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Article

The Solovetsky Archipelago and factors determining anthropogenic pressure on its natural complex

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Abstract. A set of anthropogenic factors affecting the Solovetsky Archipelago through the transformation of natural landscapes and the environment has been identified. Three-component impact is caused by the recreational activities of pilgrims and tourists; withdrawal of biological resources due to commercial/amateur fishing and wild plant collection by local population, as well as economic activities of the MU "Solovetskoye Rural Settlement". Each is influenced by the island specifics and should be considered when assessing critical anthropogenic loads on the natural environment of the archipelago.

Keywords: White Sea, Solovki, unique natural complex, recreational and economic activities, biological resources

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Научный обзор

Соловецкий архипелаг и факторы, определяющие антропогенные нагрузки на его природный комплекс

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Аннотация. Выявлен комплекс антропогенных факторов, воздействие которых на Соловецкий архипелаг выражается в трансформации естественных ландшафтов и окружающей среды. Установлено три составляющих этого воздействия: рекреационная деятельность паломническо-туристического потока; изъятие биологических ресурсов вследствие промысла, любительского рыболовства и сбора дикоросов местным населением; хозяйственная деятельность МО «Сельское поселение Соловецкое». На каждое из направлений оказывает влияние островная специфика территории. Учет этих факторов необходим при общей оценке критических антропогенных нагрузок на природный комплекс архипелага.

Ключевые слова: Белое море, Соловки, уникальный природный комплекс, рекреационная и хозяйственная деятельность, биологические ресурсы

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Introduction

The current global situation demonstrates a significant shift towards the regional tourism and the increased tourist flow in the areas of cultural-spiritual significance with a high recreational potential. In this regard, Solovki – the UNESCO World Heritage Site, is an attractive destination owing to its sacred features and natural environment uniqueness. The Solovetsky Islands are traditionally visited by a large number of people (Polikin, 2011; Prirodnaya sreda..., 2007). Putting the "Tamarin" quay in operation will contribute to arrival of more large ships to the islands and increased tourism turnover thereby deteriorating the already challenging environmental situation on the Solovetsky Islands.

In this regard, there is a pressing need to identify a full range of anthropogenic factors affecting the archipelago (including their specific characteristics), to categorize them into key areas and adequately assess each. During government meetings, a decision to examine all anthropogenic sources and calculate maximum anthropogenic loads on the natural complex of Solovki was made (Protocol No. 40 pr-P44-DCh dated December 13, 2023[1]).

The aim of this study is to detect the existing anthropogenic sources affecting the natural complex of the Solovetsky Archipelago.

Materials and methods

During the preparation of this manuscript, we used various informational and regulatory documents, as well as monographs, reports and scientific literature to study the impact of multiple factors on the natural complex of the Solovetsky Archipelago.

Brief description of the Solovetsky Archipelago

The Solovetsky Archipelago has the unique geographical location, i.e. at the junction of Bays Onega and Dvina and the White Sea basin (Prirodnaya sreda..., 2007). The islands presence in the estuary of Onega Bay provides favorable temperature and salinity conditions, high primary production and, consequently, a rich food supply for fish at different stages of their development. High diversity and density of macrophytes create optimal conditions for feeding and spawning commercial and non-commercial fish species. The latter contribute to high biological diversity, including endemic forms (Novoselov and Dvoryankin, 2023; Semushin et al., 2014).

The natural complex of the Solovetsky Archipelago is distinguished by its unique nature and landscapes. The typical structure and state of natural communities, characteristic of the tundra, forest-tundra and northern taiga zones of the European North of Russia are observed here (Feklistov and Sobolev, 2010; Nikishina, 1985). It is one of the most valuable scientific, educational and aesthetic sites in the Arkhangelsk Region and Russia as a whole. The islands of this largest White Sea archipelago represent the peculiar natural, historical and cultural phenomenon. The historical-cultural and natural complex of the Solovetsky Islands was justifiably included in the UNESCO World Heritage List in 1992.

The Solovetsky Archipelago consists of six relatively large islands (total area of 295.23 m^2) and over 110 smaller ones (Novoselov and Dvoryankin, 2023). The islands are characterized by a high lake content (12–15%). The exact number of lakes is still unknown, but their number exceeds 500 (Gritsevskaya et al., 1972; Prirodnaya sreda..., 2007) (Fig. 1). In terms of reservoirs abundance, the archipelago even surpasses Karelia. The hydrographic network of Solovki is quite exceptional because of rivers' absence here. It represents a cluster of small and very small lakes ranging in area from 1 to 230 ha connected to each other and to the sea by streams, channels or canals into a single system. Lakes vary in origin, depth, basin shape, bottom topography, watercolor, transparency, hydrochemistry and hydrobiology; some water bodies have no visible outflows (Dvoryankin, 2005; Gritsevskaya et al., 1972; Novoselov and Dvoryankin, 2023; Prirodnaya sreda..., 2007).

Forests, tundra-like wastelands, hills, swamps, lakes and the lake-channel system along with rocky placers, islets and corgis make the unity of the Solovki natural complex unique (Ipatov et al., 2009). This territory is covered by different-type forests, which serve as key habitat-forming components; they

[1] Protocol of the meeting with D.N. Chernyshenko, Deputy Prime Minister of the Russian Federation dated December 13, 2023, No. 40 pr-P44-DCh on the implementation of measures for the conservation and development of the Solovetsky Archipelago.



Fig. 1. Layout of lakes on the Solovetsky Archipelago (based on: Prirodnaya sreda..., 2007).

perform a significant protective function and determine the environmental conditions[2], [3]. Occupying more than half (67.7%) of the archipelago's territory, forests bear the brunt of recreational pressure (Feklistov and Sobolev, 2010).

Historically, the Solovetsky Archipelago and surrounding water areas have been virtually devoid of industry and agriculture. The population is primarily employed in servicing incoming pilgrims or tourists, cultural heritage sites, including the museum and monastery infrastructure[4].

Historical development of the territory

The construction of the Solovetsky Monastery, along with accompanying buildings and various natural, technical and economic structures, was started on Bolshoy Solovetsky Island in 1436 (Davydov, 2000). Strong transformation of the archipelago's natural environment (construction of the lake-canal system, drainage of swamps, grassland development) changed the island's mesoclimate, formed meadow facies and reduced the marshland area.

[2] Order of the Ministry of Natural Resources and Environment of the Russian Federation No. 908 dated November 9, 2020 (as amended on February 3, 2022).

[3] Forest Code of the Russian Federation dated December 4, 2006, No. 200-FZ (as amended on August 4, 2023) (with amendments and additions that entered into force on January 1, 2024).

[4] Research Report "Assessment of the Permissible Anthropogenic Load on the Territory of the Solovetsky Archipelago," 2014. Research work. Contract No. 0124200000614003083-131706 dated July 21, 2014. Contractor: Autonomous Non-Commercial Organization "Research and Development Center", Moscow, Russia, 99 p.

At the same time, the anthropogenic load, associated with numerous pilgrims coming to the Solovetsky Archipelago, increased. According to P.F. Fedorov (1889), the Solovetsky Islands were annually visited by 11000–15000 pilgrims. A special category consisted of "trudniks" (laborers) – people who voluntarily arrived to the islands and performed essential works, dealing with construction, agriculture and crafts of the monastery (Gemp, 1983). The period of monastic nature management continued until the early 20th century. Even in the 19th century, the flow of pilgrims to the Solovetsky Islands was significant. For instance, it steadily increased from 3000 at the beginning of the century to 23000 by its end.

In the post-revolutionary period, monastic nature management gave way to anthropogenic activities related to the Solovetsky Labour Camp (SLC), which was part of the State Administration of Camps (GULAG) and housed several thousand prisoners. The camp was established in the 1920s based on the monastery's premises (Davydov, 2000). Since then, the natural and economic structures of the monastery complex began to deteriorate: the lake-canal system silted up, shrubs became overgrown and reclaimed lands swampy. Historical and cultural structures – the Solovetsky Kremlin, sketes, dams, etc. gradually degraded as well.

In the first post-war years, man impacts slightly decreased, but the decline of natural-economic structures continued. Since then, the recreational pressure on the islands has increased due to visiting tourists and vacationers. The establishment of the Solovetsky State Historical Architectural Natural Museum-Reserve (SSHANMR) on the archipelago in 1967 helped regulate a tourist flow and preserve the unique natural landscapes and historical-cultural sites.

Works on introduction

Solovki are distinguished by a peculiar thermal regime manifested in highly heterogeneous conventional heat flow (CHF). A high-intensity positive anomaly of CHF in the north of Bolshoy Solovetsky Island reaches 40–50 W/m^2 that considerably exceeds the surface thermal characteristics of most of the western Russian Plain (Shvartsman and Bolotov, 2005). A favorable combination of microclimatic conditions was responsible for the emergence of a medicinal plant meadow on the monastery's southern slope, which later became one of the highest-latitude open-air botanical gardens and the unique floristic "introduction center" in Russia and Europe. The garden is home to over 30 tree species, as well as approximately 500 species and varieties of ornamental, medicinal, food and forage plants. The oldest trees are the Siberian cedars and Pallas's apple trees, both over 100 years old. Not typical for northern latitudes small-leaved linden, Pennsylvania bird cherry, Daurian tea, ramanas rose and other plants grow here. Nowadays, the dendrological collection of the garden includes 778 species and varieties belonging to 44 families and 103 genera. The herbaceous plant collection comprises 1062 species from 63 families and 106 genera (Ezhov, 2025). The preserved historical part of this collection is of scientific value since it has undergone extensive acclimatization to subpolar island conditions (Novinskaya and Grishanova, 2014).

The introduction of animals has had a significant impact on the natural environment of the Solovetsky Islands. The first reindeer appeared on Solovki during the abbacy of Abbot Philip in the 16th century (Fokina and Cherenkova, 2011). These were reindeer from Lapland (the Kola Peninsula) released by the monastery's abbot "into the forests... to make clothing and footwear from their skins." In the late 19th and early 20th centuries, 50–100 animals were annually net-hunted for the monastery's needs. They served as a relatively inexpensive food resource and horse-drawn transport. The Solovetsky herd was proposed to use in the development of reindeer husbandry at the White Sea territory (Fokina and Cherenkova, 2011). Until the 2010s, reindeer were found grazing on Anzersky Island. Selective eating of lichens by reindeer greatly changed the tundra vegetation on Cape Kolguyev (Andreev and Perfilyeva, 1980).

The biota of Solovetsky lakes has long been susceptible to man impacts that allows us to study the consequences and better understand the mechanisms of restructuring the anthropogenically influenced aquatic organism communities (including fish). At the beginning of the second half of the 19th century, monks undertook numerous attempts to acclimatize valuable fish species for increasing lake productivity and improving fish caught variety. Later (before 1880), transported from the mainland sterlet, whitefish, vendace and brook trout were released into the lake-canal system (Kritsky, 1983) (Table 1).

The origin of the brown (brook) trout population inhabiting the canal system of Bolshoy Solovetsky Island and associated reservoirs remains unknown (Alekseeva et al., 2014). According to some data (Anukhina, 1972a, b), this fish could be introduced by monks in the 19th century. Other sources (Pravdin, 1951) suggest that natural appearance of trout on the island is possible. Whitefish established in waterbodies of the canal system by monks in the late 19th – early 20th centuries did not become widespread here (Zakhvatkin, 1927). That time, crucian carp was repeatedly introduced into the archipelago's new reservoirs. In addition, five bream were brought from Arkhangelsk to Solovki and released into the lakes in 1881, whereas 150 tench and 5 grayling fish in 1883 (Tarnani, 1891). Ide could be naturalized in lakes of the archipelago together with other species.

In the mid-20th century, the efforts on new fish species introduction to Solovetsky lakes were resumed. In 1961, more than 10000 crucian and silver carps, as well as 200 tench fish of various ages were established in Lake Karasyevo (Kozmin, 2006). In the 1970s, peled was brought to the archipelago, but unfavorable weather conditions during fish release caused a mass mortality of its juveniles. As a result, the experiment was ceased. Today, peled are not found in the catches on Solovki. Grayling and bream have not survived. Other species have not become common as well, despite undertaken measures to protect them.

Currently absent sterlet and tench were rare in catches until 1972. Few in number whitefish, brook trout and ide were recorded only in some lakes and canals. In populated lakes, well-established silver carp surpassed goldfish in growth rates. In catches of 1965–1966, five-year-old specimens weighed 400 g and were 23.5 cm long (Anukhina, 1972a, b). However, the abundance of crucian carp subsequently failed to reach commercial proportions, being rare now. Goldfish, able to reach large sizes, are also encountered very rarely.

Of all the fish species introduced into the lakes of Bolshoy Solovetsky Island, only the European vendace has been successfully naturalized and formed local populations in several lakes in the western part of the island. At present, this species (represented mainly by large forms) is quite abundant (Novoselov and Dvoryankin, 2023).

Table 1. A list of freshwater fish in lakes of the Solovetsky Archipelago (based on: Novoselov and Dvoryankin, 2023).

Freshwater Ichthyofauna		
Fish species		Introduction impacts
Local	Introduced	
Pike	Sterlet	No
Burbot	Bream	No
Perch	Tench	No
Ruff	Grayling	No
Roach	Peled	No
Three-spined Stickleback	Vendace	Naturalization
Nine-spined Stickleback	Goldfish	Naturalization
Smelt	Silver Carp	Partial naturalization
	Whitefish	Naturalization
	Brook Trout	Naturalization
	Ide	Naturalization

Modern period

As of 2023, the population of the Solovetsky Islands was approximately 1000 people (60 were monks of the Spaso-Preobrazhensky Monastery)[5]. Nowadays, the economic activities of the local population have a minor impact on the islands' environment. As compared to the heyday of monastic nature management, agriculture in the region is in clear decline. Crop production is poorly developed and is represented only by small private gardens near houses, around the Solovetskoye settlement and sketes. At the same time, the entire Solovki area experiences varying anthropogenic loads. This pressure consists of two components: recreational and technogenic.

Natural complex (recreation)

Recreational activities[6] influencing the natural complex of the Solovetsky Archipelago (forest, meadow, lake, marsh and coastal ecosystems) are confined to the main pilgrimage and tourist routes (Fig. 2). Types and sites of recreation used by local population coincide with the areas subject to recreational pressure from tourist flows. Moreover, the number of tourists significantly exceeds that of local people; therefore, their contribution to the anthropogenic pressure on natural and cultural sites is decisive. An assessment of vacationer-induced loads on natural landscapes should be based on studying the impacts on inland waterbodies (lake-canal system) with consideration of soil and vegetation degradation in sites of major tourist and pilgrimage routes.

The impact on forest ecosystems is primarily manifested in the formation of notches on trees (primarily birch), trampled spots and a paths' network. Along the lake-canal system, two popular boat tours (rowed or powered by electric motors) – the so-called "Big Circle" and "Small Circle", are offered in summer. In addition, car tours on dirt roads that run next to lakes with paths are available. Campfire sites have been equipped on the shores of frequently visited lakes. In winter, most of the lakes are regularly visited by fishermen on snowmobiles and motorized towing vehicles, disturbing the lake ichthyofauna. Berry picking (in autumn) leads to the trampling of the surface layer of marsh ecosystems. The most pronounced transformation of marsh biotopes is noted in the vicinity of Lake Zelenoye.

Anthropogenic factors

The economic functioning of the Solovetsky infrastructure (airport, seaport, vital activity of the settlement) is the main factor of anthropogenic impact on the island. Major contributors to air, soil and water pollution are vehicles, petroleum products, power generators, household and construction wastes, as well as meeting the needs of local residents, monastery staff, tourists and pilgrims.

Vehicles

According to the preliminary estimates of the Solovetsky Archipelago Development Agency (Arkhangelsk Region)[7], 125 vehicles and 146 self-propelled vehicles (snowmobiles, ATVs, and tractors) have been registered in the Solovetskoye settlement. The development of its road network and main tourist routes transforms soils and vegetation cover; vehicle use contributes to exhaust emissions and soil pollution by chemicals[8]. The petroleum product content in the studied soils of Bolshoy Solovetsky Island ranges from 25 to 5813 mg/kg. Soils of Sukhoi Dock exhibit strong contamination with petroleum products. At the same time, this indicator in most soils is within 300 mg/kg on average (Iglovsky, 2005; Popova et al., 2016; Trofimova and Popova, 2016).

Infrastructure (water supply, sewerage)

The lack of biological treatment facilities in the Solovetskoye settlement and untreated wastewater discharges is responsible for systematic contamination of Blagopoluchiya Bay with domestic wastewater. At present, two sites of wastewater discharge operate in the settlement (Sostoyanie..., 2023). In 2022, wastewater discharges totaled 0.09 million m³. Of this, 0.06 million m³ undergone the standard mechanical treatment and 0.03 million m³ remained untreated at all. Hydrochemical studies (Lukina et al., 2025; Mokhova et al., 2018) are evidence of heavily polluted waters of Blagopoluchiya Bay.

[5] Ministry of Culture of the Russian Federation. Certificate No. 701-01.1-54@-NP dated January 23, 2024. February 9, 2024.

[6] Industry Standard OST 56-100-95. Methods and units of measurement of recreational loads on forest natural complexes. Approved by Order of the Federal Forestry Agency No. 114 dated July 20, 1995.

[7] Agency for the Development of the Solovetsky Archipelago of the Arkhangelsk Region. Certificate No. 319/40 dated February 28, 2024.

[8] SanPiN 42-18-4433-87. Sanitary standards for permissible concentrations of chemical substances in soil.

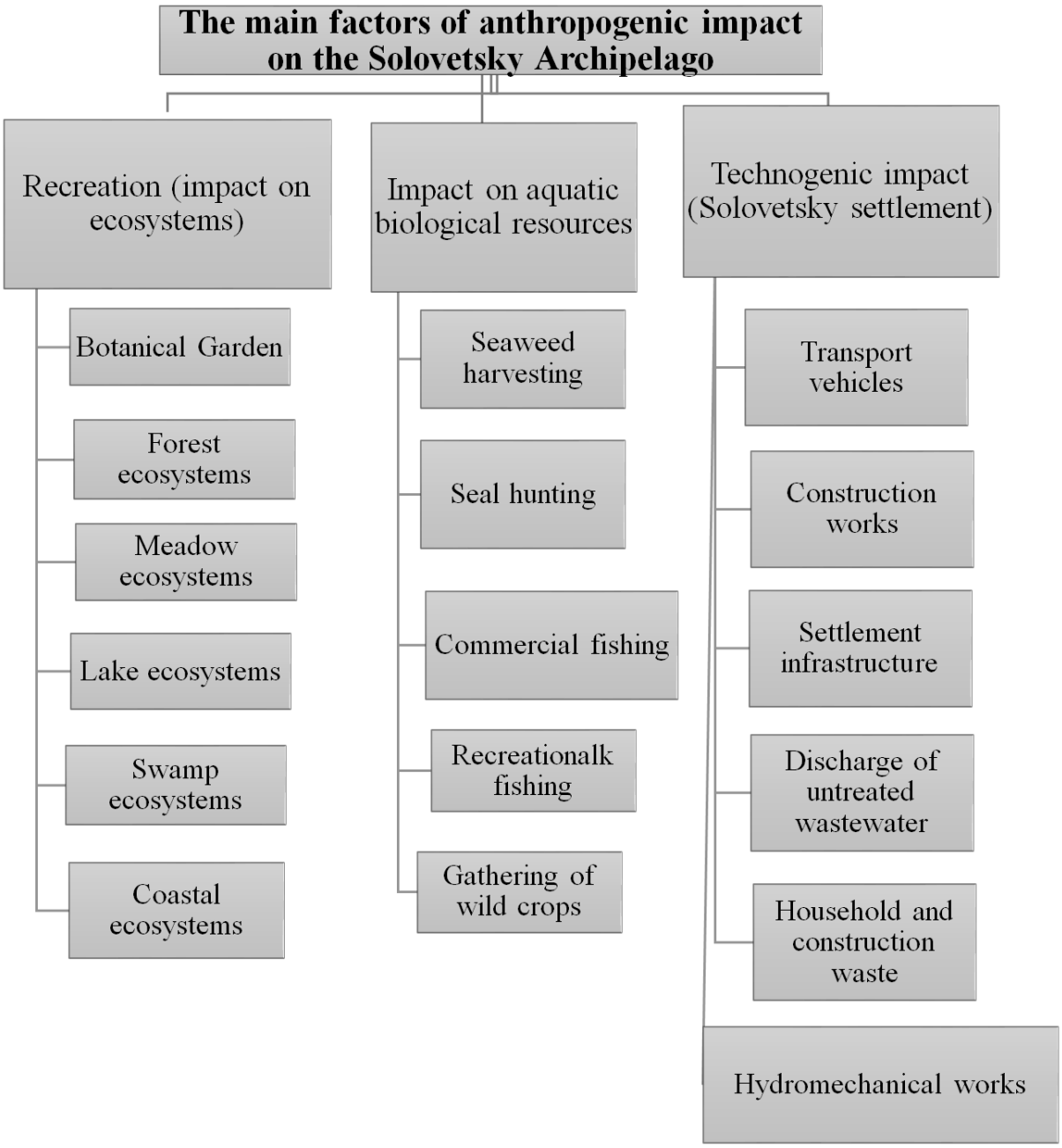


Fig. 2. Main factors of anthropogenic impact on the Solovetsky Islands.

The elevated content of pollutants, poor oxygen regime, as well as exceeding MPCs for petroleum hydrocarbons, phenols, BOD_5 and phosphates are recorded here.

Construction works

In the Solovetskoye settlement, soil and vegetation are influenced and polluted by traffic, construction debris, waste, petroleum products, including wind and water erosion (Trofimova and Popova, 2016). The territory of Bolshoy Solovetsky Island experiences significant anthropogenic loads, leading to accumulation of heavy metals. Zinc and lead are among key soil pollutants; in some plots, MACs and background values for these elements exceed critical levels (Iglovsky, 2005). Vegetation is also greatly polluted with heavy metals. At the construction sites, irreversible soil changes occur when at the preparatory construction stage the area is cleared of vegetation and a vertical land planning is performed. Therefore, construction works reduce the biological productivity of soils, disrupts their water and temperature regime thereby causing erosion (Popova et al., 2016).

Hydromechanized works

With hydromechanized works implementation in Solovki waters (pier construction, dredging), the following phenomena are observed:

1) a formation of a significant volume of suspended solids ("turbidity spots" at work sites);

2) a contamination of bottom sediments induced by probable leaks of petroleum products (fuel oil, diesel fuel, lubricating oils, etc.) from the operating marine and land-based transport, including lifting equipment;

3) a water intake for possible slurry formation or support of the machinery and equipment operation;

4) increased noise levels, the main sources of which are the fleet's technique, construction machinery and equipment, diesel engines and compressor units.

Water abstraction for construction purposes reduces fish habitats and food supply thus causing the death of planktonic organisms. The absence of fish protection structures or their failure to comply with fisheries legislation leads to mortality of ichthyoplankton and juvenile aquatic bioresources.

Household and construction waste

Landfills and accumulation of solid municipal wastes represent a serious environmental problem on the Solovetsky Archipelago. According to the report (Sostoyanie..., 2023), the total area of landfills (accumulation capacity of 300 tons per year) reaches one hectare. The total accumulated waste approaches 20000 tons, with a maximum capacity of 24700 tons. The Foundation for Preservation and Development of the Solovetsky Archipelago has developed the design documentation for the construction of the “Industrial and Consumption Waste Management Complex in the Solovetskoye settlement”. Landfill reclamation (transport of accumulated wastes to the mainland) is being currently implemented.

Impact on biological resources

On the Solovetsky Archipelago, the use of biological resources consists of seaweed harvesting, industrial and amateur fishing, wild plants harvesting by local residents.

Seaweed harvesting

Seaweed harvesting is carried out by manual mowing in the archipelago's waters, with kelp and focus as the primary species. Although the Solovetsky Archipelago boasts significant reserves of commercial macrophytes, exploitation of these seaweed resources is very poor now. The amount of harvested seaweed is steadily declining. Seaweed harvesting in the White Sea accounts less than 10% of its potential production (Semushin et al., 2014). In 2023, permits for commercial fishing in the coastal fishing grounds of the Solovetsky Archipelago were issued to the only enterprise. The actual harvest volume was approximately 1000 tons. Note that with a total quota of 50000 tons and an actual catch of 804 tons it shows a 2.8% reduction. According to the Federal Agency for Fisheries[9], the recorded catch on Solovki in 2024 was 749 tons of kelp (2.2% of the quota) and 95 tons (0.6%) of fucus. There is no information yet on the seaweed harvest for 2025, but it is clear that this resource raises no concerns.

Mammalian hunting

Currently, commercial hunting of mammals in the White Sea is not implemented, although the raw material base allows for harvesting over 10000 harp seals and 50 beluga whales. At the same time, in the Solovetsky Archipelago and throughout Onega Bay, there is a problem of unintentional catches of mammals during coastal marine fisheries. Ringed seals and bearded seals die when entering herring and Navajo tuckles (no records are kept of these animals). Experience in processing the White Sea animals has been completely lost. This type of hunting currently attracts no interest from commercial companies (Semushin et al., 2014).

Industrial fishing

Nowadays, the archipelago's coastal waters are used by local residents and tourists only for recreational and sport fishing. For residents with watercrafts, who derive their primary income from transporting and serving tourists, fishing in summer serves as extra earnings. Permits for commercial fishing in freshwater bodies of the Solovetsky Archipelago are not issued. Without exaggeration, the Solovetsky fisheries is in the depressed state at present. The former sites for fishing with throw nets have been practically destroyed; only the boulder-formed walls of capacious glaciers exist at the moment (Semushin et al., 2014). Meanwhile, recreational fishing on Solovetsky lakes yields approximately

1–2 tons, with a potential productivity of 3–5 tons (Novoselov and Dvoryankin, 2023). Traditional for Solovki population recreational fishing (both on lakes and in the coastal zone of the archipelago), does not make negative effects on aquatic biological resources.

Extraction of other biological resources

Almost all households in the Solovetskoye settlement are actively involved in gathering and harvesting berries, mushrooms and medicinal herbs that ensures food security for the island residents. Because of the lack of special grounds, hunting on the archipelago is prohibited. The nearest publicly accessible hunting grounds are located on the Summer Coast of the White Sea.

Conclusion

Thus, the anthropogenic impact on the Solovetsky Archipelago consists of three main components. The recreational effect falls on major pilgrimage and tourist routes. Biological resources are influenced by seaweed harvesting, recreational fishing and gathering wild forest products by local residents. The technogenic loading on the environment is mostly associated with the economic activities of the Solovetskoye settlement: ensured livelihood for local population and pilgrimage-tourist flow, the settlement infrastructure maintenance, the transport vehicles impact, as well as construction works implemented in the settlement and hydromechanized ones in the coastal waters.

The archipelago's environment is mainly affected by the technogenic factor, which is manifested in various local impacts on soil, water and air. Their consequences require making specific decisions and prompt measures to protect and optimize the management of the natural-cultural and architectural complex. Impact factors should be taken into consideration when assessing and conducting long-term monitoring of critical man-made loads on the natural complex of the Solovetsky Archipelago.

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