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Ensuring Environmental Safety in the Arctic While Intensifying Spatial Development and Navigation along the Northern Sea Route

Svetlana A. Lipina¹, Dr. Sci. (Econ.), Professor

Alexandra V. Lipina², Cand. Sci. (Tech.), Associate Professor

Nikita M. Kuprikov³, Dr. Sci. (Econ.), Associate Professor, Senior Researcher

Natalia S. Avdonina⁴✉, Cand. Sci. (Polit.), Associate Professor

¹ All-Russian Research Institute of Environmental Protection, MKAD, 36 km, Str. 1, Bld. 4, Moscow, Russia

¹ Russian Foreign Trade Academy of the Ministry of Economic Development of the Russian Federation, ul. Levoberezhnaya, 32, Bld. 1, Moscow, Russia

² University of Science and Technology MISIS, Leninskiy pr., 4, Bld. 1, Moscow, Russia

³ Moscow Aviation Institute (National Research University), Volokolamskoe shosse, 4, Moscow, Russia

⁴ Northern (Arctic) Federal University named after M.V. Lomonosov, Naberezhnaya Severnoy Dviny, 17, Arkhangelsk, Russia

¹ s.lipina@mail.ru, ORCID: <https://orcid.org/0000-0002-8551-0653>

² a.v.lipina@mail.ru, ORCID: <https://orcid.org/0000-0003-0835-8878>

³ nkuprikov@yandex.ru, ORCID: <https://orcid.org/0000-0003-3152-0941>

⁴ n.avdonina@narfu.ru ✉, ORCID: <https://orcid.org/0000-0001-9871-345>

Abstract. The article examines current issues related to ensuring environmental safety in the Arctic in the context of intensifying economic activity and growing cargo traffic along the Northern Sea Route (NSR). The aim of the study is to formulate scientific and methodological recommendations for reducing and eliminating environmental risks, ensuring a balance between industrial development and the preservation of vulnerable Arctic ecosystems. The methodological basis of the work comprised a systems approach, an analysis of the Russian regulatory framework and international reports (AMAP, HELCOM, Arctic Council), a comparative analysis of environmental management practices in Norway, Canada, and the Baltic states. As a result of the study, 11 groups of environmental risks (climatogenic, operational, cumulative damage risks) have been systematized, and a comprehensive approach to their minimization has been developed. The proposed methodology integrates institutional, technological, and organizational measures, including improved monitoring using satellite systems and UAVs, implementation of “green” shipping technologies, elimination of accumulated pollution, and involvement of indigenous peoples in decision-making. It was concluded that the application of this approach will improve the effectiveness of strategic planning, strengthen the region’s environmental security and enhance Russia’s position in the Arctic. The results have practical significance for updating government programs and implementing infrastructure projects.

Keywords: *spatial development, strategic planning, sustainable development, environmental risks, management methods, integrated security, environmental safety, Arctic, Northern Sea Route*

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Introduction

The current stage of Arctic development is characterized by an intensification of economic activity, the resumption of year-round shipping along the Northern Sea Route (NSR), and large-scale infrastructure projects. These processes are enshrined in the Russian Federation's strategic documents — the Strategy for Developing the Russian Arctic Zone and Ensuring National Security until 2035 and the Strategy for Developing the Northern Sea Route — which set ambitious targets for cargo traffic growth and the comprehensive development of territories^{1,2}. However, the implementation of these tasks is taking place in the context of extremely vulnerable Arctic ecosystems, the resilience of which has been significantly reduced due to climate change and accumulated environmental damage (Kudryashova, Lipina, Zaikov, 2019)³. The theoretical foundation for understanding contemporary processes in the region was laid by works devoted to the strategic development of Russia's political space in the Arctic (Morozov, Kondral, 2014), the formation of Russia's Arctic strategy as a new type of policy (Podoplekina, Bestuzheva, 2014), as well as regional aspects, such as the policy of the Arkhangelsk Oblast (Zhuravlev, 2012). It is important to remember that these processes are based on a long history of regionalization in Northern Europe, the origins and dynamics of which are explored by F.H. Sokolova and E.A. Trufanova (Sokolova, Trufanova, 2025).

The paradox of the current situation is that, despite the presence of an extensive network of scientific institutes (AARI, "Floating University") and improved monitoring systems (satellite constellation, Roshydromet stations), existing mechanisms for managing environmental risks remain fragmented. They do not fully take into account the synergy of factors such as permafrost thawing, increased transit shipping, and transboundary spread of pollutants. A review of the literature shows that most studies either focus on the technical aspects of spill prevention or are descriptive in nature, documenting the deterioration of the environment. Comprehensive methodologies that integrate strategic planning with environmental protection measures and are adapted to Russian conditions have not yet been developed.

The Arctic and Antarctic Research Institute (AARI) plays a key role in scientific activities in the Arctic. Originally specializing in organizing expeditions, the institute now combines this work with the continuous monitoring of environmental conditions through a network of fixed and drifting stations. AARI regularly conducts marine expeditions and participates in international discussions on these topics. In 2012, NArFU launched the "Arctic Floating University" project, combining an educational program and interdisciplinary natural science research in the Arctic. The project explores pressing issues ranging from the spread of microplastics to climate change. The institu-

¹ Strategy for Developing the Russian Arctic Zone and Ensuring National Security until 2035 (approved by Decree of the President of the Russian Federation No. 74 of February 26, 2020). URL: <http://www.kremlin.ru/acts/bank/45972> (accessed 01 October 2025).

² Strategy for Developing the Northern Sea Route until 2035 (approved by Decree of the Government of the Russian Federation No. 1097-r of April 28, 2020). URL: <http://government.ru/docs/46171/> (accessed 01 October 2025).

³ Arctic Council. (2017). Arctic Marine Shipping Assessment Report. URL: <https://arctic-council.org/projects/arctic-shipping-status-reports/> (accessed 01 October 2025).

tional foundations for modern research, such as the work of the Arctic and Antarctic Research Institute and the “Arctic Floating University” project, were laid decades earlier. As A.A. Saburov notes, active planning and coordination of Arctic scientific expeditions were already underway in Soviet Russia in the 1920s (Saburov, 2016).

In August 2022, a plan for the development of the NSR until 2035 was approved, providing for the creation of a state environmental monitoring system for the waterways under the leadership of the Ministry of Natural Resources and Environment and Rosatom. Currently, monitoring covers the state of the atmosphere, water, and radiation conditions. In addition, the federal project “Clean Air” is being implemented, with the aim of reducing emissions and improving the environment through energy modernization and gasification of the private sector. The results are recorded by an extensive network of monitoring stations⁴.

Surface water quality is monitored at numerous stations in the Barents and East Siberian regions, where hydrochemical and hydrobiological parameters are analyzed, including the state of phytoplankton, zooplankton, and zoobenthos. Radiological monitoring is carried out at 94 sites, providing a comprehensive assessment of the environmental situation.

Therefore, a contradiction arises between the strategic focus on accelerated spatial development of the Arctic and the need to preserve its ecosystems. Resolving this contradiction requires the development of a new approach that integrates legal requirements, best international practices, and modern monitoring technologies into a unified risk management system.

The scientific novelty of the study lies in the systematization of 11 groups of environmental risks in the Arctic, taking into account the synergistic effects between climatogenic, operational and cumulative factors; in the development of a comprehensive approach to risk reduction, integrating institutional, technological and organizational measures, adapted to Russian legal and natural-climatic conditions; in the justification of the possibilities and limitations of adapting international practices (Norway, Canada, HELCOM) for the Northern Sea Route based on a comparative analysis with specific quantitative indicators.

The aim of this article is to develop scientific and methodological recommendations for reducing and eliminating environmental risks in the Arctic and in the waters of the Northern Sea Route, ensuring a balance between industrial development and the preservation of the natural environment. To achieve this aim, the following tasks were carried out: an analysis of the current environmental situation and strategic documents was conducted, key risk groups were systematized, and a set of risk minimization measures was proposed, taking into account Russian institutional conditions and international experience.

⁴ The Northern Sea Route: what it is and how it works today. URL: <https://www.rbc.ru/base/10/09/2025/68c075ee9a79472708d42f86> (accessed 20 February 2026).

Materials and methods

As part of the study, a comprehensive analytical review was conducted to examine and systematize the regulatory and legal acts, strategic documents and scientific and methodological recommendations regulating the spatial development of the Arctic region and ensuring environmental safety along the Northern Sea Route (NSR).

The first stage involved a regulatory and legal analysis of strategic documents defining the vectors of spatial development of the Arctic zone of the Russian Federation and regulating environmental safety requirements. The empirical base included:

- Federal Law No. 193-FZ “On the Arctic Zone of the Russian Federation”⁵;
- Decree of the President of the Russian Federation No. 164 “On the Fundamentals of the State Policy of the Russian Federation in the Arctic until 2035”⁶;
- Strategy for Developing the Russian Arctic Zone and Ensuring National Security until 2035⁷;
- Strategy for Developing the Northern Sea Route until 2035⁸;
- Passport of the National Project “Ecology”⁹.

The aim of the analysis was to identify target indicators in the field of environmental protection, as well as to determine existing regulatory gaps requiring the development of additional tools.

In the second stage, data on environmental risks specific to the Arctic region were collected and systematized. The source base included:

- scientific publications on climate change in high latitudes, anthropogenic impact and the state of biodiversity;
- reports from international organizations: the Arctic Council (Arctic Marine Shipping Assessment, 2017)¹⁰, the Helsinki Commission (HELCOM, 2018)¹¹, and the UN Environment Programme (UNDP Arctic Initiative, 2020)¹²;

⁵ Federal Law No. 193-FZ “On the Arctic Zone of the Russian Federation”. URL: <http://www.kremlin.ru/acts/bank/45677> (accessed 01 October 2025).

⁶ Decree of the President of the Russian Federation No. 164 of March 5, 2020 “On the Fundamentals of the State Policy of the Russian Federation in the Arctic until 2035”. URL: <http://www.kremlin.ru/acts/bank/45255> (accessed 01 October 2025).

⁷ Strategy for Developing the Russian Arctic Zone and Ensuring National Security until 2035 (approved by Decree of the President of the Russian Federation No. 74 of February 26, 2020,). URL: <http://www.kremlin.ru/acts/bank/45972> (accessed 01 October 2025).

⁸ Strategy for Developing the Northern Sea Route until 2035 (approved by Decree of the Government of the Russian Federation No. 1097-r of April 28, 2020). URL: <http://government.ru/docs/46171/> (accessed 01 October 2025).

⁹ National Project “Ecology”. URL: https://www.mnr.gov.ru/activity/np_ecology/ (accessed 01 October 2025).

¹⁰ Arctic Council. (2017). Arctic Marine Shipping Assessment Report. URL: <https://arctic-council.org/projects/arctic-shipment-status-reports/> (accessed 01 October 2025).

¹¹ HELCOM. (2018). Baltic Sea Action Plan. URL: <https://helcom.fi/baltic-sea-action-plan/> (accessed 01 October 2025).

¹² UNDP Arctic Initiative. (2020). Community Engagement and Environmental Stewardship in the Arctic. URL: https://oaarchive.arctic-council.org/bitstream/handle/11374/2614/arctic-resilience-forum-2020_web.pdf (accessed 01 October 2025).

- materials from national environmental agencies (Environment Canada¹³, Norwegian Maritime Authority¹⁴), containing descriptions of successful adaptive management practices.

Content analysis was used to process this diverse information, enabling the identification of recurring threat patterns and their structuring according to source: climate-related, operational (related to shipping and extraction), and accumulated (historical pollution).

In the third stage, a comparative analysis method was applied to study international approaches to minimizing environmental risks in Arctic and subarctic conditions. Case studies from Norway (implementation of electric shipping and hybrid technologies), Canada (adaptive infrastructure management plans), Sweden, and Finland (limiting noise impact in the Baltic Sea as an analogy for Arctic waters) were considered. The selection criteria included the availability of documented results, similarity of natural and climatic conditions, and potential applicability within the Russian institutional environment.

In the fourth stage, the obtained data was synthesized, resulting in the development of a set of measures to reduce environmental risks. This approach is presented in the form of a classification table (Table 1), in which each of the eleven identified risk types is matched with a list of measures differentiated by functional criteria:

- institutional (improving the regulatory framework, creating coordinating bodies);
- technological (implementing innovative monitoring systems, wastewater treatment facilities, and noise-free equipment);
- organizational and preparatory (staff training, conducting exercises, public awareness campaigns).

The methodological basis of the study was a systems approach to assessing and managing environmental risks, which involves integrating various planning levels — from strategic to operational. This approach took into account the specific features of the region's spatial development, including changing climate conditions, increased shipping along the NSR, and the development of infrastructure and the extractive industry. The study additionally utilized comparative analysis, systems modeling, and expert assessment, ensuring the comprehensiveness and objectivity of the results.

The approach applied takes into account both natural and anthropogenic factors influencing the ecosystem's condition, and contributes to the formulation of balanced management decisions regarding spatial development and the sustainable management of the Arctic region.

¹³ Environment Canada. (2019). Canada's Adaptation Strategy for the Arctic. URL: <https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/national-adaptation-strategy/action-plan.html> (accessed 01 October 2025).

¹⁴ Norwegian Maritime Authority. (2021). Green Shipping Initiatives in Norway. URL: <https://www.wcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/The%20Governments%20action%20plan%20for%20green%20shipping.pdf> (accessed 01 October 2025).

Discussion

The intensification of Arctic economic development, reflected in the unprecedented growth of cargo traffic along the Northern Sea Route, is creating a fundamentally new context for ensuring the region's environmental security. The increase in shipping volumes from 4 million tons in 2014 to nearly 38 million tons in 2024¹⁵ and the strategic goal of reaching 70–100 million tons by 2030¹⁶ indicate the transformation of the Northern Sea Route into a fully-fledged transport corridor of global significance. However, such a large-scale increase in shipping objectively increases the pressure on vulnerable Arctic ecosystems, which requires adequate improvements to risk management mechanisms. The set of measures proposed in this study represents an attempt to provide a comprehensive response to this challenge; nevertheless, its viability should be assessed within the context of current data, international experience and existing institutional constraints. It is important to understand that the current intensification of NSR use is not an isolated phenomenon, but a new stage in a long-term historical and geopolitical process. Researchers such as V.I. Goldin consider the evolution from the North-Eastern Passage to the modern Northern Sea Route as a process the significance of which has been understood for millennia (Goldin, 2024). Moreover, as N.M. Terebikhin demonstrates, the very logic of the development of these spaces can be understood through the prism of the “north-eastern text” of Russian geo-historiosophy and sacred geography (Terebikhin, 2023).

Analysis of the latest scientific data confirms that the problem of anthropogenic impact on the Arctic is not limited to direct threats associated with shipping. Research by the Arctic Monitoring and Assessment Programme (AMAP) demonstrates the presence of high concentrations of persistent organic pollutants in indigenous populations of Greenland, Nunavik, Canada, and coastal areas of Chukotka (Adlard, Bonefeld-Jørgensen, Dudarev et al., 2024). This fact is particularly significant in the context of the developed approach, as it highlights the presence of at least two interrelated problems. Firstly, despite an overall decline in emissions of “classical” POPs, their accumulation in food chains continues to impact human health and biodiversity. Secondly, the existence of transboundary transfer of toxicants emphasizes the inadequacy of national measures and the need to coordinate efforts at the international level — even in circumstances where political cooperation is considerably complicated.

Russia, which accounts for a significant portion of the Arctic coastline and the region's population, continues to implement its own development strategy, relying on the potential of national scientific institutions and interaction with friendly observer states. In this regard, issues of information security and transboundary cooperation are particularly important. As A.M. Tamitskiy notes, information security is a crucial factor in contemporary international relations in the Arctic (Tamitskiy, 2013; Tamitskiy, 2014). The historical experience of similar cross-border interaction, for

¹⁵ Decree of the President of the Russian Federation No. 164 of March 5, 2020 “On the Fundamentals of the State Policy of the Russian Federation in the Arctic until 2035”. URL: <http://www.kremlin.ru/acts/bank/45255> (accessed 01 October 2025).

¹⁶ Ibid.

example, between Norway and Russia in the Far North, including its socio-cultural dimension, has been examined in detail by V.V. Tevlina (Tevlina, 2012).

In these circumstances, the role of networks such as SAON¹⁷ and AMAP, which maintain a scientific rather than political nature of interaction, becomes critically important. The developed set of measures takes this reality into account: the emphasis on establishing an interagency coordination center and improving the national monitoring system reflects the desire to ensure the sovereignty of environmental data while maintaining the possibility of integrating it into international databases as trust is restored.

International experience allows us to verify certain provisions of the proposed set of measures and identify areas for further improvement. Norwegian practice of electrifying¹⁸ shipping and creating shore-based power supply infrastructure for ports confirms the potential of technological measures outlined in the sections on promoting green technologies and reducing atmospheric emissions. Canadian developments, in particular the POLARIS methodology and its further development in the work of Kubat and co-authors¹⁹, who propose integrating into risk models not only the probability of vessel damage, but also the potential consequences for human life and the environment, are of direct interest to Russian practice in planning ice navigation. Besides, HELCOM's standardized approaches to noise pollution monitoring using octave bands to assess impacts on marine mammals can be adapted when implementing the relevant set of measures, as Russian practice does not yet have similar regulations. Overall, as M.M. Panikar emphasizes, we are currently witnessing processes of profound transformation in the international Arctic region and the formation of its new geopolitical contours (Panikar, 2023), which requires flexibility in adapting any international methodologies.

The socio-cultural dimension of environmental security deserves particular attention in this discussion, as it is not always adequately reflected in technically oriented strategies. The uniqueness of the Arctic Council lay in granting indigenous peoples' organizations the status of Permanent Participants, which ensured the integration of traditional knowledge into the decision-making process. In Russian practice, mechanisms for such participation are significantly less developed, and the proposed set of measures includes a component aimed at environmental education, public consultations and support for initiatives by indigenous communities. Implementing this set of measures can not only enhance the legitimacy of decisions taken but also ensure that local

¹⁷ SAON. Sustaining Arctic Observing Networks: Strategic Plan 2022–2030. 2022. URL: <https://www.arcticobserving.org> (accessed 01 October 2025).

¹⁸ Norwegian Maritime Authority. (2021). Green Shipping Initiatives in Norway. URL: <https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/The%20Governments%20action%20plan%20for%20green%20shipping.pdf> (accessed 01 October 2025).

¹⁹ Kubat I., Babaei M.H., Sayed M., Millan J. A framework for integrating life-safety and environmental consequences into conventional Arctic shipping risk models. National Research Council of Canada Publications. 2025. URL: <https://publications-cnrc.canada.ca/eng/view/object/?id=2d7abf8f-4002-4204-8817-bdc7aa02f8ba> (accessed 01 October 2025).

knowledge about the state of the environment is taken into account, which is particularly valuable given the limited network of fixed observation stations.

The comparative analysis conducted allows for a specific assessment of the applicability of international practices in the Russian context. Norway's experience of electrifying shipping and introducing onshore power supply in ports demonstrates a 35–40% reduction in CO₂ emissions in port areas. However, its direct application to the Northern Sea Route is complicated by the lack of shore-based power generation in most Arctic ports (Murmansk and Arkhangelsk being the exceptions), as well as the need to modernize ships' power systems. The Canadian POLARIS methodology, which takes into account not only the likelihood of vessel damage but also the consequences for life and the environment, has reduced accidents by 22% over five years. Its implementation in Russia requires adaptation to the national ice classification of vessels and NSR navigation regulations, which is possible with the support of relevant scientific organizations (AARI, Krylov Center) in the medium term. HELCOM standards for monitoring noise pollution using octave bands are technically feasible, but are not yet supported by Russian regulations and lack trained personnel; therefore, their implementation will take at least three to five years and will require the creation of national regulations. Thus, the Canadian approach to integrated risk assessment has the highest degree of adaptation readiness (medium level), while the Norwegian and Baltic practices require significant infrastructure and regulatory investments (low readiness in the short term).

Whilst the proposed measures are well-founded, it is important to be aware of the limitations of the study. The proposed set of measures is conceptual in nature and requires a quantitative assessment of implementation costs, which necessitates separate economic calculations. The effectiveness of technologies such as bioremediation under low-temperature conditions should be empirically tested in the Arctic's natural environment, as laboratory data are not always reproducible in the real world. Furthermore, this study deliberately did not rank risks according to their severity and the urgency of response; this area may become the subject of further research using multi-criteria analysis methods.

Therefore, it can be argued that the implementation of the proposed set of measures requires a phased approach. In the short term (1–3 years), the top priorities are the establishment of an interdepartmental coordination center and the updating of the regulatory framework in accordance with the requirements of the Polar Code. The medium-term phase (up to 2030) should be devoted to the deployment of a full-scale monitoring system and the launch of remediation programs for the most hazardous sites where damage has been accumulated. In the long-term phase (up to 2035 and beyond), it is advisable to complete the transition of shipping to environmentally friendly fuels and ensure the integration of the Russian monitoring system into international research networks. Interdepartmental cooperation, involvement of independent experts and active participation of all stakeholders — including the scientific community, industrial enterprises and the indigenous peoples of the North — are essential for success at every stage.

Results

The study systematized the environmental risks associated with the intensification of economic activity in the Arctic zone of the Russian Federation and along the Northern Sea Route, and developed a set of measures to mitigate and eliminate these risks, adapted to Russia's institutional framework and the region's natural and climatic characteristics. The implementation of large-scale projects to eliminate this damage, in particular, the clean-up of Arctic territories, has become an important part of contemporary state policy, and the imperatives of this policy regarding the development of the Far North are analyzed by M.M. Panikar and A.E. Shaparov (Panikar, Shaparov, 2016).

Based on an analysis of scientific literature, international reports, government monitoring data, and expert assessments, 11 risk groups were identified, classified by their sources and mechanisms of impact on ecosystems. The proposed classification takes into account not only isolated threats, but also their synergistic effects, which are characteristic of polar regions.

Contemporary development of the Arctic is associated with the impact of a complex set of natural and anthropogenic factors, forming a multi-component system of environmental risks. This system is typically divided into several key categories, each distinguished by specific sources of hazard and mechanisms of environmental impact. Climate-related risks are currently acting as a fundamental driver of change, as climate parameters are rapidly transforming at high latitudes. In particular, the increase in average annual temperatures in the Arctic exceeds the global average by two to three times²⁰, leading to permafrost degradation, accompanied by a reduction in soil bearing capacity by up to 50% in some areas, as well as a reduction in the area and thickness of the ice cover. According to satellite monitoring data, the area of Arctic sea ice in September has decreased by 13% over the past twenty years, significantly altering the hydrological regime and increasing the frequency of hazardous events, including storms and ice shifts, requiring constant adjustments to infrastructure construction and operation standards.

Along with climate change, pressure from operational risks directly related to the intensification of shipping and industrial activity is increasing. The growth of cargo traffic along the Northern Sea Route from 4 million tons in 2015 to 34 million tons in 2022 proportionally increases the likelihood of accidents, the most dangerous of which are spills of heavy fuel oils, which can persist in Arctic conditions for decades²¹ (Zhuravlev, 2012). Ship engines and industrial facilities emit sulfur dioxide, nitrogen oxides, and black carbon into the atmosphere, the deposition of which on ice and snow reduces the surface albedo and accelerates melting. Furthermore, physical impacts in the form of noise pollution from ship engines and vibration during icebreaking operations create a chronic stress factor for marine mammals, disrupting their communication, orientation, and re-

²⁰ AMAP. Arctic Climate Change Update 2021: Key Trends and Impacts. Summary for Policy-makers. Arctic Monitoring and Assessment Programme, Tromsø, Norway. 2021. URL: <https://www.amap.no/documents/doc/arctic-climate-change-update-2021-key-trends-and-impacts.-summary-for-policy-makers/3508> (accessed 01 October 2025).

²¹ Arctic Council. Arctic Marine Shipping Assessment Report. 2017. URL: <https://arctic-council.org/projects/arctic-shipping-status-reports/> (accessed 01 October 2025).

productive cycles. The increase in cargo traffic and the number of crew members also leads to the accumulation of solid municipal and industrial waste, the disposal of which is extremely difficult in the absence of developed infrastructure.

A special category of risks arises from the accumulated environmental damage caused by decades of economic activity during the Soviet and post-Soviet periods. As a result, persistent pollution sources have emerged in the form of abandoned military facilities, fuel and lubricant depots, and unauthorized landfills, leading to the accumulation of petroleum products, heavy metals and polychlorinated biphenyls in concentrations exceeding maximum permissible levels by five to ten times in local areas²² (Zhuravleva, Artyushina, Vinogradova et al., 2020). The situation is exacerbated by transboundary transfers, in which air and sea currents bring persistent organic pollutants from industrial regions of Europe, Asia, and North America to the Arctic. These toxicants are accumulated in food chains, reaching maximum concentrations in the bodies of predators and indigenous populations consuming traditional foods. Socio-ecological risks further complicate the overall picture, manifesting themselves in the reduction of biodiversity, the erosion of the resource base for traditional natural resource management, personnel shortages, and the technological backwardness of monitoring systems.

A key feature of the Arctic region is the high degree of interdependence between various risk groups, with climate change acting as a catalyst, amplifying the negative impacts of anthropogenic factors. Permafrost degradation reduces the resilience of infrastructure, increasing the likelihood of man-made accidents and fuel spills²³ (Kudryashova, Lipina, Zaikov, et al., 2019); shrinking ice cover opens up new waters for shipping, creating additional pressure on previously undisturbed ecosystems. Rising water temperatures accelerate biogeochemical processes, increasing the mobility of toxicants and their entry into food chains, while melting glaciers and permafrost releases previously sequestered pollutants, creating a secondary pollution effect. Taking these interrelationships into account is a prerequisite for developing effective management solutions, as fragmented measures aimed at isolating a single risk will not produce the expected result without simultaneously addressing related factors.

The developed set of measures to reduce and eliminate environmental risks represents a comprehensive tool that integrates regulatory, technological, and organizational measures into a single management system, the structure of which is based on the principles of adaptive management and provides for the differentiation of measures according to their functional purpose, implementation timeframe, and levels of responsibility. This approach corresponds to contemporary research on Arctic identity, where, as S.V. Shachin demonstrates, analyzing the history and

²² AMAP. Arctic Climate Change Update 2021: Key Trends and Impacts. Summary for Policy-makers. Arctic Monitoring and Assessment Programme, Tromsø, Norway. 2021. URL: <https://www.amap.no/documents/doc/arctic-climate-change-update-2021-key-trends-and-impacts.-summary-for-policy-makers/3508> (accessed 01 October 2025).

²³ Roshydromet. Review of the State and Pollution of the Environment in the Russian Federation for 2021. Moscow: Roshydromet. 219 p. URL: https://www.meteorf.gov.ru/upload/iblock/88f/O63op%203a%202024%20год_300625.pdf (accessed 01 October 2025).

present-day situation of the North from the perspective of dialectical methodology allows for the complexity and contradictions of the region's development processes to be taken into account, which is crucial for formulating flexible management solutions (Shachin, 2019). The set of measures is based on a systematized list of measures, grouped by functional criterion into 11 blocks corresponding to specific risk categories. Institutional measures include improving the regulatory framework, creating coordinating structures, and developing standards aligned with the international requirements of the IMO Polar Code²⁴ and HELCOM recommendations. Technological measures are aimed at implementing continuous monitoring systems using satellite constellations, drones, and automated buoy stations, applying treatment technologies based on bioremediation and phytoremediation, and switching to environmentally friendly fuels. Organizational and preparatory measures include personnel training, regular exercises, environmental education of the population, and the creation of mechanisms for involving indigenous peoples in decision-making processes, which ensure the necessary level of information transparency and emergency preparedness. Table 1 lists the measures for each risk group in descending order of priority: from institutional (regulatory and legal framework) through technological (monitoring and treatment systems) to organizational and preparatory (training, exercises, and public awareness). The ranking is based on the authors' expert assessment, taking into account the implementation timeframes (short-term — institutional, medium-term — technological, long-term — organizational) and the degree of impact on risk reduction.

Table 1

Measures for implementation of scientific and methodological recommendations on reducing environmental risks in the Arctic and on the NSR

No.	Environmental risks	Measures in order of priority and significance
1	Monitoring and adaptation to climate change	- analysis of existing monitoring systems in Russia (e.g., Roshydromet, Arctic and Antarctic Research Institute); - development of requirements for expanding the network of automated stations and incorporating satellite data, taking into account integration with international platforms (e.g., Arctic Observing Network); - establishment of an interagency coordination center for climate monitoring, consolidating data from various organizations; - implementation of adaptive management through regular updates of norms and standards, taking into account new climate scenarios; - personnel training and preparation of specialists to work with modern monitoring technologies
2	Prevention and response to fuel spills	- updating the regulatory framework (e.g., Federal Law No. 7-FZ "On Environmental Protection") to take into account the IMO MARPOL international standards; - development and testing of bioremediation technologies and sorbents adapted to Arctic conditions, in collaboration with leading research centers; - creation of regional emergency response units equipped with specialized equipment;

²⁴ IMO. International Code for Ships Operating in Polar Waters (Polar Code). London: International Maritime Organization. 2015. URL: <https://www.imo.org/en/ourwork/safety/pages/polar-code.aspx> (accessed 01 October 2025).

		- organization of regular exercises in collaboration with the private sector and military units; - implementation of a satellite and drone monitoring system for rapid detection of incidents
3	Reduction of atmospheric pollutant emissions	- development of incentive mechanisms for the transition to LNG and alternative fuels (tax breaks, subsidies); - tightening control and monitoring of emissions through the installation of automated monitoring systems on vessels and industrial sites; - modernizing port infrastructure to receive and process marine fuel with minimal emissions; - conducting scientific research to assess impacts and develop local emission standards
4	Elimination of accumulated background pollution	- mapping contaminated areas and prioritizing remediation planning; - implementation of innovative soil and water treatment technologies (phytoremediation, microbiological methods); - attracting funding through government programs and international grants (e.g., BRICS Bank); - monitoring the effectiveness of measures using digital platforms
5	Minimisation of the impact of physical factors	- development and adoption of standards for noise and vibration in the marine environment, taking into account the recommendations of HELCOM and the International Maritime Organization; - implementation of noise reduction technologies on vessels and industrial equipment; - identification and prohibition of navigation in particularly sensitive areas during specific periods of animal migration; - educating shipowners and operators on the need to comply with these standards
6	Reduction of water pollution and transboundary transfer of toxins	- development and implementation of comprehensive wastewater treatment and discharge control programs; - use of modern technologies for the treatment and restoration of aquatic ecosystems; - ensuring transparency and accessibility of monitoring data for stakeholders
7	Waste management	- creation of regional waste management centers taking into account climatic conditions; - introduction of a system for separate waste collection and recycling, including incentives for businesses and the public; - organization of educational campaigns and training on waste management issues; - monitoring and reporting on the volume and quality of recycled waste
8	Combating chemical pollution and preserving biodiversity	- strengthening control over the use and disposal of hazardous substances; - expanding the network of specially protected natural areas and establishing buffer zones around key ecosystems; - support for scientific research and monitoring of biodiversity; - involvement of local communities in nature conserva-

		tion programs
9	Increasing environmental education and public participation	• development and implementation of educational programs in schools and universities across the region; • organization of public hearings and consultations on environmental policy; • creation of platforms for information exchange and engagement of indigenous peoples and local residents; • support for NGO and environmental organization initiatives
10	Improving the technological infrastructure for monitoring and response	• investing in digital technologies, including AI and Big Data for environmental data analysis; • creation of a unified, integrated, open-access monitoring platform; • training personnel to use modern monitoring and response systems; • organization of emergency centers to coordinate responses to environmental incidents
11	Promoting the implementation of environmentally friendly technologies	• development of government programs to support innovation and environmentally friendly technologies; • introduction of tax incentives and subsidies for businesses implementing green technologies; • promotion of international cooperation and technology transfer; • organization of competitions and grant programs for innovative projects

The proposed system of measures to ensure the environmental safety of shipping and economic activity in the waters of the Northern Sea Route is based on four key areas, which form a comprehensive set of technological, regulatory, and organizational solutions. Fundamental importance is attached to the creation of a three-level system for monitoring and adapting to climate change, as the timeliness and reliability of environmental data determine the effectiveness of all subsequent environmental protection measures. This system includes a space-based system using remote sensing satellites (“Arktika-M” and “Meteor” series) to monitor ice conditions, surface temperature and concentration of pollutants in the atmosphere; an aerial system using unmanned aerial vehicles for detailed surveys of localized areas; and land-based and marine systems relying on the expansion of the network of automated hydrometeorological stations and drifting buoys. It is proposed that the coordination of data collection and processing should be entrusted to an interdepartmental center under the Ministry of Natural Resources and Environment of the Russian Federation, with the participation of Roshydromet, the Rosatom State Corporation, and scientific organizations (AARI, All-Russian Research Institute “Ecology”). This will ensure regular updates of climate scenarios and economic activity standards.

The second area focuses on the prevention and response to fuel spills, where a set of measures is aimed at reducing the likelihood of accidents and minimizing damage. Key elements include the implementation of technical standards, such as the requirement for double hulls on all tankers and equipping them with automatic leak detection systems, as well as the establish-

ment of a network of regional emergency response centers in major ports with specialized vessels and equipment on permanent duty. Particular attention is paid to response technologies, including the use of biological remedies based on psychrophilic microorganisms and peat-based sorbents, and regular interagency exercises to practice coordination under conditions of polar night and low temperatures.

The third set of measures focuses on reducing atmospheric emissions of pollutants by encouraging the transition of vessels and port infrastructure to environmentally friendly fuels. This involves the introduction of economic incentives, including reduced port charges for vessels powered by liquefied natural gas and electric propulsion, subsidized conversions, and tax breaks. Meanwhile, it is proposed to tighten regulatory requirements by limiting the sulfur content in fuel to 0.1% in the NSR waters and mandating the installation of scrubbers on ships over a certain age, as well as developing onshore infrastructure to provide ships with electricity while moored.

The final area of focus involves the systematic elimination of accumulated background contamination through public-private partnerships. The work involves conducting an inventory and creating a digital register of contaminated sites, assigning a hazard class to each site, applying modern remediation technologies (phytoremediation, microbiological treatments, waste encapsulation), and diversified financing. The financial basis should consist of federal budget funds from the “Clean Country” project, compensation funds from subsoil users, and the attraction of international grants and loans through the Green Climate Fund or the BRICS Bank.

Interagency cooperation is a key condition for successful implementation. It is proposed to establish a permanent working group on Arctic environmental safety under the Government of the Russian Federation, including representatives from the Ministry of Natural Resources, the Ministry of Transport, the Ministry for the Development of the Russian Far East, the Ministry of Emergency Situations, the Rosatom State Corporation, the Russian Academy of Sciences, indigenous peoples’ organizations, and shipowners’ associations.

The developed set of measures can serve as a basis for updating existing strategic documents (the Strategy for Developing the Russian Arctic Zone, the Northern Sea Route Development Plan) and formulating new federal and regional programs in the field of Arctic environmental safety, as well as being used in the preparation of project documentation for specific investment projects in the region. As V.I. Goldin rightly notes in a recent publication on the relationship between “the Arctic — Regions”, it is impossible to fully comprehend contemporary challenges and prospects without taking into account the diversity of regional aspects and their integration into the overall Arctic agenda (Goldin, 2024).

Conclusion

This study, aimed at developing scientific and methodological recommendations for ensuring environmental safety in the Arctic and along the Northern Sea Route in the context of intensifying spatial development, allows formulating the following conclusions.

As a result of a comprehensive analysis of the current state of the natural environment, strategic documents of the Russian Federation and international reports, 11 groups of environmental risks associated with the development of the Arctic region have been identified. The risks are classified according to their sources: climatogenic (degradation of permafrost, reduction in ice cover, increased frequency of hazardous hydrometeorological phenomena), operational (fuel spills, emissions of black carbon and greenhouse gases, noise pollution, waste accumulation), cumulative damage risks (background contamination of soils and water bodies, transboundary transfer of persistent organic pollutants and heavy metals) and socio-environmental risks (loss of biodiversity, threats to indigenous peoples' traditional use of natural resources, a shortage of skilled personnel and technological backwardness of monitoring systems). It has been established that these risks are characterized by a high degree of interdependence and synergistic effects, with climate change acting as a catalyst, significantly amplifying the negative impact of anthropogenic factors.

Analysis of current data (2024–2025) identifies a number of key challenges requiring a scientifically based response:

- the rapid growth of cargo traffic along the Northern Sea Route (38 million tons in 2024), while maintaining a significant share of hydrocarbon cargoes, requires improved navigation safety systems and preparedness for emergency spill response;
- the increase in shipping traffic highlights the need to monitor the technical condition of vessels and ensure compliance with environmental standards by all parties involved in the transportation process;
- the use of various types of marine fuel and their impact on the Arctic environment require further study and development of optimal technical solutions, taking into account the climatic characteristics of the region;
- recent studies by AMAP and Adlard et al. have documented the presence of long-chain perfluoroalkyl substances (PFAS) in the bodies of the Arctic population, which necessitates the inclusion of these substances in national monitoring programs and the development of appropriate control methods.

The development of the environmental safety system in the Arctic is taking place within the context of changing international relations. At the same time, opportunities for scientific collaboration through specialized research networks (AMAP, SAON) and bilateral cooperation with friendly states are still available. The Russian Federation is consistently implementing its sovereign policy in the Arctic, relying on its own scientific and technological competencies, and devel-

oping partnerships with interested countries. In these specific circumstances, the role of national monitoring systems, their technical upgrading, and integration with international databases is becoming critically important for ensuring global environmental security.

The authors propose an approach to reducing and eliminating environmental risks (Table 1), characterized by the integration of three types of measures: institutional, technological, and organizational-preparatory. The proposed approach is based on an adaptive principle that allows for the adjustment of management decisions as new monitoring data becomes available and climate scenarios change.

The comparative analysis confirms the feasibility of adapting successful international practices to Russian conditions:

- Norway's experience of electrifying shipping and introducing onshore power supply in ports can be studied and applied in Murmansk, Arkhangelsk, and other key NSR ports, taking into account Russian specifics;
- the POLARIS methodology and Canadian developments on integrating accident impact assessments into voyage planning are of interest for improving Russian navigation regulations in Arctic conditions;
- standardized approaches to noise pollution monitoring developed by HELCOM can be adapted to Russian practice for the protection of marine mammals.

The comprehensive approach that has been developed is a practical tool that can form the basis for implementing a whole range of management and project-related decisions at various levels. First and foremost, its provisions can serve as a scientifically justified foundation for updating key strategic planning documents, such as the Strategy for Developing the Russian Arctic Zone until 2035 and the Northern Sea Route Development Plan until 2035. This will allow for not only the declaration, but also the inclusion of specific measurable environmental safety indicators, as well as clearly defined mechanisms for achieving them, thereby increasing the effectiveness of public administration in the region.

At the level of implementing specific infrastructure projects, the proposed approaches can be used in developing technical specifications and conducting expert assessments for projects. Integrating this set of measures into these processes ensures that environmental risks are assessed and taken into account during the design stage rather than at the final stages, significantly reducing potential damage and subsequent remediation costs. Furthermore, this approach serves as the basis for developing targeted regional programs aimed at addressing the most pressing issues: from organizing waste management systems and remediating areas with accumulated environmental damage to preserving biodiversity, whilst actively utilizing public-private partnership mechanisms.

Finally, an equally important area of application is the development of human capital. The materials and conclusions contained in the developed approach can be adapted to create specialized educational programs aimed at improving the skills of specialists working in Arctic

conditions. At the same time, this opens up opportunities for the development of environmental education programs for local population, including for the indigenous peoples of the North, which will promote a responsible attitude towards the environment and the sustainable development of the region as a whole.

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