

The environmental impact caused by developing energy resources in the Arctic region

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Abstract. The Arctic region has been attracting a great deal of interest from numerous researchers. Developing the oil and gas resources of the Arctic shelf is an important task for the national economy, especially since the area supply with hydrocarbons is decreasing. At the same time, preserving the integrity of Arctic marine ecosystems is of paramount importance taking into account the vulnerability of the Arctic seas. In view of the current trends, the Arctic region is rightfully considered strategically significant for further sustainable development of the Russian Federation. Intensified industrial development of hydrocarbons in the Arctic shelf of the Russian Federation lends urgency to assessing the impact of developing energy resources on the environment. The main conditions for successful development of oil and gas resources on the Arctic shelf of Russia are economic efficiency and environmental safety. Biological diversity (of species) is one of the main indicators of ecosystem sustainability. Species diversity may be affected not only by climate change, but also by the environmental changes associated with anthropogenic impacts, such as products of hydrocarbon exploration, extraction and refinery, heavy metals and other metallurgical wastes. Using approved environmental monitoring methods the paper presents the results of the assessment of the current environmental status and biodiversity in industrial development areas illustrated with the example of the Barents Sea shelf ..

1. Unique region

The Arctic is rightly considered to be a unique region of our planet, because, despite its severe climatic conditions and geographical location, this region possesses virtually all kinds of natural resources. The Arctic has large reserves of energy resources, with 90 billion barrels in potential oil reserves, 47.3 trillion cubic meters in potential gas reserves and 44 billion barrels in potential gas condensate [1]. The Arctic marine environment is the habitat of many unique animal species, including particularly rare ones such as the polar bear, the narwhal, the walrus and the beluga. More than 150 species of fish inhabit Arctic and subarctic waters, including cod and flounder, important for the fishing industry [1].

The Arctic harsh environment is particularly vulnerable, which means that the region faces the issues of maximum preservation of the natural environment, development and implementation of a rational “environmentally balanced model of natural resources’ sustainable management”. The economic interest in using the Arctic resources is steadily increasing. Intensified economic activity in the Arctic upsets the ecological balance. The Arctic ecosystem is quite sensitive to anthropogenic impact and takes very long to recover after “mindless” intervention. In addition, the climatic and hydrological parameters of the Arctic Ocean such as depth, salinity, temperature, velocity and



direction of currents, stratification of water and total water balance contribute to a significant dilution of polluted effluents and to heavy deposition of pollutants that remain in marine ecosystems for a long time.

The conditions in which the shelf is developed are difficult, which is why a special focus has to be given to the environment, with each of the development stages having its own specifics. Much effort is currently put into creating a comprehensive environmental protection policy for the region, where not only the countries located along the Arctic coast, but also international organizations and indigenous peoples participate in the decision-making process. Arctic geopolitics is changing [2].

The issues concerning the development of the oil and gas industry and its interaction with the environment are of particular importance, due to significant anthropogenic impact that the industrial development of hydrocarbons on the Arctic shelf has on the environment. This impact is made up of oil spills, greenhouse gas emissions, release of contaminants into the atmosphere, and other factors.

2. The Russian Arctic

Russia has a special geopolitical position in the Arctic region. Environmental safety is crucial for sustainable development of the Russian Arctic. Monitoring of economic activity on the shelf is necessary during active development of hydrocarbon resources of the North and their transportation by sea: this would prevent possible emergencies of anthropogenic nature.

At a major annual press conference held in Moscow on December 14, 2017, the President of the Russian Federation Vladimir Putin discussed the development of the Arctic region. "Industrial development of the Arctic, development of mineral reserves should go together with protection of nature," he stated, answering a journalist's question about the priorities of the state policy in the Arctic.

The current trend in the development of the Russian Arctic is towards intensified economic use of the region's potential. The task is to update the transport and military infrastructure. [3]

The Russian Arctic region is divided into the western and eastern parts along the eastern border of the Vilkitsky Strait (along 105°54'E). The Western Arctic region combines the components of the continent-ocean profile of three oil and gas provinces: the Barents-Kara basin, also called the oil and gas province of the Arctic seas, along the ocean margin, and the Timan-Pechora basin and six Arctic oil and gas regions of the West Siberian oil and gas province (South Kara, Yamal, Gydan, Ust-Yenisei, Nadym-Pur and Pur-Taz) along the continental margin.

This combination of traits is particularly obvious in the basins of the Kara and Barents seas which are some of the most productive shelf seas, with significant deposits of hydrocarbons found on their shelf. At the same time, since the development of energy resources is the key factor governing the social and economic status of the Arctic region, the areas with the largest gas reserves located in oil and gas regions should be taken into account when determining the region's boundaries. In addition, the Barents Sea is known for its high biological productivity, equal to that of the North Sea. Among the thirteen shelf seas, it is these two seas that have both high productivity and multiple resources and can be classified as large marine ecosystems.

3. The environmental conditions in the Barents Sea

Economic efficiency and environmental safety are the main conditions for successful development of oil and gas resources on the Arctic shelf of Russia [4]. The second condition is very important for Arctic seas because the cold arctic climate renders marine ecosystems particularly vulnerable due to ice, slow wave movement, low chemical and biological activity [5]. Biodiversity (of species) is one of the key indicators of the ecosystem sustainability.

Marine biota of the Barents Sea contains a great variety of phytoplankton, zooplankton, benthos, ichthyofauna, avifauna and marine mammals.

To date, unicellular algae of the pelagic zone of the Barents Sea have been rather well-studied, with more than 300 valid species of phytoplanktonic algae found. These algae belong to 8 taxonomic groups: diatoms or Diatomeae (Bacillariophyta), dinoflagellates or Peridineae (Dinophyta), green

algae (Chlorophyta), Haptophyta, Prasinophyta, Cryptophyta, golden algae (Chrysophyta) and euglenids (Euglenophyta). The majority of the recorded species are diatoms and dinophytes (about 150 species (50%) and about 120 species (40%), respectively). The share of the remaining species is small and does not exceed 10% [6,7,8]. The abundance of phytoplankton in the Barents Sea ranges from 0.02 thousand cells/l in winter to 2,000 thousand cells/l at the peak of spring bloom. The phytoplankton biomass changes throughout the year: from 0.14-0.4 $\mu\text{g/l}$ in winter and autumn to 3000 $\mu\text{g/l}$ in the spring maximum [7]. The average annual values of primary production vary from 20-25 $\text{gC/m}^2/\text{yr}$ in the northern regions to 200-250 $\text{gC/m}^2/\text{yr}$ in the south-western part of the Barents Sea [5].

While much data has been obtained on the zooplankton of the Barents Sea in general, the zooplankton of some northern regions (especially the northern sector of the sea) remains poorly studied. The list of zooplankton taxa of the Barents Sea [8] includes about 200 species of animals. The zooplankton is divided into taxonomically close groups. A separate large group consists of unicellular zooplankton. Multicellular zooplankton is represented by holoplankton whose entire life cycle is spent in the pelagic zone: Coelenterata, Ctenophora, Crustacea, Gastropoda, Chaetognatha, Rotatoria, Appendicularia and meroplankton (pelagic larvae of benthic animals). The average mass of zooplankton in the upper 100-meter layer of the Barents Sea is more than 200 mg/m^3 . Areas of increased concentration (more than 500 mg/m^3) are found in the waters of the continental shelf. The biomass of zooplankton in the cold Arctic regions does not exceed 100-200 mg/m^3 . Only a small group in the diverse zooplankton species of the Barents Sea plays a significant role in forming the biomass of the community and, accordingly, takes a prominent place in the diet of fish, mainly crustaceans; these are, mainly, copepods, euphausiids and hyperiids.

About 2300 species of invertebrates, including benthic species, live in the Barents Sea [9]. The fauna of the Arctic seas typically has the following ratio of benthic invertebrate groups: macrobenthos (organisms that are visible to the naked eye) makes up about 60% of the total number of species, meiobenthos (organisms with the size less than 1 mm) makes up 34%, and plankton 6% (planktonic invertebrates are represented by 16 species of radiolarians) [9].

In the entire history of observations of ichthyofauna in the Barents Sea under different climatic conditions, 182 species and subspecies of fish belonging to 59 families, 28 orders and 5 classes were found [5]. However, according to expert estimates, no more than 126 species and subspecies of fish that either constantly inhabit the Barents Sea or spend a part of their life cycle can be encountered in actual surveys [5]. No more than 50 species and subspecies of fish can be simultaneously encountered in the central region of the sea. Other species pass through a certain region in certain seasons, temporarily, during feeding or spawning migrations, or are observed only sporadically. The main part of the ichthyofauna (103 species, or 56.6%) is confined to demersal or benthic habitats. Most species are omnivores (i.e., able to subsist on a variety of foods) but the main trophic group is made up by benthivores (i.e., organisms eating benthos), comprising 52% [5]. Pelagic species include capelin, Atlantic herring, Arctic cod and pollock; benthic species include cod, haddock, rockfish, halibut, catfish and flounder. The sea lamprey (*Petromyzon marinus*) is the only species living in the Barents Sea that is included in the Red Data Book of Russia (2000). Changes in the behavior of individual fish species have been observed, for example, Atlantic cod (*Gadus morhua*) leaves the continental shelf waters and migrates to deeper waters [11]. These changes in migratory behaviors have been linked with environmental conditions due to physical factors or competition for food. According to the data of [12], climate change in the Arctic has a lesser effect on the health and population of commercial fish than the 'fishing pressure'.

The diversity and abundance of the bird species that regularly occur in open areas of the Barents Sea are low and markedly different in different areas of the sea. The species regularly observed in the Barents Sea included 19 species of marine colonial birds, 9 species of Anseriformes and 9 species of waders [10]. The 19 species found directly in open water areas belong to 4 orders: Gagariformes, Anseriformes, Procellariiformes and Charadriiformes. Laridae are the most widespread birds in the Barents Sea (9 species), including 4 species of skuas. However, the avifauna of the open areas of the

eastern part of the sea consists of only three species of sea birds: the Arctic fulmar (*Fulmarus glacialis*), the black-legged kittiwake (*Rissa tridactyla*), and the thick-billed murre (*Uria lomvia*).

Both boreal and arctic species can be found in the Barents Sea as it is strongly influenced by the North Atlantic Current in most parts of its waters. The most numerous species of Cetacea are the minke whale, the fin whale, the humpback whale, the killer whale, the Atlantic white-sided dolphin and the white-beaked dolphin. The Arctic fauna consists of pagophilic species inhabiting the cold Arctic waters and the floating ice zone, such as the polar bear, the Atlantic walrus, the bowhead whale, the beluga whale, the narwhal, the harp seal, the ringed seal and the bearded seal.

Species diversity can be affected not only by climate change but also by changes in the environment due to the anthropogenic impact, such as urban or industrial runoff and emission, the products of hydrocarbon exploration, extraction and refinery, heavy metals and other metallurgical waste, pollutants from coastal military bases, waste from vessels operating on nuclear fuel.

The Arctic is attracting growing attention of entrepreneurs in many countries, including Russia; in view of the above, the biodiversity of regional marine ecosystems must be protected as effectively as possible. Ref. [13] proposed to create a network of protected marine areas, selecting them using a methodology based on the MARXAN decision support tool, supplemented by extensive post-analysis. Determining such priority areas for conservation is extremely important.

According to PINRO data (Nikolai M. Knipovich Polar Research Institute of Marine Fisheries and Oceanography) of February 2012, the specific activity of the artificial radionuclide ^{137}Cs was 0.60 Bq/kg dry weight in the bottom sediments of the Barents Sea, and that of ^{90}Sr was 0.85, which corresponded to the background values from the literature data. The artificial background radiation in the coastal waters is generated by objects posing a radiation hazard, concentrated in the Kola and Motovsky Bays, in the cities of Murmansk, Severomorsk, Polyarny, Gadzhiyevo, and in the Sayda, Olenya, Pala, Zapadnaya Litsa, Ura and Ara bays. The water masses of the Barents Sea had a relatively high activity of ^{137}Cs (up to 40-90 Bq/m³) in the 1980s but by the mid-1990s its content dramatically decreased (to about 15 Bq/m³). The activity of artificial radionuclides continued to decline in the 2000s. The volumetric activity of ^{137}Cs in the sea water varied from Bq/m³ in 2005-2008. The activity was distributed relatively evenly in the open sea waters, amounting to 1-2 Bq/m³ but the activity of ^{137}Cs is higher in the coastal zone of the Kola Peninsula in open bays (Zelenetskaya Guba, Teriberskaya Guba and others) and amounts to 3.0-3.6 Bq/m³.

According to MMBI (Murmansk Marine Biological Institute), the total content of petroleum hydrocarbons (aliphatic and polyaromatic) in the upper water layer of the Barents Sea has been varying from 0 to 1.13 mg/l for several years. According to PINRO data, in different seasons of 2010, the concentrations of aliphatic hydrocarbons (n-paraffins) varied from 0.84 to 6.6 µg/l in the surface water layer and from 0.56 to 4.3 µg/l in the benthic layer, and did not exceed the threshold concentration of 50 µg/l established for the fishing industry.

Technogenic and oil pollution of the environment is assessed by the content of polycyclic aromatic hydrocarbons (PAHs). Their total concentrations in the waters of the Barents Sea are generally low, and the composition is poor. According to PINRO data, in different seasons of 2010, the total PAH concentration in the water of the Barents Sea varied from 0.96 to 122 ng/l in the surface water layer, and from 0.41 to 144 ng/l in the benthic layer, exceeding the global background level of 20 ng/l. Higher concentrations of PAHs are characteristic for the Atlantic and Barents Sea waters. The total concentrations of carcinogenic compounds (benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene and dibenz[a,h]anthracene) varied from 0.03 to 6.3 ng/l in the surface water layer and from 0.03 to 5.7 ng/l in the benthic layer, generally not exceeding 1.5% of the total PAH concentration. Naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, phenanthrene, which are the products of combustion of fossil fuels and organic raw materials, were prevalent in the pelagic layer.

The total concentrations of isomers of hexachlorocyclohexane in the surface water layer of the Barents Sea varied from 0.16 to 5.8 ng/l and from 0.15 to 5.7 ng/l in the benthic layer in 2010. The

total concentrations of DDT metabolites varied from 0.16 to 1.8 ng/l in the surface water layer and from 0.12 to 1.4 ng/l in the benthic layer.

The concentration of polychlorinated biphenyls in the open water area of the Barents Sea is very low and is detected by highly sensitive methods of analysis in quantities not exceeding several nanograms per liter of water or in trace amounts. The average concentration of these compounds is 4.29 ng/l according to MMBI data. The total concentrations of detectable organochlorine pesticides and polychlorinated biphenyls in the surface and benthic layers did not exceed the threshold concentration of 10 ng/l at all stations.

The concentrations of detergents (surfactants) were insignificant in the coastal waters as well as in the open areas of the Barents Sea; an increase was occasionally observed in the waters of the Motovsky Bay.

Pollutants in the form of aerosols are released into the Barents Sea from the territory of Northern Europe and the Kola Peninsula; this gets especially acute in winter. Aerosols in the atmosphere of the Barents Sea sub region are considerably saturated with heavy metals (HMs) from regional sources (Ni, Cu, Zn, Cd, Pb, Cr and Hg). The mass of heavy metals released into the Barents Sea with precipitation over the year is by far lower than the mass of the HMs already contained in its waters. Therefore, the release of HMs with precipitation does not lead to noticeable changes in the sea water composition.

According to PINRO data, the concentrations of 11 heavy metals and trace elements (copper, zinc, nickel, chromium, manganese, cobalt, lead, iron, cadmium, arsenic and mercury) examined in different seasons of 2010 in the waters of the Barents Sea tended to increase from west to east and were significantly lower than the threshold concentrations established for the fishing industry. The concentrations of lead varied from 0.10 to 1.4 µg/l in the surface water layer, and from 0.10 to 1.3 µg/l in benthic layer, the concentrations of cadmium varied from 0.01 to 1.3 µg/l in the surface layer, and from 0.01 to 0.90 µg/l in the benthic layer, the concentrations of arsenic varied from 0.10 to 0.80 µg/l in the surface layer, and from 0.10 to 0.80 µg/l in the benthic layer. The concentrations of mercury in the water column varied from analytical zero to the threshold concentration of 0.10 µg/l.

As the pollution of bottom sediments is fairly stable over time in contrast with the pollution of water masses, it follows from publicly available data that elevated levels of bottom sediment pollution are observed mainly in the eastern part of the Barents Sea, as well as in the coastal zone of the Western Murman.

According to MMBI data, the concentration of oil products in the bottom sediments of the open areas of the Barents Sea is very small and varies in the range from trace values to 80 µg/g of dry sediment. The highest concentrations were recorded in the sediments of the Central Groove and the coastal zone. According to PINRO data, in 2010 the content of aliphatic hydrocarbons in the upper 1-3 cm layer of the bottom sediments of the Barents Sea varied from 0.19 to 6.8 µg/g dry weight. Hydrocarbons of both biogenic and petroleum origin were detected in the composition of aliphatic compounds of most samples, as indicated by the dynamics of the pristane/phytane ratio > 1 or ≤ 1 . Russian Federation has not adopted any standards for the n-paraffin content in bottom sediments. The total content of n-paraffins in the bottom sediments of the examined areas of the Barents Sea was significantly lower than the technogenic background level typical for the upper layer of the bottom sediments of the Western Arctic Shelf, amounting to 340 µg/g dry weight.

The publicly available data indicate a relatively low content of polycyclic aromatic hydrocarbons in the bottom sediments of the Barents Sea. Russian Federation has not adopted any standards for PAH content in sea bottom sediments. According to the classification of pollution levels of sea bottom sediments adopted by the Norwegian Pollution Control Authority (SFT), the content of PAH and benz[a]pyrene in the bottom sediments did not exceed the background levels < 300 and < 10 ng/g dry weight, respectively, in the examined areas of the Barents Sea.

Residual amounts of α , β , γ -isomers of hexachlorocyclohexane (HCH) and DDT metabolites were the prevalent organochlorine pesticides in the bottom sediments of the Barents Sea examined in 2010. The total content of DDT in bottom sediments varied from 0.37 to 7.3 ng/g dry weight at all stations

and exceeded the technogenic background level of 0.5 ng/g dry weight, which corresponded to the “moderately polluted” and “markedly contaminated” categories.

According to the PINRO studies, in 2010 the PCB content in the bottom sediments of the Barents Sea varied from 0.67 to 2.1 ng/g dry weight and did not exceed the technogenic background level of 5 ng/g dry weight.

According to the MMBI data, the level of PCB accumulation in the bottom sediments of the Barents Sea can also be categorized as very low. The concentration of these compounds in 35% of the tested precipitation were below the detection threshold. The concentration of PCBs in the sediments of open sea areas averaged 0.3 ng/g dry weight. A relatively PCB high content (1.0-1.5 ng/g dry weight) was detected in the sediments of the Central Groove (Polar Front region) as well as in the coastal zone.

Most of the heavy metals and trace elements, except for iron and manganese, do not accumulate in the sediments in substantial concentrations. According to MMBI data, the spatial distribution of copper, cadmium, nickel, chromium, iron, manganese, zinc and arsenic has a general trend towards the concentrations increasing from coastal zones to the deep water regions of the Central Bank. Russian Federation has not adopted any standards for the content of heavy metals in sea bottom sediments. According to the pollution criteria in sea sediments adopted in Norway for arsenic content, all the bottom sediments examined can be classified as “moderately polluted”. The cadmium content in bottom sediments corresponded to the “moderately polluted” and “markedly contaminated” categories at most stations. The content of the remaining metals corresponded to the natural background levels.

The results presented confirm that the present pollution level of the marine environment of the Barents Sea is relatively low, with the exception of the narrow coastal zone of the Kola Peninsula.

4. Environmental risks in developing energy resources

The studies based on modern methods of environmental monitoring have revealed no significant changes in the current environmental status of the Arctic region. However, the existing methods of medium and long-term assessment of marine biota habitats are rather imperfect. It is known that Russian rivers annually carry up to 500,000 tons of oil products (including those formed in accidents during oil extraction and transportation) into the Arctic Ocean. This means that the negative environmental impact of developing energy resources in the Arctic region is likely to result in an irreversible environmental crisis.

It should be understood that intensified search and extraction of hydrocarbons in the Arctic will lead to increased pressure on the Arctic ecosystems. With no effective mechanisms of environmental control, this could exacerbate the environmental problems even more, especially on the continental shelf of the Barents, Pechora and Kara Seas.

Environmental hazards in the extraction of energy resources in the Arctic include drilling wells, which can cause pollutants' release into the atmosphere and into the marine environment, volatile emissions of liquid hydrocarbons and hydrocarbon gases from the wells during drilling, emissions of greenhouse gases that can lead to climate change, transportation of hydrocarbons by tankers and pipelines, which carries a risk of spills during loading /unloading and emergencies.

Even insignificant spills of extracted energy resources lead to irreparable environmental damage, especially on the shelf that is covered by thick ice for most of the year.

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