An assessment of the condition of the Igarskaia Protoka on the Yenisei in 2018: side-scan sonar imagery interpretations and bathymetry

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Abstract. For almost eighty years, the town of Igarka on the Yenisei River had been an important timber industry center and seaport on the Northern Sea Route. Since the early 2000s, however, the town and its economy fell into decline resulting in the termination of timber export and, consequently, maritime navigation. In September 2018, a team of researchers from Reshetnev Siberian State University of Science and Technology, headed by the author of this paper conducted a side-scan survey of the Igarskaia Protoka, which had been the port’s harbor, in order to access the current state of its aquatic environment. This paper describes some preliminary results of this investigation, which is the first study of the underwater environment of this particular body of water.

1. Introduction

In 2018, side-scan sonar and bathymetric data was collected within the Yenisei River in central Siberia as part of a multidisciplinary scientific project under Reshetnev Siberian State University of Science and Technology (Krasnoyarsk, Russia) to provide information on the state of the riverbed under the Geographic Information System Yenisei – Arctic Project. The purpose of the project is to build a complex system of digital models and maps of the Yenisei and its tributaries that will include and encompass data on riverbed topography, sedimentology, hydrology, river and bank archaeology, and the location of significant anthropogenic underwater objects, e.g. shipwrecked vessels, sunken vehicles, and clusters of submerged timbers. The project is designed to help better understand the Yenisei River and the relationship between the river’s limnology and its exploitation through historical and modern themes. While conceived a few years earlier, the project received official support from the university administration only in 2018, allowing the project team to secure necessary scientific instruments and arrange fieldwork. It is panned that during the course of the project, a series of expeditions will be staged to the lower reaches of the Yenisei, the river’s delta, and estuary to collect new geographic data. Further, the gathered information will be processed using a high-level performance computer for compiling the GIS.

During the last decades, the use of side-scan sonar (SSS) for river research has become a widespread practice—a phenomena attributed to the availability of various acoustic imaging devices and their comparatively low price. Despite being designed for recreational purposes, many low-cost side-scan sonar modes have been effectively used to study the hydrographic, benthic (biological) geomorphologic and archaeology of riverbeds [1]. Sonar modes with a fixed transducer can produce effective imagery of the riverbed when operated in shallow environments; however depths of over 10 meters limit the effective range of these devices as the acoustic shadow increases. To investigate the riverbed at depths exceeding the effective range for low-cost side scan sonar modes, it was necessary to use a towed transducer, commonly referred to as a fish. As the fish is towed behind the vessel, it dives and moves closer to the riverbed allowing, thus to reduce the acoustic shadow and visualize the submarine environment.

2. Study area and methods.

The town of Igarka (67°28´N, 86°34´E), situated within the Turukhanskii Raion municipal district of the Krasnoiarskii Krai, had until recently been among the largest and timber exporting centers of Russia and one of the most developed seaports on the Northern Sea Route. Since the dissolution of the Soviet Union, Igarka has been in decline, particularly after the Siberian timber trade shifted towards the Chinese market. The last seagoing vessel sailed from Igarka in 2006, thus putting an end to a history of maritime shipping which had begun in 1928. Today, there are less than 6,000 inhabitants in this town, which had once boasted a population of over 18,000 (1989 census [2]).

The study area for this research encompasses the lower nine kilometers of the Igarskaia Protoka, from its confluence with the main channel of the Yenisei at Mys [cape] Karmakuly to a point near a high voltage power
line spanning between Igarka and Ostrov Igarkskii [Igarka Island] (Fig. 1). Overall during the investigation, 3,750 m² of the survey area were covered with the riverbed surface visualized by the side-scan sonar.

![Fig. 1. Igarskaya Protoka. Satellite image from Yandex Maps web mapping service with central track of study area. Map legend: (1) Mys Karmakuly; (2) Ostrov Igarkskii; (3) Site of the original location of Igarka and its sawmills.](image)

The Igarskaia Protoka (historically known as Samoedskaia Protoka) is an approximately 15-kilometer side channel of the Yenisei situated between the right bank of the Yenisei and Ostrov Igarkskii. Unlike other side channels of the lower Yenisei, Igarskaia Protoka is deep in its lower part (~13–15 m) and sheltered from northern, eastern, and southern winds, making the site an ideal location for harboring both riverine and seagoing vessels.

Due to the fact that September this region on the Yenisei is characterized by severe north winds, which generate 1.5–2.5 m waves on the Yenisei, the Igarskaia Protoka was the perfect location for investigating the performance of side-scan sonar on the lower Yenisei and developing techniques for acquiring quality imagery of the riverbed. What is more, the channel is known to be full of sunken timber and woody debris, shipwrecked vessels, sunken boats, and other traces of human activity, which made it an ideal location to not only assess the pollutedness of the riverbed, but to investigate the industrial history of this site.

For the purpose of our investigation, the Nautilus-50 Underwater Search Complex manufactured by the Russian Tetis-Pro Company had been employed. The complex is largely built on the StarFish SSS by Tritech International Ltd. with the difference of incorporating the sonar equipment, GPS module and processor into one unit, which includes a water and shatterproof computer.

In Table 1 are some of StarFish 990F towed SSS specifications:

| Specification                  | Value                  |
|--------------------------------|------------------------|
| Towing cable length           | 25 m                   |
| Maximum towing speed          | 5 kn                   |
| Maximum towing depth          | 8 m                    |
| Transducer vertical beam      | 60° nominal width      |
| Transducer horizontal beam    | 0.3° nominal width     |
| Frequency                      | 1 MHz                  |
| Acoustic range                | 1–35 m on each channel |
| Mode                           | CHIRP pulse compression|
| Pulse length                   | 100μs                  |

Table 1. Specifications of StarFish 990F (compiled from product data sheet [3]).

3. Desk study information.

There is little published information on the Igarskaia Protoka, despite the fact that the site had been thoroughly mapped by Soviet and later Russian authorities during the time when Igarka was an important port on
the Northern Sea Route. It is understood that the most recent bathymetric chart of the area was produced in 2006 and is largely a corrected edition of charts produced during the 1980s [4]. Nautical charts containing historic bathymetric soundings of the Igarskaia Protoka taken during 1936–37, 1956, 1964, 1981, 1987, and 2006 were obtained for the desk study performed prior to the field work. From the accumulated information, it was concluded that the depth of the channel range from 10 to 28 meters; greater depths were found at Mys Karmakuly – at the mouth of the channel, whereas the average depth of the channel between Ostrov Igarskii and the mainland ranged from 10 to 15 m. Depths decreased further southeast into the channel, ranging from 10 to 6 m along the centerline of the waterway.

The original port complex occupied approximately 160 hectares of land and water along 3.5 km of waterfront. Overall, approximately 10 km of the channel had been exploited for various purposes: (1) a sheltered wintering harbor was established in the mouth of the River Cherniaia; (2) coal was unloaded between Lisii Log and Volechi Log; (3) timber rafts were floated through the channel to the sawmills (1 km upriver from the wharves of the seaport); (4) a roadstead for seagoing vessels awaiting transshipment was located opposite of the wharves and Medvezhii Log; (5) wharves for riverine vessels were situated to the southwest of the passenger floating pier; (6) a roadstead for riverine vessels was located opposite of the wharves for riverine vessels along the southwestern tip of Ostrov Igarskii; (7) the pier of the fuel installations was the last of the industrial facilities in the channels and was situated on the mainland. The above information arrives from the chart of the channel published in 2006 (the last time Igarka was used as a seaport) [4].

![Fig. 2. A view of the port of Igarka and the Igarskaia Protoka (looking east) during the 1970s. Courtesy of the Municipal Archive of the City of Igarka (file: A1/38/19/2).](image)

A ferry service has been operating across the Igarskaia Protoka since the 1930s, linking Ostrov Igarskii and the mainland. Presently, the ferry provides communication between Igarka and the airport, which is situated on the island. During the Soviet era, Ostrov Igarskii was the location of a number of lesser industries, such as the state-run agricultural farm ‘Poliarnyi’, which is currently abandoned.

The desk study amassed information on the scale and intensity of the timber industry and shipping at Igarka. As anticipated, there was a steady development of both of these activities throughout the Soviet era. The table below illustrates the scale of timber exports through the port of Igarka from 1928 to 2005:

| Year | Amount of timber exported in m³ | Exported timber produced in Igarka in m³ |
|------|---------------------------------|----------------------------------------|
| 1928 | 9,400                           | 83,800                                 |
| 1932 | 123,900                         | 178,700                                |
| 1957 | 307,000                         | 293,100                                |
| 1965 | 899,900                         | 249,100                                |
| 1978 | 1,322,500                       | 383,500                                |
Table 2. Amount of timber exported from Igarka, 1928–2005. Compiled from [5].

| Year | Volume (m³) | Volume (m³) |
|------|-------------|-------------|
| 1985 | 1,217,900   | 370,500     |
| 1991 | 750,400     | 275,600     |
| 2005 | 81,500      | 65,500      |

As seen from the aforementioned table, wood production and export peaked during the 1970–80s and rapidly declined after the collapse of the Soviet Union. Igarka produced a line of wood products and yielded an average of 35.5% of the exports from the port. The remaining products were delivered to Igarka from the sawmills at Lesosibirsk.

It was expected that this massive amount of processed and unprocessed timber, which came to Igarka for almost eight decades had great affect on the aquatic environment of the Igarskaia Protoka. As said above, the city’s timber production rate was intense and followed a simple scheme. Timber rafts were floated or towed to Igarka from the upper reaches of the Yenisei, typically, from the basin of the Angara River, which was heavily exploited due to the presence of valuable tree species such as the Angara pine, an ecospecies of the Scots pine (*Pinus sylvestris*), which is prized for its density. After passing through the Igarskaia Protoka, the rafts were unchained and transferred to the log booms; from here the logs were collected and transported to the sawmills (Fig. 3).

![Fig. 3. Timber rafts being dissembled in the Igarskaia Protoka at log booms number 3 and 4 (1987). Courtesy of the Municipal Archive of the City of Igarka (file: 227).](image)

The fact that river currents allowed floating timber rafts to Igarka without the need to employ riverine vessels (this was especially important during the 1920–30s when there was a shortage of riverine vessels on the Yenisei) was among the key factors for selecting Igarskaia Protoka as a location for a timber exporting center.

4. Results of side-scan sonar investigations.

Side-scan sonar investigations of the Igarskaia Protoka were carried out using a 6-m inflatable catamaran during September 2018. The working conditions were quite difficult as they had to be performed from an open deck, exposing the operators and the equipment to temperatures around 5°C and constant precipitation. Intense motorboat traffic on the waterway also posed problems because closely passing watercraft generated interference and waves that negatively affected the sonar imagery. Another problem was the need for the operator to simultaneously focus on the side-scan sonar monitor and a tablet computer in order to follow a steady track. Despite a more or less stable bathymetry of the study area, there occurred numerous situations when the towfish had to be abruptly extracted due to threat of snagging. Nonetheless, despite these difficulties, the results of the investigation produced some fascinating results, including the first known underwater images of this part of the...
Yenisei. More importantly, it is now possible to assess the amount of sunken timber in the channel and estimate its impact on the aquatic environment of the Yenisei.

Microsoft Paint was used to construct a mosaic of the side-scan sonar imagery (Fig. 4); a similar method is described by Kaeser and Litts [6]. The reviewed images enable us to clearly identify both individual timbers and their clusters, many of which are composed of hundreds of logs and cut boards (Fig. 5). These log caches originated from logs that absorbed access water, described by Kaeser and Litts as dead-head logs [5] and boards that had been dropped into the water during ship loading operations. Other large woody debris originated from port and ship structures, such as ramps, railings, cargo cranes, etc.

Fig. 4. Side-scan sonar mosaic fragment showing a shipwrecked vessel (upper center), layers of sunken timber (middle left), and a sudden rise of the riverbed (lower center), caused by piled sunken logs.
Fig. 5. Samples of the Igarskaia Protoka riverbed revealing clusters of sunken timber and woody debris. Average depth at 10–15 m. Sonar acoustic range is set at 25 m on each channel.

Along with vast amounts of sunken timbers, the investigation revealed the presence of at least five shipwrecked vessels, the largest of which are 100-meter barges, at least ten sunken motorboats, and large amounts of miscellaneous river debris (steel cables, vehicle tires, containers, etc.) (Fig. 6). Most of the litter entered the environment after being dropped (accidentally or intentionally) from vessels or from the river ice after it had melted away.
5. Conclusion.

This study is the first to reveal the current state of the underwater world of the Igarskaia Protoka, which had once been the site of the busiest and most important port of the Northern Sea Route. The investigation provided information for estimating the amount of sunken timber and its location (it is planned to count how many logs, boards, and woody debris are situated within the studied area in the nearest future). It was possible to locate and identify at least five large shipwrecked vessels in the Igarskaia Protoka along with at least twenty sunken small craft. Applying SSS revealed large amounts of river debris left over from shipping operations and human activity in this part of the Arctic.

The Igarskaia Protoka and the remains of the port of Igarka are potential candidates for conducting further environmental studies and research on the history of the Arctic. Since the potential of the first field was touched upon in this paper and has, in terms of SSS application, been widely discussed in scientific literature [e.g., 1, 6, 7], it is worth to briefly address the second. Igarka vanished as an industrial center in Russia’s Arctic frontline almost as quickly as it had once appeared. Its destiny was, on the one hand, bound to the Soviet economic model, which ceased existing soon after the collapse of the Soviet Union. This inevitably signaled the demise of Igarka, which itself was a creation of the socialist economy. On the other hand, Igarka was a product of what historian Michael Wood refers to as the “modern, Western scientific civilization” [8, p. 204], the fundamental principal of which was the exploitation of nature for the benefit of humanity. SSS has offered us a glimpse into this materialistic past of Igarka – a benchmark of Soviet Arctic development. Like many other industrial projects of the era, little attention was paid to certain environmental issues. Today, this careless treatment of the environment has returned to haunt the town’s residents. It is known that Igarka’s tap water arrives from the Igarskaia Protoka. During 2015–18, there have been numerous media reports on the topic of low water quality in Igarka. According to them, it is hazardous to not only to drink local tap water, but to even to bath in it [9]. It seems very likely that this is the result of the heavy pollutedness of the Igarskaia Protoka. A complex historical investigation of Igarka’s industrial development, including the application of industrial archaeological methods, is therefore required to obtain a full picture of the ecological problem we are facing today.
6. Acknowledgements.

This research was completed thanks to the assistance of Andrei Shapovalov during the field work in 2018 and Svetlana Fedorovna Titova during the archival work at Igarka in 2016. The research was supported by the Reshetnev Siberian State University and Technology Geographic Information System Yenisei – Arctic Project.

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