Influence of the bottom relief on the formation of the navigable routes network in the water area of the Northern Sea Route

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Abstract. The paper is devoted to the study of the influence of the bottom relief on the formation of the navigable routes network in the water area of the Northern Sea Route. A brief historical overview of the main stages of mapping the bottom relief of the Arctic seas in the interests of the Arctic shipping development is given. The results of the bottom relief survey are summarized. A high degree of hydrographic knowledge of the coastal routes, intended for use by vessels with a draft of 6-7 meters in summer, is noted. The navigation and hydrographic conditions for the development of the navigable routes network intended for large-capacity vessels with a large draft are determined. Data on the cartographic study of the water area of the Northern Sea Route, basic information on the depths distribution over the Arctic seas area, as well as information on areas with insufficient hydrographic study, are given. The principles of formation of the shipping routes network of large-tonnage vessels in the water area of the Northern Sea Route are formulated. Recommendations on aligning the level of hydrographic knowledge into line with the requirements of navigation safety of large-tonnage shipping at promising projects implementation are presented. The results of research can be used for planning the hydrographic works and the development of a promising network of shipping routes in the Arctic basin.

1. Introduction
The water area of the Northern Sea Route (NSR) includes the water area adjoining to the northern coast of the Russian Federation. It covers the internal sea waters, the territorial sea, the adjacent zone and the exclusive economic zone of the Russian Federation. It is bounded to the east by the delimitation line of the sea spaces with the United States of America and by the parallel of Dezhnev Cape in the Bering Strait. It is bounded to the west by the Meridian of the Cape Zhelaniya to the archipelago of Novaya Zemlya, by the eastern coastline of the archipelago of Novaya Zemlya and by the western borders of the Matochkin Strait, the Kara Strait and the Yugorsky Strait [1].

The NSR runs through the Kara Sea, the Laptev Sea, the East Siberian and Chukchi seas, as well as the northeastern part of the Barents Sea and the northern part of the Bering Sea. The length of the NSR varies from 2700 miles for circumpolar routes to 3500 miles for the coastal route. The total length of the NSR tracks exceeds 14 thousand miles. The access to the NSR is through the Kara Gates from the west or from Cape Zhelaniya from the north. The distance from the port of Murmansk to the Kara Gates is 528 nautical miles. The distance from the port of Murmansk to Cape Zhelaniya is 758 nautical miles. The access to the NSR is through Cape Dezhnev from the east. The distance from Cape Dezhnev to the port of Petropavlovsk-Kamchatsky is 1037 nautical miles.
The border of the NSR is shown in figure 1 by the red line.

![Figure 1. Scheme of the NSR border.](image1)

The navigation on the NSR is carried out mainly on the recommended routes. The NSR includes the coastal traditional routes and deep-sea routes. The coastal routes are shown by the lines in figure 2.

![Figure 2. Scheme of the coastal routes.](image2)

The coastal routes have been formed for several decades since 1933 [2]. The routes mainly pass at a relatively short distance from the coast in the places that had been earlier freed from ice in summer.

The coastal routes are shallow. The routes are mainly used by the vessels with a draft of 6-7 m from July to mid-November. In winter, the coastal routes are covered with ice and are not used. The use of icebreakers on these routes is impossible because of their draft from 9 to 10.5 m.

The network of shipping routes of large-tonnage vessels in the central and eastern sectors of the Arctic is in the development stage. Existing routes are used occasionally in the summer - autumn period and are practically not used during the rest of the year.

The development plan for the network of shipping routes of large-tonnage vessels in the NSR water area includes a draft of the main and alternative high-latitude routes intended for navigation of vessels with a draft of up to 15 m. The routes are put into operation according to the results of hydrographic survey, which guarantees the absence of dangerous depths on them. New ports in the Arctic and on the Northern Sea Route need safe shipping routes with guaranteed depth, this article is devoted to the study of possible options for the development of deep-water routes for year-round use, depending on the bottom topography.
2. Materials and method
The shallow depths at the approaches to the Arctic ports mainly determine the restrictions on the draft. The maximum draft at the berths of the ports of Amderma, Khatanga, Tiksi is 1.6, 4.2 and 3.9 meters, respectively. The ports of Sabetta, Dixon, Dudinka, Pevek are relatively deep-water ports with drafts at berths exceeding 8 meters.

The recommended coastal routes were being laid according to the data of the hydrographic survey of the bottom relief, which was being carried out from 1933 to 1990 [3]. The survey was being carried out in the NSR water area, bounded by the coastline from the south, and by the dotted line from the north, which is shown in Figure 3. The water area located north of the dotted line had not been surveyed for the purpose of transport shipping. The area where the systematic hydrographic survey was not performed is indicated as “Unsurveyed”.

The water area located to the south of the dotted line was surveyed with different details.

![Figure 3. The boundary of the surveyed part of the water area.](image)

The choice of survey bandwidth is associated with a compromise solution to the tasks of planning and performing hydrographic work in high latitudes of the Arctic seas with the possibility of transport vessels to follow strictly the surveyed routes. Going beyond the limits of the surveyed strip is associated with the possible landing of the vessel on an unknown stranded.

3. Results
The depths had been examined more thoroughly in the shallow areas of the recommended routes. In relatively deep-water areas, as well as in areas remote from the navigable routes, the bottom relief had been examined in less detail.

There are areas in the coastal zone where a systematic survey of the bottom topography had not been performed. The largest of them have dimensions of 120x50 miles. They are shown by the orange circles in figure 3.

The detail of the survey is determined by the interval between the tacks at which the depths were measured with an echo sounder. The general information about the details of survey of the bottom relief of the Arctic seas is shown in table 1 [4].
Table 1. The distribution of the survey details of the bottom relief over the area of the Arctic seas

| Detail (m) | The proportion of the area, % |
|-----------|-------------------------------|
|           | Kara Sea | Laptev sea | East-Siberian Sea | Chukchi Sea |
| ≤500      | 28       | 35         | 15                | 9           |
| 1000      | 38       | 39         | 20                | -           |
| 2000–4000 | 16       | 11         | 14                | 21          |
| ≥4000     | 10       | 10         | 10                | -           |
| Routing survey | 8       | 5          | 41                | 70          |

The collection of marine navigational charts on the NSR water area has 680 Admiralty issues (a scale larger than 1: 500 000). The distribution of the total number of charts and plans for the seas of the NSR is given in table 2 [5].

Table 2. Cartographic provision of the NSR water area

| Denominator of scale | The number of maps and plans |
|----------------------|-----------------------------|
|                      | Kara Sea | Laptev sea | East-Siberian Sea | Chukchi Sea | Total |
| 500000               | 13       | 11         | 10                | 5           | 39    |
| 200000               | 39       | 12         | 20                | 10          | 81    |
| 100000               | 68       | 24         | 45                | 16          | 153   |
| 50000                | 144      | 27         | 22                | 14          | 207   |
| 25000                | 49       | 21         | 40                | 21          | 131   |
| 10000                | 25       | 8          | 11                | 4           | 48    |
| 5000                 | 11       | 2          | 6                 | 2           | 21    |
| Total:               | 349      | 105        | 154               | 72          | 680   |

The distribution of depths on the areas of the Arctic seas is given in table 3 [6].

Table 3. The distribution of depths on the areas of the Arctic seas

| Depths range, m | The proportion of the area, % |
|-----------------|-------------------------------|
|                 | Kara Sea | Laptev sea | East-Siberian Sea | Chukchi Sea |
| 0–10            | 3,5      | 11,1       | 14                | 1           |
| 10–20           | 5,3      | 37,4       | 47                |             |
| 20–30           | 10,1     | 22,7       | 25,5              | 6           |
| > 30            | 81,1     | 28,8       | 13,5              | 93          |

The task of searching routes for the vessels with a draft of 13 m and more was set in 2010 [7]. Depths must exceed 20 m throughout the routes. The coastal routes do not satisfy this condition, so they cannot be used. Depths requirements can be met in areas remote from the coastal routes for a long distance to
the north. The scheme of deep-sea routes is shown in figure 4 [8], where the deep-sea routes are marked in green.

![Figure 4. The scheme of deep-sea routes.](image)

4. Discussion

Hydrographic study of the NSR is insufficient, especially for the transit navigation of ships with a draft of more than 15 meters. The network of deep-sea routes is under development. The number of large-tonnage vessels on the NSR is increasing.

The deep-sea routes represent a complex of 2 km wide strips with depths exceeding 20 m. Within each strip, the bottom has been surveyed using multipath echo sounders. It provides passage of Mega ships [9] for year-round navigation.

Outside the strips, the hydrographic exploration of the bottom does not meet the requirements for safe navigation of large-tonnage vessels.

The vessels passage outside the surveyed strips may occur when, for example, the path for the vessel is blocked by thick ice, in unstable operation of satellite navigation systems or for other reasons. The vessel passage beyond the limits of the surveyed strip leads to the threat of vessel stranding, which is not displayed on the map. The methods for calculation of the permissible deviation of the vessel from the boundaries of the surveyed band are used to reduce such threats [10]. To design a network of shipping routes, for example, for container ships [11], the several options, which multiply the hydrographic survey, need different navigation periods.

The existing configuration of shipping routes on the NSR allows intercontinental transportation during the summer period for ships with a draft of 12 meters, for the year-round transit passage there is a very limited route that requires additional hydrographic study. All results of this paper were obtained at the Arctic Faculty of the Admiral Makarov State University of Maritime and Inland Shipping, as main direction of scientific research.

5. Conclusions

The following principles should be used at the perspective development of a network of shipping routes:

- depths should ensure safe navigation for vessels with a maximum draft throughout the deep-sea routes;
- the areas adjacent to the routes should be studied in detail so that to ensure safe navigation for vessels at their leave the boundaries of surveyed strip;
the routes network must contain backup routes that can be used in cases when the navigation along the main route is limited or impossible;

− ships networks development should take into account the prospects for the construction and use of offshore oil and gas installations in the NSR water area.

Planning the perspective hydrographic works should be carried out taking into account the priority of forming the deep-water routes network. The results of the study can be used when searching for optimal routes for navigation in ice conditions, when planning hydrographic works and developing a promising network of shipping routes in the Arctic seas.

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