

# **ECOLOGICAL AND GEOMORPHOLOGICAL ASSESSMENT OF THE VULNERABILITY OF THE COASTS OF THE KARA SEA TO THE OIL SPILL**

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**International experience of oil spill response in the sea defines the priority of coastal protection and the need to identify as most valuable in ecological terms and the most vulnerable areas. Methodological approaches to the assessing the vulnerability of Arctic coasts to oil spills based on international systems of Environmental Sensitivity Index (ESI) and geomorphological zoning are considered in the article. The comprehensive environmental and geomorphological approach allowed us to form the morphodynamic basis for the classification of seacoasts and try to adapt the international system of indexes to the shores of the Kara Sea taking into account the specific natural conditions. This work has improved the expert assessments of the vulnerability and resilience of the seacoasts.**

*Key words: seacoasts; oil spills; environmental sensitivity; international system of indexes; geomorphological zoning; Kara Sea*

## **I. INTRODUCTION**

The Russian Arctic shelf is very promising in relation to oil. The development of offshore fields is inevitably connected with the development of mining and transport infrastructure (construction of the offshore ice-resistant stationary platforms, pipelines, oil terminals of various types, etc.), including the Northern sea route. This requires the development of measures for environmental protection, including the protection of the coasts, to prevent and eliminate consequences of possible oil spills and oil products. For these goals, developing special environmental sensitivity maps of the coast, reflecting the complex expert evaluation as a tool for operational decision-making.

In this paper, we consider the coast of the Kara Sea, the offshore areas that are evaluated as one of the most promising in respect of oil and gas. The aim of this work is to assess environmental sensitivity to spills of oil and oil products and the mapping of the investigated part of the coasts of the Kara sea on the basis of the international system of indices of ESI (Environmental Sensitivity Index) and morphodynamic typing of the coastal zone.

The index of environmental sensitivity (ESI - Environmental Sensitivity Index) was first proposed in 1978 by American scientists [13] to assess the vulnerability of the coastline to oil pollution and the ranking of banks in the development of measures for oil spill response. Over the years, the method has gained wide recognition, classification of coasts with its use spread along the shores of the seas of many countries. Today, according to the requirements of the International Maritime Organization (IMO) ecological sensitivity maps of the coast should be prepared for all areas of coastal-marine areas, where there is a risk of oil pollution.

In Russia the assessment of environmental sensitivity to oil pollution in recent years has also received considerable attention [1, 6, 10 et al.]. Active participation in development of

methodical approaches to creation of maps of ecologically vulnerable zones and regions of priority protection of water areas and coasts of the Russian Federation from oil spills and oil products adopted the world wildlife Fund (WWF-Russia). Under the auspices of this organization released a number of summarizing publications [2].

## II. METHODOLOGICAL APPROACHES

Despite the relevance of this type of research and the presence of well-defined development prospects of oil fields on the continental shelf of Arctic and Far Eastern seas in Russia there is still no single accepted methodology for the assessment of the sensitivity of the coasts. Geological-geomorphological factors underlying international methods are considered very superficially or not addressed at all. This is reflected in the terminology used by the Russian authors in relation to the coastal zone. The geomorphology of the coasts - formed scientific direction, studying the structure, formation conditions and contemporary dynamics of the coastal zone [8].

To emphasize the importance of the geomorphology of the coast in assessing its environmental sensitivity should refer to the original methodology, the basic principles of which remain unchanged for many years [11]. In our opinion, the most important are the following.

- Sensitivity maps are designed to display the necessary environmental information, based on which the decision can be made regarding priorities for oil spill response and appropriate cleaning methods;

- Sensitivity includes three main components: geomorphological, biological, and anthropogenic (social and economic);

- Geomorphological conditions (type of coastline, etc.) involve ranking in order of increasing sensitivity, usually on a scale of 1 to 10. This takes into account the biological component is directly related to geomorphological factors (eg, marshes, swamps, mangroves, etc.);

- Other biological and socio - economic components are shown as out of scale symbols (points , polygons , etc . ) without sensitivity values. Their sensitivity may be varied over a wide range depending on the season and other factors.

By following these basic principles of sensitivity, maps do not contain:

- defining the complex sensitivity (for example, geomorphological + biological + socio-economic = final sensitivity). It remains the prerogative of the user with the ability to separately assess the sensitivity of each component and to determine the most appropriate response in a particular case;

- indicate the different sensitivity of similar sites, despite the possibility of increasing the sensitivity when combined with other components, especially biological and socio-economic.

There are 10 main levels/of indices from one (low sensitivity) to ten (high sensitivity) in the international system of the environmental sensitivity index (ESI) [12, 14]. Given the many regional differences, individual levels of ESI include several types of banks, designated by the alphabetic indexes. In total there are 25 types of the coast. Each type is color-coded in accordance with the increase of the index of environmental sensitivity from cold color to warm, according to the approved color scale. It provides a simple and rapid identification of environmental sensitivity of the shore at the mapping and GIS work in spill response, allows identifying the most vulnerable, and are more resistant to contamination areas. The last is the key point of the planning process to eliminate contaminants in the plans of oil spill, because it determines the choice of priorities when cleaning.

Despite the versatility, the proposed list of the types of banks and their sensitivity towards oil spills require adaptation and detail (if necessary) for each particular region, and especially to

the Arctic coast. This is due to specific natural conditions, a variety of morphological and dynamic environments, unequal individual knowledge of the coastal areas, different mapping scale and other factors. The typing of the coasts at any one symptom is not able to reflect all the features of their modern development and environmental sensitivity. Therefore, the basis of the ranking according to the methodology [12] was based on three main factors.

- Characteristics of the shoreline (granulometric composition of the sediments, the profile of the coastal zone) that defines the possibility of penetration and/or burial of oil, oil products on the shore, and move them;

- The impact of waves and tidal energy, which determines the time of natural resilience (safety) of oil on the shore;

- General biological productivity and sensitivity of the coast, socio-economic aspects.

The authors of the original ideas [13] do not recommend the use of integrated assessment - to combine biological, socio-economic and geomorphological component in a single index of sensitivity. When making decisions it is important to have an idea about the relative sensitivity of each of the components of the ecosystem to determine appropriate responses for a specific time and place. Given this, in our work we deliberately do not consider the biological component, of course, the most important from the point of view of nature conservation and socio-economic aspects, with an extremely limited distribution on the coast of the Kara Sea. The evaluation of these factors should be performed by qualified specialists and be accounted for separately from the geological and geomorphological conditions. For these purposes, are encouraged to develop thematic maps, or use proposed by the American specialists of the system of point (regardless of scale) conventional signs covering important ecosystem components. On the shores of the seas to such valuable and sensitive components are rare habitats, breeding sites for birds, the lot of migrating animals, places of feeding and spawning fish, and so on [2].

In this paper, we consider only the basic criteria for zoning shores in their sensitivity according to their sensitivity to pollution by oil and oil products, namely, geological-geomorphological and hydrodynamical conditions of the functioning of coastal systems. We hope that this will allow not only to communicate the sensitivity of the shores of the Kara sea to oil spills with their lithology, morphology and dynamics, but also to link ecological typing with traditional typing for sea coast morphodynamic zoning.

The practical significance of this approach lies in the fact that geomorphological analysis is able partly to offset the lack of information about the banks in remote areas of the Arctic seas. The practical experience gained in similar projects has shown that adopted as the underlying research method and information gathering specialized aerial and videography coastline using a light aircraft is not able to fully satisfy the requirements of completeness and detail of the original information. In particular, one disadvantage of this approach is a very rough estimate of the granulometric composition of the sediments composing the beach. Another factor complicating predictive assessment of the interaction of oil with the shore, is the low informative value of photographs on the dynamics of sediment transport in the coastal zone, the speed of retreat of the coastal terraces, the power of beach sediments, permafrost conditions, the depth of seasonal thawing, the development of specific coastal processes, underwater slope relief, etc. Without a comprehensive geomorphological assessment of primary data and conducting field studies in key plots it is impossible to assess all factors of sustainability of the coast to the pollution or its capacity to cleanse itself. So, widespread on the coasts of the Arctic seas is the process of thermoabrasion almost did not take into account the international system of indexes. In addition, because it is

widely known that due to the destruction of permafrost, the pillars of the Bank, the rate of retreat of coastal scarps can reach up to few meters-tens of meters during a single storm season.

Based on the understanding of the geomorphology of the coastal zone, the proposed morphodynamic approach does not contradict the principles of the international system of indices of sensitivity, as is its broader counterpart, which can and should be the basis for the ecological typification of the seacoast. In our opinion, the assessment of the environmental sensitivity of the coast made taking into account the geomorphological factors is more complete and accurate than the simplified typology for the individual ranking criteria in accordance with the method IMO/IPIECA and OGP [12].

The results of the geomorphologic zonation is most often present in the form of typing morphodynamic of the coast. The type of shore is a generalized morpholithodynamics characteristic of the coastal zone, reflecting the set of shared morphological and dynamic characteristics of a particular segment of coast. It takes into account the manifestations and activities of not only wave propagation but also other factors - hydrodynamic, geological, permafrost, fluvial, which determine the character of the shore is not less than excitement, or push his influence into the background. In addition, the type of Bank reflects the current state of the coastal system and in many ways indicates the trend of further development, accumulation or erosion. This allows taking into account, the features of the movement and sedimentation are necessary to understand the nature of distribution of oil products in the coastal zone, identify areas of possible accumulation of oil and residence time of her on the beach.

### III. THE SHORES OF THE KARA SEA

The most important factor determining the susceptibility of coastal areas to pollution is the geological structure of the banks and the composition of deposits pririsoval (beach) area. On the coasts of the Kara Sea, traditionally there are two main groups of banks composed of solid bedrock and Quaternary sedimentary deposits. Deposits almost everywhere are in a permafrost condition.

#### *Morphodynamic types of the shore of the Kara Sea (scale 1:200 000)*

Shores developed in solid bedrock (permafrost):

1. Abrasion and abrasion-denudation, developed in the rocks;
2. Thermodenudation, formed by outlet glaciers;

Shores composed of unconsolidated sediments (permafrost):

3. Abrasion with thermoabrasion-thermodenudation coastal scarps;
4. Abrasion with dead or dying coastal scarps, bordered by accumulative terrace;
5. Abrasion-denudation and thermodenudation (in gulfs, straits and lips);
6. Accumulative aligned, with joined accumulative terrace and tidal flats;
7. Accumulative shallow, lagoons and delta (including marshes, inundated low-lying

tundra);

The proposed morphodynamic typology of the coasts can be considered universal for the investigated area, as the use of very capacious names of banks capable of numerous variations of the content of each selected type that are so necessary in the zoning and mapping of such complex objects in a chosen scale. If you change, the scale of mapping classification of banks can be expanded.

Transitions between different types of banks are often elusive and only found differences when comparing sites located at some distance from each other. The sharp boundaries of adjoining

shores of various types, as a rule, coincide with tectonic faults, oriented at an angle to the coastline and separating the blocks of the Foundation with different intensity of neotectonic movements. Often, the contact area is accented by elements of hydrographic network and/or different height position of the roof of bedrock. The mouth of the rivers, as well as outstanding in a sea of capes, often share the field with various lithodynamic conditions, respectively, and with different types of banks.

Dissemination of particular types of coasts in the study area is very uneven, which emphasizes the marked differences of the morphological, geological and geomorphological structure of the coasts, the nature of the dismemberment of the coastline. On the Novaya Zemlya archipelago, Vaigach Island, Western part of the Yugor Peninsula and the coast of Taimyr is dominated by abrasion and abrasion-denudation shores developed in solid bedrock. On the coast of the Yugorskiy Peninsula, the Western coast of the Yamal Peninsula is dominated by open coast with thermoabrasion or abrasion-thermodenudation coastal scarp, interspersed with lengthy sections aligned and shallow accumulative shores with joined accumulative forms and lagoon-butovych coasts, the vast space is a sea lady, which are widely spread in the corner of Baidaratskaya lips. On the coast of the Taz Peninsula and Gydan, Yenisei Gulf in the open areas is dominated by thermoabrasion beach, lips and bays protected by the abrasion-denudation and thermoabrasion the shore, as well as extensive space nevanova accumulation. A feature of the shores of New Land and Northern Land is widespread in the coastal zone of outlet glaciers that form the ice thermodenudation scarps. Among the Islands of the Kara sea is composed of many indigenous rock is characteristic of the abrasion and abrasion-denudation type of shore, alluvial island, composed of loose Quaternary sediments are exposed to abrasion and thermoabrasion processes, accumulative plots are of secondary importance.

Analysis of the length of the individual types of banks showed that in the study area is dominated by shore type abrasion (abrasion-denudation, and thermoabrasion-thermodenudation). Accumulative areas together occupy less than 40% of the coastline of the Kara Sea.

#### IV. ECOLOGICAL AND GEOMORPHOLOGICAL SENSITIVITY OF THE COAST TO OIL SPILLS

Presents ecological and geomorphological approach applied in the creation of a series of maps of environmental sensitivity of the coast of the Kara Sea to oil spills and oil products. Types of emergencies, distribution models (drift, spreading etc.), possible methods of spill response options and physico-chemical and mechanical interaction of the oil with sediments on the Arctic coasts were adopted in accordance with [7, 9]. In view of the complexity of the object and the scale selected for mapping was not able to exclude some generalizations, but they were all made in accordance with the recommended precautionary principles in favor of the object.

Environmental sensitivity to spills of oil and oil products were determined on the basis of expert assessment of the main ranking criteria using all available data banks (satellite images, aeroformation, literary, stock, field data, etc.) and included analysis of geomorphological, hydrodynamic, geological and geocryological conditions of each segment of the coast, as well as analysis of lithodynamic features of the development of the site. Take into account the peculiarities of interaction of oil with different substrate established experimentally [7, 9], the possibility of a natural burial of oil and displacement of soil, possible ways to eliminate the pollution.

As the basis of typing in the first stage were used morphodynamic zonation, which is in accordance with approaches of the international system ESI additionally took into account the openness of the coast to the excitement and lithology of the rocks composing the coastal zone. A more detailed analysis was conducted under a separate lithodynamic systems or segments of coast

with similar characteristics of morphology and lithology. Using a combination of the factors discussed above, each site was assigned an index of sensitivity to oil pollution in accordance with the ESI system.

Just within the surveyed part of the Kara Sea has been allocated 11 types of banks with different indexes of environmental sensitivity:

- 1A - exposed rocky (ice) shore;
- 1C - exposed rocky cliffs with boulder talus base;
- 2A - exposed wave-cut platforms (benches) in bedrock, clay and silt deposits;
- 3A - fine- to medium-grained sand beaches;
- 3B - scarps and steep slopes in sand;
- 5 - mixed sand and gravel beaches;
- 6A - gravel beaches (gravels and pebbles);
- 8A - sheltered scarps in bedrock, clay and silt deposits and sheltered rocky shore;
- 8D - sheltered rocky rubble shores;
- 9A - sheltered tidal flats;
- 10A - salt and brackish water marshes (laidy).

Changes the names of types of banks, made to their original names, can be considered minimal. This was achieved due to the "increase capacity" of individual concepts and generalization of the similar nature of the intended interaction with oil and petroleum products types of Bank. Foreign colleagues proposed a gradation of grain size of beach sediments in the name of banks, corresponding to the ESI indices, adopted that position. In the future, it will allow creating a unified typing of the coast of all seas of the Arctic Ocean that meets international standards.

Comparative analysis of morphodynamic and ecological types of banks showed that the same ecological types of banks could be allocated at different dynamic in relation to the land. For example, beaches, sprinkled with various particle size sand and gravel-pebble deposits are found both on accumulative and abrasion areas with dead or dying coastal ledge. This indicates the same level of environmental sensitivity of such banks. In some cases, the dynamic type of coast can match the coast with different environmental sensitivity index. Otherwise, there is regular correspondence of the individual type's dynamic and environmental banks, which allows the use of a pivot typing is to interpret a poorly known ecological sensitivity of coastal areas.

The length of the individual types of banks in the surveyed part of the coast of the Kara Sea. The most sensitive to oil pollution protected shallow alluvial, lacustrine-deltaic butovye and beach with extensive tidal foreshores and lidumi (indexes 9A and 10A) is more than 2000 km, which is about 20% of the total length of investigated shoreline. They are confined mainly to southern and Southwestern part of the Kara Sea. About the same and is the least sensitive of the abrasion and abrasion-denudation rocky shores of Islands and the northeastern coast (index 1A and 1C) – 2000 km and of the order of 20%. Abrasion and accumulative shores, and the shores with dead or dying cliffs composed of loose sediments of different composition, combine to form a large part of the coastline and are characterized by moderate susceptibility to oil spills. Arctic shores composed of dispersed frozen rocks are from the shores of the ice-free seas a number of specific features. Located in the high latitudes, they develop in short dynamic (ice-free) season, which is 5-10 times shorter than in the seas of temperate latitudes. In the winter months, ice and frozen substrate of the coastal zone block the activity of most relief-forming processes reduced the permeability of sediments for petroleum products. Accordingly, changing the nature of the interaction of the substrate with oil from season to season.

Covered by land fast ice for 6-9 months of the year the coast is almost not sensitive to oil spills in the water area, and are relatively insensitive to spills directly to coastal areas where land fast ice meets (corsets) with the bottom remaining fixed during the freeze-up. Thawing sediments of the upper part of the underwater slope and beach, and therefore the ability to accumulate oil on the shores of the Arctic seas, appears only in the short ice-free period of the year. At the same time possible and distribution of oil in the coastal zone, its direct contact with the shore. This period in the Kara region occurs in June-July and continues until mid-October-November (depending on local conditions). The warming is accompanied by intensive heat exchange of the permafrost with the atmosphere and hydrosphere - thaw of the active layer and activation of exogenous geological processes. It was during this period of time the sea shore are vulnerable from an environmental point of view to the probable oil spills, then the most actively developing morphodynamic coastal processes.

Thus, the presented ecological typification of Arctic coasts will be relevant only for the short ice-free period of the year with maximum depths of seasonal thawing of coastal sediments. This should be considered when developing spill response plans of oil, the probability of which is not restricted to the warm period of the year.

## V. CONCLUSION

Geomorphologic zoning of the coast of the Kara Sea and to assess their environmental sensitivity to oil spills, made in accordance with the system of indices of ESI, along with the decision of assigned tasks demonstrated the capability of this integrated approach in the development of sensitivity maps of the coast. The necessary consideration of the specific natural conditions (permafrost, lithodynamic, ice, etc.) development of the coastal zone and adaptation of the international system of indexes to the shores of the Arctic seas. But in general, ecological and geomorphological approach does not contradict the principles of the original method (IMO/IPECA/OGP) and allows to take into account how the particle size distribution of coastal sediments and the influence of excitement, and features of the dynamics of substances in the coastal zone, the direction of coastal processes, the morphology of the coastline and so This increases the accuracy of expert estimates of the sensitivity and forecast resilience of banks, but does not replace the recommended conduct field verification studies in the key areas. For the Arctic coasts of the latter circumstance is of particular importance because it allows to define more precisely the areas requiring priority protection from contamination.

Developed geomorphological typing of banks can be considered universal for the investigated area. With slight modifications, it can be used to assess sensitivity to oil pollution in the Arctic and other seas. We emphasize that the proposed ecological typification of current for a relatively short ice-free period of the year with maximum depths of seasonal thawing of coastal sediments (July-October). At this time, you can directly contact the oil spill with the coast, its distribution and accumulation in the coastal zone, blocked by land fast ice for much of the year.

In conclusion, it should be noted that zoning and mapping of the coast in accordance with the index of environmental sensitivity and development of spill response plans are only the first steps towards environmental safety of the Arctic coasts. Not less important are speed alerts, timely response to the spill and the application of the most efficient technologies of liquidation of oil spills in the far north, where carrying out any actions associated with a number of serious limitations.

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