and oil by power plants and factories, combustion of gasoline in cars, non-ferrous and iron ore smelting, cement manufacturing and waste incineration.

The main source of cadmium is natural marine sources, but its level in some marine birds is quite high, thus creating a risk of renal irritation.

In most cases lead pollution is caused by leaded petrol (its consumption in recent decades has been greatly reduced) and the use of lead shrapnel bullets for hunting resulting in accumulation of lead in ponds and marshes and toxic effects on fish, birds, wild animals and plants.

The greatest threat is mercury pollution which accumulates in fish, wildlife and plants. In the natural environment it can be transformed into a strong neurotoxin (methyl mercury) which may greatly affect the neurological development and functions of wild animals and humans even in relatively low concentrations. The main sources of mercury pollution of the Russian Arctic marine environment are emissions from coal-fired power plants. The share of industrial sources located beyond the Russian Arctic (in Europe and North America) regarding heavy metal pollution is approximately one third of all fallout, and the maximum quantity is emitted in winter.

The sources of regional and local heavy metal pollution in the Russian Arctic are the mining and metallurgical enterprises of the Kola Peninsula and Norilsk region, as well as companies involved in the incineration of waste in Murmansk.

A significant source of heavy metal supply to the marine environment, especially of zinc, cadmium and lead (to a lesser extent) is river runoff. The pollution level depends on the season, properties of the river system and distance to the source, as levels are usually close to background values far from local sources of pollution. Metal-containing sediments brought by river water to the coast are usually deposited on the shelf, and only a small amount is transported to the open ocean.

Migration and transformation of heavy metals in the marine environment is potentially affected by climate change. The seasonal extension of ice-free water area increases the level of exchange between the ocean and atmosphere, as well as the removal of heavy metals which are currently captured by ice, soil or bottom sediments.

One of the major threats of environmental pollution in the Russian Arctic is from persistent organic pollutants which include a special group of organic substances with hazardous biological properties and degradation resistance in the environment, including: organochlorine pesticides such as dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane (HCH), used in agriculture and their degradation products, namely dichlorodiphenyldichloroethylene (DDE), industrial organochlorine compounds (PCB and others), and combustion products (eg, polychlorinated dibenzo-para-dioxines and furans).

The Russian Arctic has no major sources of persistent organic pollutants (POPs), and as a rule the existing local sources of POPs are associated with operational and retired electrical equipment, barrels containing used oils and other fuels and lubricants, stockpiles, and haphazard stores of obsolete pesticides.

Most of the POPs enter the region's environment as a result of long-range transport of atmospheric fluxes, rivers, and ocean currents originating in Asia, Europe, and North America. Because of their exceptional lipophilism, most chlororganic compounds accumulate in the fatty tissues of species in the food chain. The highest concentrations of pollutants are found in the subcutaneous fat and adipose tissues of animals at the upper levels of the food chain (for example, polar bears, seals, and whales). This poses potential hazards for the small populations of indigenous people who consume large amounts of lipid-rich food products provided by hunting and fishing. In the Russian Arctic, the POPs concentrations that are a threat to the health of the indigenous population are the highest in the circumpolar Arctic.

As a result of regulatory measures implemented at national and international levels (the Protocol on Persistent Organic Pollutants developed by the United Nations Economic Commission for Europe within the framework of the Convention on Transboundary Air Pollution and Stockholm Convention on POPs) their production and use has significantly decreased over the past decade.

Oil pollution of the Arctic basin has reached high levels. Every year, several hundred thousand tons of petroleum products are transported by rivers into the Arctic seas. River runoff is a key source of transport of oil and petroleum products to the marine environment. This primarily applies to the Ob and Enisey rivers, characterised by the maximum runoff amount and increased oil pollution. Estuaries are extremely polluted - on the bottom of the Gulf of Ob the deposited oil sometimes amounts to 10% of sediment (silt and sand). Approximately 40% of oil entering the water basin settles on the bottom as sediments which are further oxidized. The main sources of pollution are transportation of oil and oil products, dumping of wash and ballast water, and accidental spills and leaks caused by imperfection of modern extraction and refining technologies. A certain amount of pollution is caused by atmospheric transport.

Severe pollution of surface waters has been found beyond the boundaries of oil- and gas-bearing deposits and even the basins of the rivers flowing into the Arctic seas. The concentration of petroleum products found in ground waters in certain sectors of the Timan-Pechora Oil and Gas Basin reaches levels equivalent to several dozen MPC.

The threat of polluting the marine environment with oil is associated with plans to produce oil on the continental shelf of the Russian Federation. Most hydrocarbon resources (about 70%) are in the seas of the western Arctic - the Barents, Pechora, and Kara seas. Within the next decade the transport of oil by sea from the western Arctic, in particular, from the White, Barents, and Pechora seas may increase several fold.

Anthropogenic hydrocarbons are transported to certain areas within a short period of time, resulting in negative environmental impact that disturbs the natural cycle in the marine environment. Once transported to the aquatic environment of natural reservoirs, oil and oil products are subjected to various physical, chemical and biogeochemical processes such as evaporation, emulsification, dissolution, oxidation, aggregate formation, sedimentation and biodegradation (including microbial destruction and assimilation by planktonic and benthic organisms). Air temperature and the presence of biogenic elements play a major role in the transformation of oil.

The main effects of oil pollution occur in the formation of a film of oil on the surface of the sea, and settling of mud and heavy oil on the bottom. All these factors cause the death of benthic vegetation. Environmental effects also occur as persistent, reversible or poorly reversible stress for populations of marine birds, mammals and benthic communities in the marine coastal and shore area. Sublethal effects (reduced rate of growth, reproduction, etc.) and acute oil toxicity occur in coastal areas featured by strong and persistent local pollution (oil terminals, ports, etc.). Oil affects all the components of an ecosystem by dramatically altering the structure, fractional composition of humus and physical properties of the water-salt interface, altering the redox conditions and chemical composition of soils, deteriorating the environmental conditions of plant and animal life development, destroying the ground vegetation, contaminating surface and groundwater as well as the ground air.

Ice cover, at all stages of its formation, slows down the processes of oil transformation, contributes to the formation of stable emulsions, accumulates large amount of oil and completely blocks its transfer under the ice layer. Transformation of oil products in the snow and ice cover is determined by the weather conditions in the disaster area, the temperature gradient in the water-ice-air system, the structure of ice and properties of the oil. Hydrophobic properties of aliphatic hyrocarbons determine their high weighted content in snow and ice. The transfer of oil in the ice depends on its age, structure, porosity, density, snow content and other properties. At the same time, sorption of oil products by ice and their filtering through the ice layer may occur in capillary and drain channels. During the transformation of oil hydrocarbons in old ice, wind processes are the main factor, and in fast, porous ice the major factor is the filtering through capillaries and drain channels caused by the convection-diffusion mechanism.

Snow and ice cover has properties that make it a convenient indicator of the state of an ecosystem, as it acts like a «tablet» which absorbs «fresh» pollution transported by both precipitation and air, and pollution transported by water. Therefore, increased concentrations of hydrocarbons in the impact areas occur in snow and the top ice layer (and in background areas on the ice-water border).

The main source of radiation contamination of the Russian Arctic is the nuclear weapons testing carried out by the USA, USSR, China, United Kingdom, and France in 1945–90 in different regions. The 1986 Chernobyl incident was an additional source of radionuclides entering the Arctic environment, as well as ocean currents of the Gulf Stream system continuing, though to a lesser degree than before, to transport radionuclides across borders from nuclear facilities in western Europe. The region also has large potential sources of radiation contamination associated with the activities of the naval and civilian nuclear fleet spread along the entire northern coast of the Kola Peninsula and coastal belt of the White Sea.

The storage sites for spent nuclear fuel are a potential danger and containers with spent nuclear fuel sunk in the sea off Novaya Zemlya.

Other potentially dangerous sources of radiation are the Kola (Murmansk Region) and Bilibino (Chukchi Autonomous District) nuclear power plants.

Radioisotopic thermo-electric generators (RITEGs), which are used in navigation equipment, present a special problem when their service lives have expired. If handled improperly, they can present a lethal threat of irradiation, while lack of proper control over nuclear materials increases the risk of such materials getting into the hands of terrorists. At present, the stocktaking and replacement of most RITEGs in the western part of the Russian Arctic has been completed, and this should be continued in the Sakha Republic and Chukchi Autonomous District.

Deterioration of surface and ground water quality in the Russian Arctic is caused by a number of reasons, including institutional and regulatory. The main cause of surface and groundwater deterioration is transport of pollutants to the environment of the Russian Arctic from various sources located both outside the Russian Arctic (as a result of transboundary and transregional transport) and from sources within the Russian Arctic, as well as their accumulation due to specific features of Russian Arctic ecosystems and development of economic activities.

This necessitates the development of measures to prevent and eliminate the negative effects, including the rehabilitation of water bodies. The solution shall be complex as we need to minimize the different scale impact factors: from transboundary and transregional pollution transport by air and water to impact and local effects, including the status of water bodies in hot spots of the Russian Arctic. A necessary condition for the development and implementation of such actions is a complex inventory inspection of surface and groundwater water bodies in the Russian Arctic.

10.4. Land degradation and land-use impairments

Land degradation in the Russian Arctic is the most evident in hot spots and impact areas as a result of increased anthropogenic stress on ecosystems (mining, construction of transportation and industrial infrastructure), and due to climate change and permafrost conditions (thawing).

Vegetation degradation in large areas of the Arctic is caused by the following main factors: pollution, deforestation, exploitation of reindeer pastures and mechanical disturbances.

The anthropogenic impact on the Russian Arctic ecosystem substantially differs depending on sensitivity level of the major biomes of the Russian Arctic. Arctic deserts, excluding minor coastal areas near the research stations and military facilities, have not undergone any anthropogenic changes.

The total amount of transformed tundra is 1–3% of the total area of the mainland Russian Arctic, but near the copper and nickel plants in Norilsk, Monchegorsk and Pechenga there is evidence of destroyed soil mantle, altered natural landscapes, and destroyed vegetation as a result of emissions of sulfur and nitrogen compounds within an area of tens of kilometers.

The alteration of domestic reindeer pastures covering a total of more than 334.7 million ha, has now reached a figure of 63%. In different tundra and northern taiga areas of the Kola Peninsula, and in western and north-eastern Siberia, there are areas of anthropogenic disturbances in the oil, gas and other mineral resource production areas (amounting in total to 3–8%).

The diversity and areas of coastal, lowland, and delta ecosystems – meadows, thickets, and lowland forests and others – have shrunk considerably in certain regions of the Russian Arctic. Pockets of degraded reindeer pastures have been observed in recent years in the Nenets and Yamalo-Nenets Autonomous Regions. Large segments of fragmented ecosystems have formed in the lower reaches of the Pechora River in the Nenets Autonomous Region, around the city of Vorkuta in the Komi Republic, in the southern part of the Yamal Peninsula in the Yamalo-Nenets Autonomous Region, in the Norilsk industrial district, in northern Yakutia, and in the gold-mining districts of the Chukchi Autonomous Region. The area along the east coast of Novaya Zemlya, where nuclear tests were conducted, is among the affected areas.

As a rule, generation and accumulation of solid industrial and domestic waste in territories involved in the economic development of the Arctic is accompanied by their unauthorized and uncontrolled dumping.

Up to 1 billion tons of waste rock and solid waste is annually generated in the Russian Arctic. Significant areas of dumps and solid waste are concentrated in the Murmansk Region, in the lower course of the Pechora River in the Nenets Autonomous District, in the south of the Yamalo-Nenets Autonomous District, in the Norilsk industrial region, in the north of the Republic of Sakha (Yakutia) and around the gold mining areas on the Chukchi Peninsula.

The consequences of unregulated waste accumulation include constant land, groundwater and soil pollution, degradation of natural ecosystems, destruction of traditional habitats of plants and animals, creation of new anthropogenic structures being the basis for complexes of introduced species.

Large pockets of degraded lands have been formed in forest-tundra and southern tundra areas as a result of logging, and tundra and forest fires. Parts of the cut-and-burn area have become waterlogged, but in major cases forest vegetation in the Russian Arctic restores itself.

Soil, thermokarsts and thermal erosion are increasingly evident in industrial centers and along linear structures such as oil and gas pipelines, railways, highways, and power lines. Warming and rising of the sea level are responsible for the increased rate of thermal abrasion of the Arctic coast, flooding and salinization of lowland areas of the coastal plains, especially composed of rocks and pool-forming underground ice.

The shores of the Russian Arctic seas from the Kola Peninsula to the eastern tip of the Chukchi Peninsula stretch for 22,635 km, and, considering the coastline of the Arctic islands, the total coastal belt is 36,136 km long. The rate of abrasion processes on the Arctic coast is determined by exogenous factors: sea wave energy, sea ice conditions, air temperature, as well as cryolithogenous factors (composition and ice content of sediments forming the coastal cliffs). The maximum rate of abrasion processes occurs within the Yamal-Gydan part of the Kara Sea, where the banks are composed of icy dispersive formations including pool-forming underground ice; and within the sea from the Khatanga estuary in the Laptev Sea to the Chaun Bay in the East Siberian Sea with extremely unstable banks formed by thick fine sediments with high ice content and strong cavern-load ice deposits. The shores of the Arctic seas differ from other coasts of the Global Ocean as they have considerably long areas formed by permafrost, including underground ice. Anthropogenic impact could have a significant effect on the dynamic development of the Arctic coast. Their negative effects occur as activation of destructive processes, increasing the rate of the coastal belt retreat, pollution and degradation of coastal ecosystems.

The characteristic feature of land degradation processes in the Russian Arctic is the fragmentation of ecosystems from focal disturbances with a minor area of natural and anthropogenic transition zones (ecotones) to increased areas created as a result of the construction of linear structures connecting the transformation areas. As a result, some foci interlock over time and regional land disturbances occur with further extension process in the direction of neighboring structures of degraded lands. The main impact issues of pollution, land and soil contamination occur. The main effect of this issue is the disturbance of the original habitat of indigenous and minority peoples of the North and a negative impact on traditional land use.

Ecosystem fragmentation processes occurring in the Russian Arctic have their own features. They include the following stages:

– formation of focal disturbances with minor areas of natural and anthropogenic ecotones;

– extension of these areas, including connection of the transformation areas as a result of the construction of linear structures. Creation of focal and band disturbance areas with relatively wide (comparable in size to pocket and belt disturbances) ecotones;

– closure of pockets and belt disturbance areas by ecotones and creation of frontal disturbance zones;

– formation of large (regional) frontal disturbances and their extension toward the nearby similar formations (through fragmentation of inter-focal and inter-frontal areas).

These processes are characteristic of the Kola Peninsula, the lower course of Pechora river (the Timan-Pechora field complex), the Vorkuta area, Southern Yamal, and the area between Norilsk and Dudinka.

10.5. Biodiversity change and depletion of biological resources

The general trend of biodiversity changes in the Russian Arctic corresponds to global trends in the Arctic region of the Earth. These trends are characterized by the decline in quality of plant and animal life habitats, loss of a number of habitats and population decline as a result of economic development and climate change on the back of increased vulnerability of Arctic vegetation and wildlife to external impact.

Large-scale economic development and climate change have made the remote areas of the Russian Arctic more accessible for people and have increased the load on the biota as transformation of the habitats of rare species in the Arctic region, biodiversity changes, and reduction of populations occur. The current change in biological diversity, and reduction of the bioresource base of the Russian Arctic and other environmental issues of the region, still has a pocket and focal nature and is localized in hot spots and impact areas caused by specific anthropogenic impact in the Russian Arctic.

In some industrially developed regions of the Russian Arctic, there is a reduction in the number of rare Arctic species, including red-listed species such as the polar bear, the Atlantic walrus, whales, snow sheep, certain species and subspecies of whitefish and salmon, and waterfowl and shorebirds such as geese, brant, and waders.

Changes in biological diversity, and the reduction of bioresources in the Russian Arctic, are caused by reasons of an institutional, as well as a legal, nature. In this case, the main reason is the development of economic activities on natural resource management in the Russian Arctic, associated environmental pollution and other types of negative impact on biota. Overexploitation of biological resources leads to depletion and loss of natural self-regeneration capabilities.

As a result of climate change, there is an increased rate of Arctic ice melting in the Arctic Ocean, decreased thickness of snow cover and thawing of permafrost leading to changes of habitats along animals migration routes, particularly migration routes of migratory birds and other seasonal migrations.

The main threats to biological diversity of the Russian Arctic seas are:

– transport, accumulation and long-term effect of persistent pollutants;

– development of marine production and transportation of hydrocarbons;

– active shipping;

– poorly regulated fishing and aquaculture;

– invasion of alien species to ecosystems (potential threat);

– waterlogged vessels and abandoned military bases and other ownerless facilities;

– poaching and illegal fishing;

– facilitated access to previously inaccessible areas.

Specific features of biological processes in the Russian Arctic contribute to the accumulation of pollutants and their extremely slow natural detoxification. Specific effects of the Arctic terrestrial biota pollution include:

– dropout of spore-bearing plants from plant communities (algae, lichens, mosses and liverworts) that are highly sensitive even to low and average levels of pollution by sulfur and nitrogen compounds as well as heavy metals;

– thinning of egg shells of some species of birds of prey caused by residual DDT;

– reduction of the reproductive capacity and significant destruction of embryos (resorption of embryos) in waterfowl, especially receiving a large dose of pollution in wintering and migration areas located on middle and southern latitudes;

– lowered immunity of arctic birds and mammals as a result of environmental pollution by PCB, DDT and other pollutants.

The highest-priority environmental issues are poaching of wild reindeer, fur mammals and waterfowl and uncontrolled use of biological resources including uncontrolled catch of oceanic and migratory fish and other seafood since they can lead to the loss of biodiversity in some regions of the Russian Arctic, including within ethno-economic areas. For example, the level of polar bear poaching in recent years amounts to approximately 300–350 pcs, while the number of particular species populations is decreasing and amounts just to 800–1,000 in the Laptev Sea, 3,000 in the north of the Barents Sea, and 2,000 on the Chukchi Peninsula and Alaska.

There is a threat of rapid decline in the number of the unique Taimyr population of wild reindeer. This is currently the largest in the world, covering an area of almost the whole Taimyr Peninsula and south of Evenkia with seasonal migrations carried out through five natural zones and subzones (from arctic tundra to northern taiga, 1,500 km). As a result of poaching and injuries received while taking antlers from live animals, the estimated annual death rate of reindeer may exceed the population growth (approximately 80,000 pcs and more) (Agricultural Research Institute of the Far North, Norilsk).

The poachers (seafood, salmon, caviar, velvet antlers and meat of wild reindeer, spring hunting for geese and brant, etc.) are primarily local residents who are isolated from the modern economy and have very low incomes. In the high Arctic, bird rookeries are subject to human impact on individual islands and the mainland coast.

Biotic pollution on account of invasive species and the introduction of exotic species are, and will be, a high priority because of expanded economic activity and climate warming in the Arctic. This includes the acclimatization of the Kamchatka crab and Far Eastern salmon species into the Atlantic sector of the Arctic and the broad northward expansion of many species of plants and synanthropic animals, which settle primarily in industrial areas where they form relatively stable natural-anthropogenic communities and drive out the native flora and fauna.

The introduction of opportunistic plants species and the development of new habitats occur in the Russian Arctic thus preventing the restoration of the original vegetation within anthropogenic habitats.

10.6. Deteriorating living conditions of the indigenous population of the Russian Arctic and disruption of traditional land use of small populations of indigenous peoples of the North

Traditional land use is the basis of the ethnic and cultural diversity of the indigenous population and an indicator of the environmental health of the Arctic. Lifestyle unification in the Arctic, reducing ethnic and cultural diversity, may result in potential loss of adaptability of the human community. Kept up to date, traditional knowledge can ensure the revival of traditional land use and adaptability to new climatic conditions.

Deterioration of the indigenous habitat in the Russian Arctic and conditions of traditional land use are caused by the combined effect of environmental pollution and other types of anthropogenic impact as well as natural and anthropogenic climate change. Currently, traditional land use is subject to significant changes as a result of deteriorated environmental quality in the residential areas of the indigenous peoples of the Russian Arctic.

Active industrial development of particular regions of the Russian Arctic during recent years has led to degradation of indigenous land use conditions within large areas previously used for reindeer breeding, as well as conditions of marine resource production, including marine mammal hunting. Climate change may result in destruction and reduction of opportunities related to all the traditional activities of indigenous peoples. The most sensitive is the leading sector, large-herd, tundra reindeer breeding which has already suffered from frequent ice-covered ground causing famine and deaths in the herds. Other types of traditional land use (hunting, fishing, sea mammal hunting) will also be hampered by the effects of climate change.

Anthropogenic factors have caused stress impact on reindeer pastures and hunting grounds. Toady these factors have an impact on up to 40% of the traditional land use area. The main areas of anthropogenic impact on the traditional indigenous land use territory are the Kola, Timan-Pechora, Novaya Zemlya, Vorkuta, Per-Nadym, Yamal, Mid-Ob, Norilsk, Anabarsky, Yano-Indigirka, Valkumey and Bilibino regions. Withdrawal of large land plots from areas of traditional economic use in the Russian Arctic may cause the rupture of rangelands and possible disturbance both of the soil mantle, permafrost and hydrological conditions within large areas of the Russian Arctic, as well as pollution of rivers and lakes, depletion of biological resources and other changes. Having increased in the last decade, the rate of expansion of the oil and gas industry in the Russian Arctic and the planned development of the Arctic sea shelf has threatened the traditional lifestyles of some indigenous peoples, preservation of their unique culture and led to near extinction of certain ethnic groups.

The high degree of dependence of the indigenous peoples on the traditional, natural nutrition patterns based on high consumption of protein and animal fats (which is currently the only possible way to maintain the energy balance in harsh Arctic conditions) causes a lack of alternatives and irrelevance of forced consumption of products delivered from mid-latitude or from other states, leading to significant morbidity. Therefore, preservation of native habitats and traditional land use of indigenous people are of vital importance for them.

10.7. Adverse effects and threats of global climate change

Climate change observed in the Russian Arctic is characterized by a significantly increased temperature in cold seasons, an increased evaporation level (while the amount of precipitation during the warm period is the same or reduced), changes in the annual river runoff and its seasonal redistribution, and changes in ice cover conditions in the Arctic Ocean and the estuaries of northern rivers.

Instrumental observation of the Arctic ice from satellites confirms a significant reduction of the glacial area during the last 30 years (by 15–20%).

In addition to degradation of the sea ice, the area of inland glacier in the Russian Arctic also decreases: during the past 50 years the glacial area of the Russian Arctic archipelagos has decreased by 725 km^2.

Over two thirds of the Russian Arctic is located in the permafrost zone. In general, changing climatic conditions result in the increased temperature of the permafrost layer and increased seasonal thawing layer. Permafrost degradation will affect ecosystems leading to the occurrence of sinkholes, drainage of lakes, and eutrophication in particular regions.

Warming of the sea water, as well as rapid melting of inland glaciers, results in a rising sea level. Over the past hundred years, the sea level, and level of the Arctic seas, has increased by 10–20 cm. Today the rate of shoreline erosion in some locations exceeds 10 m per year.

Later freezing and earlier breaking up of ice on rivers and lakes causes a shortened ice formation period (from one to three weeks in some regions).

The snow cover area in the Russian Arctic has decreased approximately by 10% over the past 30 years.

Adverse effects of climate change in the Russian Arctic occur in response to an increased frequency of hydrometeorological hazards and a risk of adverse abrupt weather changes.

The expected climate changes in the Arctic have both a positive and a negative socio-economic impact.

The positive impact of the expected climate changes in the Russian Arctic include the expanded access to new mineral deposits, increased productivity and stocks of some fish species due to migration of southern species, reduced heating costs, increases in hydro- and wind power potential, improved navigation conditions on the NSR; access to coastal waters in summer, expanded forests, increased growing season and the development of summer tourism. However, the development of certain types of activity may lead to an increase in anthropogenic stress on the Arctic ecosystems and changes in environmental quality.

The main types of negative impact of the expected climate changes in the Russian Arctic are:

increased risks, threats and costs due to the need to address the strengthened threat of environmental and economic infrastructure transformation, including life support systems in residential areas;

increased risk from economic activities in coastal areas (erosion, floods, water logging, storms);

changes in animal habitats (objects of traditional indigenous harvesting such as marine mammals, reindeer, Arctic fox, freshwater and diadromous fish, waterfowl) and reduced populations thereof;

risk of the transformation of traditional domestic reindeer pastures and directions of their seasonal migration resulting in degradation of deer farms;

irreversible changes in the freshwater traditional fishing (dried up rivers, destruction of spawning grounds, drainage and eutrophication of lakes) and destruction of the indigenous fisheries population;

loss of traditional cultural orientations and social identification, risk of extinction of some traditional cultures based on the use of particular resources, habitats and harvesting grounds;

possible significant rise in the costs of industrial, transportation and utilities design, engineering and maintenance works.

The environmental, climatic and socio-economic features of the Russian Arctic necessitate an integrated consideration of issues relating to industrial and population adaptation to global climate changes with a view to environmental protection issues. The unpredictability of long-term changes in the productivity of marine, terrestrial and marsh ecosystems of the Russian Arctic requires the development of different possible climate change scenarios for the Russian Arctic, and all should include environmentally-friendly actions in relation to population and economic adaptations. Preventative adaptation actions may create significant economic benefits and minimize the threats related to conservation of ecosystems, degradation of human health, sustainable economic development and safe operation of infrastructure facilities.

Strategies of adapting the agriculture and Russian Arctic populations to climatic changes in the Arctic should include a scientific risk assessment, vulnerability and potential benefits assessment with a view to proposed climate change considering the environmental, geographic, economic, social and other features of the Russian Arctic. In this context, the most important task is to conduct economic assessments of costs and benefits of the proposed adaptations.

10.8. Priority areas of environmental protection

To address the above key environmental challenges of the Russian Arctic we propose to implement environmental protection activities in the following areas:

Prevention and reduction of the environmental pollution level (including the transboundary transport of pollutants by water and air, and oil, chemical, and radiation contamination);

Conservation and improvement of the quality of the environment, living conditions of the small populations of indigenous peoples and conditions for traditional land use by native people of the region;

Prevention and mitigation of the negative consequences of natural disasters and technological emergencies, as well as of global climate change.

We shall focus our efforts on implementing a number of major objectives and goals in each area.

Component 1. Prevention and abatement of pollution of environment in the Russian Arctic

Key objectives of this Component are:

– Establishing the legal and institutional frameworks to prevent or reduce the levels of environmental contamination with the focus on preventative measures due to the development of hydrocarbon resources on the continental shelf;

– Improving the energy and environmental efficiency of the national economy including stronger liability for failure to meet the permissible environmental impact standards and for reclamation of past environmental damage; encouraging the implementation of energy-saving and environmentally-friendly technologies including tax and other incentives to be offered to companies that apply the above technologies;

– Assessment of anthropogenic contamination levels of the Russian Arctic seas, strengthening control over the transboundary transport of pollutants in the Arctic;

– Reducing the negative environmental impact of hot spots in the Russian Arctic;

– Developing/improving financial and economic mechanisms for attracting investments to solve environmental problems in the Russian Arctic;

– Raising the level of environmental education and awareness; ensuring public access to information concerning environmental pollution in the Russian Arctic;

– Developing international cooperation among the Arctic countries in the area of environmental protection in the Russian Arctic.

The Component I objectives will be implemented through the following *main activities*:

– Preparing analytical materials and a report to the Government of the Russian Federation concerning the need to improve the Russian environmental legislation and to develop the regulation framework to ensure environmental safety in the Russian Arctic;

– Preparing draft regulations concerning the establishment of special approaches to natural resource management and environmental protection in the Russian Arctic including monitoring of its contamination on the basis of international law and international commitments of the Russian Federation as well as international best practices;

– Preparing proposals to the Environmental Sections of the Strategy and State Programme of Socio-Economic Development of the Russian Federation till 2020;

– Developing and adopting, under the regional strategies and programmes of the system of socioeconomic development, specific measures for protection of the environment in all areas of the Russian Federation that are fully or partially located in the Russian Arctic;

– Preparing proposals to adjust the existing, or develop new, general and special technical regulations setting the requirements with due regard to the specific character of the environment and climate changes in the Arctic;

– Compiling and maintaining the geoecological datasheets for the licensed areas of the continental shelf;

– Establishing new and upgrading the existing points of the marine observational hydrometeorological network; improving the list of the monitoring parameters and improving their quality by making use of the modern measuring systems;

– Establishing new and upgrading the existing centres for the collection, processing and dissemination of environmental information;

– Developing the systems of satellite and aircraft monitoring of the environment;

– Establishing publicly accessible information databases on the environmental status of the Arctic by making use of GIS technologies;

– Conducting strategic environmental assessment (SEA) of the Russian Arctic focusing on the areas of its future development and adjacent sea areas of the Arctic Ocean;

– Developing and adopting regional standards for safe concentrations of oil products and other hazardous materials in soil and water with due regard to the specific features of the regions;

– Expanding the programme for the recovery and utilization of associated natural gas in the oil-producing regions;

– Upgrading production processes and implementing air and water protection activities at pulp and paper works, non-ferrous metal mills, coal mining enterprises, thermal power plants, and utility and housing facilities (under regional and corporate programmes);

– Developing and implementing governmental and corporate programmes aimed at improving the safety of radioactive waste and management of spent nuclear fuel; implementing activities to prevent the risk of radioactive pollution of the environment;

– Developing instruments of long-term co-sharing and financing of investment projects aimed at addressing environmental problems in the Russian Arctic;

– Developing a regulation on the introduction of charges relating to the development of natural resources to finance rehabilitation of the environment in the «hot spots» of the Russian Arctic;

– Developing measures to encourage the use of renewable energy sources in the Russian Arctic;

– Developing and implementing financial and economic instruments that prevent the delivery of unrecoverable packing to the Russian Arctic;

– Developing proposals for the intensification of fundamental and applied research for the protection of the Arctic environment (including in the area of transformation of permafrost processes); erosion of the banks and shores of rivers, lakes and seas; status of ecosystems;

– Assessment of the pollution status of the Arctic seas and coastal zone due to the development of economic activities in the Russian Arctic and adjacent areas;

– New technologies for monitoring the status of the marine and land ecosystems; environmental protection in the open seas and deep water areas, which are subject to the sovereign rights of the Russian Federation;

– Developing effective green sources of energy;

– Creating effective methods of cleaning-up oil pollution in the ice-covered marine environment;

– Studying the impact of environmental pollution on human health and ecosystems in the Arctic; using biotechnologies to prevent and clean-up pollution of the marine environment by oil, radionuclides, and heavy metals;

– Managing training and retraining of government authorities and local municipalities in the issues related to environmental protection of the Arctic;

– Environmental education;

– Expanding the participation of the Russian Federation in the activities of working groups, development and implementation of the programme of Arctic Councils.

Component 2. Conservation and improvement of the quality of the environment, living conditions of the indigenous small-in-numbers peoples and conditions for traditional land use by native small nations of the North

Key objectives of this Component are

(With respect to remedying past environmental damage on land and in the coastal zone of the Arctic seas):

– Improving, at the federal and regional levels, the legal and regulatory frameworks for control of petroleum, chemical, and radioactive contamination associated with activities on the land and continental shelf;

– Expanding public-private partnerships to improve the effectiveness of environmental protection;

– Developing and implementing investment projects aimed at remedying past environmental damage on land and in the coastal zone of the Arctic seas;

– Using the existing and developing new international instruments for attracting investments into the implementation of environmental projects in the Russian Arctic;

With respect to improving surface and ground water quality in coastal areas of the Russian Arctic:

– Improving the water management system in the Russian Arctic;

– Ensuring environmentally sound utilization of liquid and solid wastes in the areas adjacent to water intakes;

– Introducing modern technologies and facilities for the treatment of wastewater and storm water runoff and the utilization of contaminated sediments;

– Establishing and developing water-protection zones and shoreline protection belts around water bodies;

– Improving monitoring of the condition and quality of surface and ground waters;

With respect to the conservation of biological and landscape diversity and the potential for renewable biological resources affected by technology and pollution as a result of human activity:

– Developing new legal and economic instruments to regulate the management of biological resources in the Arctic in order to improve the system of payments for biological resource use and to combat poaching;

– Strengthening the system of land-based and marine protection of the Russian Arctic biodiversity, taking into account effects of existing and future human-related impact;

– Developing research on the biota and ecosystems of the Arctic, including research with international and regional participation;

– Improving the system of monitoring biodiversity and natural ecosystems in the Arctic, including this system into the circumpolar network of monitoring flora and fauna;

– Supporting activities for the ecological reclamation and rehabilitation of disturbed land; implementing re-introduction activities for the restoration of populations of extinct species in certain regions;

With respect to preserving living conditions of the indigenous people of the north and their traditional land use:

– Improving the legal and regulatory framework for the protection of the traditional way of life of indigenous people in the Russian Arctic;

– Improving mechanisms of interaction between the authorities and industrial companies on one hand, and non-governmental organizations of the indigenous people on the other hand;

– Implementing instruments for comprehensive ecosystem management in areas with compact settlements of indigenous people.

The Component II objectives will be met by implementing the *following activities:*

– Establishing and improving the legal and regulatory framework that permits legal and financial liability for failure to take measures for remedying past damage; and application of financial and economic incentives for such activities;

– Developing a set of environmental quality standards for the Arctic and methodologies for the incorporation of these indicators in the calculation of pollution charges;

– Establishing the federal and regional information systems with data on past environmental damage and the current status of the environment in the Russian Arctic;

– Preparing and implementing programmes and investment projects relating to remediation of past environmental damage covering the priority types of pollution/damage, territories and sea areas of the Russian Arctic including:

- reducing mercury contamination; disposing of obsolete and banned dielectric liquids and pesticides from the POP category;
- cleaning-up bodies of water, coastal marine areas, islands, and the sea coast from abandoned vessels, abandoned large-size property and garbage;
- cleaning-up the area along the Northern Sea Route from obsolete RITEGs and their utilization;
- comprehensive cleaning-up of the territories of abandoned polar stations, hydrometeorological posts and military bases of drums, abandoned machinery, frames of vessels, aircraft and other metal structures;
- reclamation of natural landscapes;

– Implementing scheduled utilization of ships with over-age nuclear installations, as well as radioactive waste;

– Developing and implementing innovative technologies for the reclamation of areas contaminated with oil and oil products including developing and testing of biotechnologies;

– Developing a regulatory act to ensure safe transportation of hydrocarbons in the Russian Arctic with due attention to the vulnerability of the environment and minimization of risks of natural disasters and technological emergencies;

– Rendering government support to projects aimed at improving water bodies used as a sources of drinking water supply under federal, departmental targeted and regional programmes;

– Improving the water management system in the Russian Arctic; developing and updating the scheme for comprehensive management and conservation of water bodies and regional programmes with specific measures for the improvement of water bodies used as sources of drinking water supply;

– Developing and approving target indicators, maximum permissible impacts, and territorial plans for attaining water quality standards in water bodies in accordance with the applicable legislation concerning the use and protection of water bodies and sanitary epidemiological wellbeing of the population;

– Implementing environmentally-friendly technologies and facilities for the cleanup of the marine environment (including establishing buffer zones of seaweed around the pollution sources), for the treatment of wastewater and storm water runoff and the utilization of contaminated sediments;

– Upgrading water supply systems by implementing modern water treatment, wastewater and storm water treatment techniques, and sludge recovery methods;

– Establishing and developing water protection zones, and sanitary protection zones around the water supply sources including the implementation of measures for the collection and treatment of surface runoff from residential and production areas;

– Establishing zones of special protection and use of mothballed water supply sources in case of emergencies;

– Developing research of biota and ecosystem of the Arctic including means of international participation;

– Improve monitoring of the condition and quality of surface and ground waters; expanding and upgrading networks for the observation of hydrological, hydrochemical, and hydrobiological regimes of water bodies;

– Developing and implementing new economic incentives and instruments of government regulation concerning the use of biological resources in the Arctic aimed at improving the system of payments for the use of biological resources, combating poaching, and developing environmental partnerships with private companies;

– Amending the framework of regulation and management of bioresources in the Russian Arctic;

– Improving economic and financial mechanisms for the conservation of biodiversity including insurance and compensation of pollution charges;

– Strengthening the system of land-based and marine protection of biodiversity in the Russian Arctic, with allowance for the effects of existing and potential technological impacts;

– Establishing new land and marine based, federal-level, specially protected natural areas in the Russian Arctic;

– Organizing the network of stationary studies concerning the status of the Arctic biota and biological resources;

– Preparing the concept for the development of a network of monitoring stations in the Arctic including permanent and remote stations, as well as mobile observation platforms;

– Organizing seed stations and nurseries for wild flora and fauna to support the work of ecological restoration and rehabilitation of disturbed lands; implementing re-introduction measures for restoration of populations of extinct species in certain regions including musk ox, wild northern reindeer, birds of prey, water fowls, etc;

– Ensuring expanded involvement of Russia in the Arctic Council Programme «Conservation of Arctic Fauna and Flora» (CAFF) including the Circumpolar Biodiversity Monitoring Programme;

– Supporting the development of territorial public self-governance and community forms of self-governance among indigenous people in the Russian Arctic;

– Creating regional mechanisms in the Russian Arctic to ensure participation of representatives of the regional authorities and local governments, communities of indigenous people, and industrial corporations in jointly addressing environmental problems in the areas of traditional settlements and traditional economic activities of the indigenous people;

– Organizing and conducting monitoring of the living conditions and environmental status in the areas of traditional settlements and traditional economic activities of the indigenous people;

– Developing and adopting regulatory acts concerning the assessment and calculation of damage incurred by commercial entities on the traditional land use of the indigenous people in the Russian Arctic.

Component 3. Prevention and mitigation of the negative consequences of natural disasters and technological emergencies, as well as of global climate changes

Key objectives of this Component are:

– Creating scientific, legal, regulatory, methodological, and institutional frameworks of governance concerning prevention and mitigation of negative consequences caused by natural disasters and technological emergencies;

– Reducing risks inherent in the adverse consequences of climate change for the environment, economy, and residents.

Component III Objectives include the *following activities*:

– Establishing a system of integrated security to protect territories, people and facilities (that are critically important for the national security of the Russian Federation) of the Russian Arctic from the risks of natural disasters and technological emergencies;

– Studying hazardous and critical natural events; development of modern technologies and techniques for their forecasting in the context of climate change;

– Predicting and assessing the consequences of global climate change in the Russian Arctic for the natural environment, economy, and residents under the influence of natural and human -induced factors in the mid- and long-term perspective including improvements in infrastructure sustainability;

– Establishing financial mechanisms to support activities aimed at reducing the adverse consequences of climate change;

– Taking into account negative consequences induced by climate change in the federal, sectoral, regional and corporate programmes;

– Making adaptations to traditional land use by the indigenous peoples in response to climate change;

– Expanding international cooperation on adaptation to global climate change, primarily under the Arctic Council.

* * *

The main activities identified to prevent, eliminate and reduce the adverse anthropogenic environmental impact in the Russian Arctic, based on the results of the diagnostic analysis, are included in the Strategic Action Programme for Environmental Protection of the Arctic zone of the Russian Federation (SAP-Arctic). The Marine Board of the Russian Government approved the SAP-Arctic on June 19, 2009 and recommended the federal executive bodies, executive bodies of subjects of the Russian Federation and organizations (stakeholders) upon development of policy documents relating to development of Russian Arctic to follow the SAP-Arctic. The Intergovernmental Arctic Council welcomed the adoption of SAP-Arctic and called on the Arctic state, and all stakeholders, to participate in the proposed programme.

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