DPSIR Framework

(Drivers, Pressures, States, Impacts and Responses)

Case-Study of Four UNESCO National Parks and Reserves in Russia and Finland

WP1 REPORT

KA5033-SUPER Project

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SUPER

Sustainability Under Pressure: Environmental Resilience in natural and cultural heritage areas with intensive recreation

Association "Centre for Problems of the North, Arctic and Cross-border Cooperation"

Forest Administration Metsähallitus, Parks & Wildlife Finland

Kizhi State Open Air Museum of History, Architecture and Ethnography

Water, Energy and Environmental Engineering Research Unit, University of Oulu

Karelian Research Centre of the Russian Academy of Sciences (KarRC RAS)

Centre for Economic Development, Transport and the Environment for North Karelia

National Park "Vodlozersky"

United Nations Educational, Scientific and Cultural Organization

Man and the Biosphere Programme

POHJOIS-KARJALAN BIOSFÄÄRIALUE
North Karelia Biosphere Reserve

SUPER KARELIA CBC // Project

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Contents

Abbreviations

BR	Biosphere Reserve
CC	Climate Change
DPSIR	Drivers, Pressures, State, Impacts, response
EU	European Union
IUCN	International Union for Conservation of Nature
KarRC RAS	Karelian Research Centre of the Russian Academy of Sciences
MSW	Municipal Solid Waste
NK	North Karelia
NKBR	North Karelia Biosphere Reserve
NPA	Natural Protected Area
NP	National Park
NPs	National Parks
REE	Rare earth elements
UOulu	University of Oulu
UNESCO	United Nations' Educational, Scientific and Cultural Organization
TOC	Total organic carbon
COD	Cr [subscript] – chemical oxigen demand (Cr)
COD	Mn [subscript] – chemical oxigen demand (Mn)

EXECUTIVE SUMMARY

This report is an integral part of the "Sustainability Under Pressure: Environmental Resilience in natural and cultural heritage areas with intensive recreation" (KA5033-SUPER) project of the Karelia CBC Program, financed by the EU, Russia and Finland . The Project work was carried out in October 2018 – January 2021, focusing on creation of conditions to improve environmental resilience of the unique natural and cultural heritage sites found in the boreal landscapes of Karelia and Finland: 1) Kizhi State Open Air Museum and its buffer zone with more than 20 villages (UNESCO heritage site); 2) Vodlozersky National Park, including Kuganavolok village (UNESCO Biosphere reserve); 3) North Karelia Biosphere Reserve (NKBR) in Finnish–Russian border region (UNESCO Biosphere reserve); 4) Rokua Geopark located 100 km from Oulu in the region of Oulu and Kajaani (UNESCO Geopark site).

Main idea of the SUPER project was to deal with weak or uncertain environmental resilience of the chosen target areas. They are visited by numerous tourists and it is hard to handle the side effects of tourism and other anthropogenic factors (i.e., waste management, wearing out of the surroundings and vegetation, pollution, eutrophication of waters, etc.).

This report presents a comprehensive case-study of four UNESCO national parks and reserves in Russia and Finland conducted by a team of international environmental researchers and specialists from seven organizations across the border: 1) Association "Centre for Problems of the North, Arctic and Cross-border Cooperation" (North-Centre, Lead Partner); 2) Kizhi State Open Air Museum of History, Architecture and Ethnography; 3) Karelian Research Centre of the Russian Academy of Sciences (KarRC RAS); 4) National Park "Vodlozersky"; 5) Water, Energy and Environmental Engineering Research Unit, University of Oulu (UOulu); 6) Forest Administration Metsähallitus, National Parks Finland; 7) Centre for Economic Development, Transport and the Environment for North Karelia. Several study methods were employed to generate this report, including field visits, sample analyses made by specialists, modelling and application of the DPSIR Framework method to the data collected (more in chapter 2).

The DPSIR (Drivers, Pressures, State, Impacts, Responses) model is a causal framework for describing the interactions between society and the environment, adopted by the European Environment Agency; Where: **Drivers** are individual, social, economic, industrial and governmental needs for its growth and development; **Pressures** – human activities in meeting the needs (Drivers); **State** – state of the environment (physical, chemical and biological conditions) as a result of the Pressures; **Impacts** – quality of ecosystem and human welfare determined by the State; **Responses** – comprehensive actions by the society and policy makers as the results of undesired Impacts. The goal of the DPSIR framework is to help local decision makers, inhabitants, and stakeholders understand how different drivers can for example impact their local economies, and how responses influence the current state of environments. It also helps decision makers to identify areas needing work and prepare appropriate response pathway.

For the Russian study sites of Vodlozero and Kizhi, the DPSIR framework was updated with field visits and studies by researchers from University of Oulu (UOulu) and Karelian Research Centre of the Russian Academy of Sciences (KarRC RAS) with help from the staff of Vodlozersky NP and Kizhi. Researchers from UOulu concentrated on the general hydrogeological conceptual analysis of the waste sites. KarRC RAS researchers studied soil, hydrology, microplastic contamination and plant biology (plant cover) of the sites. The sites in Kizhi and Vodlozero included waste dump sites, and in Vodlozero the tourist sites with trampling issues were included were subjects of ecological and soil analyses.

Particularly, the conducted soil surveys in the waste dumps forming spontaneously near villages in the Kizhi skerries region, and the largest unauthorized landfill near Kuganavolok village in the Vodlozersky National Park have been conducted. The soils were sampled from each site, and heavy metal content was determined as one of the most important indicators of waste dump's detrimental effect on soils. In addition, the temperature conditions were monitored, sanitary bacteriological surveys were carried out, and soil acidity was determined.

The studies showed that the pH of soils in the waste dumps was higher than in the background, i.e., the acidity was declining. Soil contamination in the dumps depends on waste composition. Smaller dumps, where the main components are glass and plastic bottles, are less hazardous, as they do not cause heavy metal pollution or alter the sanitary parameters. The dumps with substantial amounts of cans, nails, springs and other waste containing ferrous and non-ferrous metals featured elevated concentrations of some elements – zinc, copper, and arsenic – were discovered. The largest waste dump in the Kizhi skerry region (in village Sennaya Guba) is a serious source of soil pollution with heavy metals. It was found to contain high concentrations of copper, cadmium, zinc, antimony, tin and other heavy metals and semi-metals.

The surface layer of soils in the large unauthorized waste dump near village Kuganavolok in Vodlozersky NP contained zinc and lead concentrations exceeding national regulatory levels. Maximum permissible concentrations were exceeded also for tin and antimony. Sanitary bacteriological analyses showed enterococci to exceed the limit 1000-fold, and the coliform bacteria index was at the threshold of permissible levels.

Another aspect studied in the camping grounds most popular among tourists in the Vodlozersky NP was the effect of recreation on soil water and physical properties. They were found to change in line with the degree of trampling – free moisture content in the soil declined and upper soil layers became slightly compacted, affecting moisture and nutrient supply to tree roots.

The temperature conditions in waste dumps differ significantly from the control. The primary reason is alteration of the ground cover, the lack of which in wastes dumps facilitates warming up of their soils. The temperature rise is the most substantial in the upper soil layer, but the tendency persists, although to a lesser scope, in the underlying horizons, too.

The plant cover of tourist campsites and waste dumps in Vodlozersky National Park and Kizhi Archipelago was surveyed during the Project. Assessment of the living ground cover (LGC) in campsites (Vodlozersky NP) showed their flora to be vastly different in the species diversity from natural undisturbed forest sites, being 5.4-7.6 times richer. On top of retaining a majority of typical forest-associated species, campsite flora is continuously enriched by introductions of regionally common meadow and ruderal elements.

Each site has areas with heavy, moderate, and mild trampling damage. The spatial scope and characteristics of the disturbance depend on the presence/absence, siting and number of infrastructure elements (fire sites, shelter pavilions, utility structures, etc.) within the sites, as well as on the site's accessibility by transport.

In heavily trampled areas, plant communities are disturbed in very similar ways: the forest floor is ruined, soils are worn out down to the mineral horizon, tree roots are exposed, the field (sub-shrubs and herbs) and ground (mosses and lichens) layers are represented by singular, usually trampling-resistant, species. Such heavy disturbance occurs locally, not reaching beyond campsite limits, since trampling areas are dictated by a wide arrangement of utilities. Zones affected by heavy (sweeping) trampling take up some 30-35% of the campsite area.

In the moderate trampling damage zone, the living ground cover is fragmented, vegetation patches retain traits of the campsite's background plant communities. Forest-dwelling species remain dominant (*Vaccinium myrtillus, Vaccinium vitis idaeae*, Deschampsia cespitosa, etc.). This zone occupies 50 to 70% of the campsites and has a higher species diversity than the other two due to enrichment with ruderal and meadow species. The ground cover in such zones can differ significantly among campsites depending on habitat conditions and the chance of introduction of diaspores of species alien to this specific forest community.

The mild trampling damage zones occupy 10-25% of the campsites' total area, usually along the periphery. The living ground cover is disturbed only in paths; the percent area worn out by trampling is 10-15%. In the future, given the same mode and intensity of use, the disturbed area within the campsites will not grow any significantly. Further changes will probably be connected with the introduction of native meadow species and alien species.

The flora of waste dumps in Vodlozersky NP and Kizhi Archipelago features a far greater (2-8-fold) diversity compared to the surrounding undisturbed forest communities. The number of species in the largest dumps (Kuganavolok, Sennaya Guba) is expectedly higher, whereas the number of species in the micro-dumps far away from human communities is 2-3 times lower.

The flora composition in all the dumps is mainly made up of native species, while the share of alien species can be 3–6 times lower, depending on the dump size, waste fractions and amount. Plant communities in the dumps are mostly composed of boreal meadow and forest species. A substantial group (approx. ¼ of all species) is pioneer species (ruderals). Usual inhabitants of waste dumps are so-called “escapees” – ornamental and food plants people commonly grow in their subsistence plots (dill, onion, potato, etc.). The dumps were found to contain four species classified as invasive in Karelia: *Sambucus racemosa, Epilobium adenocaulon, Impatiens glandulifera, and Malus domestica.*

The microplastics (MP) content in lake sediments was studied in protected areas – Vodlozersky National Park (Lake Vodlozero), and Kizhi Open Air Museum (Kizhi skerries region of Lake Onega). A total of nine sediment samples were collected and treated. All the samples contained microplastics. Their average content in sediments from the Kizhi skerries was 3413 ± 1965 pcs./kg dry weight, which is somewhat higher than the levels previously determined for Petrozavodsk Bay and the open part of Lake Onega. The highest MP content was observed near the main pier of the Kizhi Open Air Museum. Average MP content in sediments from Lake Vodlozero was 1506 ± 845 pcs./kg. The elevated content of microplastics in sediments in the protected areas is probably due to its input with wastewater and the degradation of large plastic objects on the shore and in unauthorized waste dumps, after which runoff carries the secondary microplastics to the water bodies.

Hence, in Vodlozero and Kizhi sites, the most pressing waste-related problems in both natural parks seem to be illegal dumping of waste and insufficient waste management systems. In addition, challenges are caused by the waste load due to rather heavy tourism, growing number of private recreational housing (dachas), recreational fishing (also partially industrial fishing in Vodlozero case) and insufficient and especially outdated waste management systems. Moreover, infrastructures of the areas are not always on the good enough level to maintain sufficient and sustainable waste management system.

The Rokua case site example in Finland showed how DPSIR approach (edited from the conducted Multicriteria decision analysis) can clarify the connections between different aspects of a protected groundwater area with seasonally low water levels and how it is managed. The connections between lake ecosystems, groundwater and land use can be shown in an orderly fashion which helps the discussions between experts, stakeholders, locals and regional authorities.

Modelling is a powerful tool to analyze different management scenarios. The key part of the modelling process is the conceptualization of case site and the studied hydrogeological dynamics. The groundwater model conceptualization was studied in Rokua as a tool to enhance the management of region. This helped to plan where to monitor the studied system for most valuable data and visualizing the system for discussions. It is a key step to build a functioning model where the key dynamics of the system are represented in needed detail.

For the Rokua case, different land use scenarios were studied for management solutions. Extensive drainage restoration by completely filling significant amount of ditches of the whole protection zone could be seen currently as a too oversized, uncertain and expensive measure compared to the benefits. Even though there was acceptability for the measures, the effects from the lowest water levels were with economic impacts to tourism were temporary during the dry periods. A smaller, sub-catchment scale pilot test of ditch filling would improve our knowledge on the effectiveness of ditch filling restoration method. Also, the groundwater modeling approach used in Rokua would be interesting to conduct for a smaller aquifer, of recharge area less than 5 km. The impacts of peatland ditches for a smaller aquifer might differ with scale.

NKBR case site in Finland for DPSIR concentrated on the municipal solid waste (MSW) management. The results showed that despite the increasing rise of popularity and demand for outdoor recreation and increased number of visitors to national parks within NKBR, there has not been any major environmental impacts regarding MSW across environments. Waste management inside the national parks are largely under control, and waste related impacts on the state of environments both inside the national parks and surrounding areas within the biosphere reserve are minimal. However, visitors and residents land-use values are linearly aligned with these values concentrated along hiking routes, waterbodies, and protected areas. Active marketing of the region as clean nature also requires that the promises are kept once visitors are at the destinations. These pressure areas present the need for enhancing awareness to both visitors and residents on importance of waste sorting and correct disposal of waste.

Moreover, under the NKBR scenario of continued growth in visitor numbers, ongoing tourism plans, and linearity of land-use values by both visitor and residents in the area, considerable attention needs to be given to the roles that residents and visitors can play, as well as tools (such as reliable funding) that could help destination managers guide such actions.

When considering the well-functioning and more sustainable waste management in parks, the issue of major concern is infrastructure and logistics improvement in the areas. For instance, Kizhi could benefit from better shipping arrangements for the waste transportation – investments in water transport could help to improve waste management not only on the island, but also in the protective zone. Vodlozersky National Park could also benefit from arranging transportation across Lake Vodlozero. To find out the best solution for waste transportation and management in the areas, the detailed and careful studies should be done, and amount of waste and waste fractions need to be solved for the proper planning and sizing of the more sustainable waste management system.

Results from the different DPSIR-studies in the case sites reveal the need for continuous cross-border collaboration as a way of exchanging information and ideas, experiences and best practices regarding waste management and water resource management across protected areas.

1. INTRODUCTION

The SUPER project has aimed at creating conditions for improving environmental resilience of the selected pilot areas in Russian Federation and Finland. The pilot territories are protected areas with intensive recreational load. The project has focused on unique natural and cultural heritage sites found in the boreal landscape of the Republic of Karelia and Finland: the Kizhi State Open-Air Museum, Vodlozersky National Park, North Karelia Biosphere Reserve (NKBR) and Rokua Geopark.

National Parks (NPs) have become increasingly popular environments for visitors seeking outdoor relaxation and recreation in recent years, this trend is visible in both Finland and Russia. Tourism in protected areas like NPs is unique in its sensitivity to human-impacts and climate-change driven pressures. Statistical analysis shows that tourist inflow is positively correlated with the waste generation problem. Furthermore, ecosystems' sustainability is affected by the activities of local villagers and enterprises.

The problems, which the SUPER project consortium has tried to tackle, are the risk of environmental degradation of territories with high recreational load and the risks from land use to the case area. The consequences of human-induced impact can be the wearing out of the surroundings and vegetation, eutrophication of waters, soil and water contamination, etc. The side effects are different in different sites and presented in this report. Often these problems are exacerbated by insufficient infrastructure and poor knowledge of local actors about environmental risks.

Research is necessary to investigate how recreational pressure influences protected areas, since their mission, on the one hand, is to conserve the nature, while on the other hand people need the opportunity to communicate with the nature. It is therefore important to assess and define an optimal level of the load on protected ecosystems.

Waste is a serious environmental issue in the modern world. Virtually everything that the man extracts, produces and consumes eventually turns to waste, harming the environment unless properly deposited and recycled.

Water resources management is recognizably a challenging task worldwide. River catchment management, restoration of eutrophic lakes, and agricultural irrigation in arid regions are just a few examples of areas where expertise in hydrology, ecology, economics, and many other fields is needed to build coherent plans for the future.

This report is the result of scientific cooperation within the SUPER project by partners from the University of Oulu, KarRC RAS and CEDTENK. In their work they were assisted by partners from the Kizhi Museum, Vodlozersky National Park, Metsähallitus, Parks & Wildlife Finland and Association “North-Centre”, the lead partner of the project.

The particular study objects were determined by specialists working in the protected areas together with the researchers. As a framework the partners have chosen the DPSIR (driving forces, pressures, states, impacts, responses) model - a causal framework for describing the interactions between society and the environment adopted by the European Environment Agency. In this report you can find the DPSIR frameworks for the four pilot territories: the Kizhi State Open-Air Museum, Vodlozersky National Park, North Karelia Biosphere Reserve and Rokua Geopark.

The DPSIR analysis is supplemented in this document by results of soil, botanical, hydrological and microplastic field research, conducted on the Russian sites. The case study of Rokua Geopark contains model conceptualization of the Rokua esker system, it is an example of a method, which can be used for better hydrogeological understanding of protected areas. At the end of the document, you can find additional conclusions and recommendations.

1.1. Project presentation

SUPER, Sustainability Under Pressure: Environmental Resilience in natural and cultural heritage areas with intensive recreation (KA5033) project has lasted over two years, October 2018 – January 2021, and it has aimed at creating conditions to improve environmental resilience of the selected pilot territories, which are protected areas with intensive recreational load.

The project partners are:

- Lead partner / Association "Centre for Problems of the North, Arctic and Cross-border Cooperation" (North-Centre), Russia;
- Kizhi State Open Air Museum of History, Architecture and Ethnography, Russia;
- Karelian Research Centre of the Russian Academy of Sciences (KarRC RAS), Russia;
- National Park "Vodlozersky", Russia;
- Water, Energy and Environmental Engineering Research Unit, University of Oulu (UOulu), Finland;
- Forest Administration Metsähallitus, Parks & Wildlife Finland;
- Centre for Economic Development, Transport and the Environment for North Karelia, Finland.

SUPER project focuses on unique natural and cultural heritage sites found in the boreal landscape of Karelia and Finland:

- Kizhi State Open Air Museum and its buffer zone with more than 20 villages (UNESCO heritage site);
- Vodlozersky National Park, including Kuganavolok village (UNESCO Biosphere reserve);
- North Karelia Biosphere Reserve (NKBR) in Finnish – Russian border region (UNESCO Biosphere Reserve);
- Rokua Geopark located 100 km from Oulu in the region of Oulu and Kajaani (UNESCO Geopark site).

The sites are attractive and visited by numerous tourists, making them vulnerable, and threatening their conservational values and capacities to handle the side effects of tourism (i.e., management, wearing out of the surroundings and vegetation, eutrophication of waters). Proper environmental management and development of waste management capacities are needed to reduce these negative impacts and maintain areas attractive also for tourism.

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The main idea of the project has been to deal with weak or uncertain environmental resilience of the chosen target areas – protected territories with intensive recreational load.

The problems identified are:
- Lack of knowledge of reasons for environmental degradation and poor knowledge of risks related to the future status of the environment;
- Insufficient knowledge of waste management practices and traditional landscapes maintenance;
- Low awareness and educational level of the target groups in sustainable development management practices;
- Poor infrastructure and visibility to deal with the waste and other contaminants.

Within the SUPER project, the partners have attempted to comprehensively address the identified problems:
- Our activities were aimed at studying recreational pressures (such as illegal dumps, effects of transport and tourist activities) at the protected areas and improving environmental monitoring through new methods;
- In order to build up resilience of protected areas we improved infrastructure - stations for sorted waste and composting, containers, renovated tourist toilets, information boards, etc.;
- We conducted outreach activities (seminars, camps, volunteer clean-ups, drawing contest) and created educational materials in order to reach out to all relevant target groups.

While implementing the above-mentioned activities we were looking for best practices in Russia and Finland, exchanging information and learning from each other.

Karelia CBC is a cross-border cooperation programme creating an attractive region for people and business. The Programme is financed by the European Union, the Russian Federation and the Republic of Finland.

1.2. Study sites in brief

Study sites are presented in detail in chapters 3–6.

National Park "Vodlozersky" is a conservation, research and environmental education institution whose aim is to conserve the natural complexes and sites of special environmental, historical and esthetic value, which are to be used for nature protection, education and awareness-building, scientific and cultural purposes, and for controlled tourism. Since 2001, Vodlozersky National Park has the status of a UNESCO Biosphere Reserve. Around 5000 tourists annually visit the park.

Kizhi State Open Air Museum of History, Architecture and Ethnography Federal State open-air museum is the largest open-air museum in Russia. The exhibition comprises age-old wooden buildings, including houses, maintenance facilities, chapels and churches, transferred from all over the Republic of Karelia, in total there are 80 architectural monuments dated 15–20 century. The center of the exhibition is the Kizhi Pogost – the architectural ensemble of two 18th century wooden churches and a belltower, inscribed on the UNESCO list in 1990. A buffer zone covering 9,999 ha has been established around Kizhi Island to ensure due protection of the unique landscape of the area. Kizhi Museum is a nature reserve, working on preservation of natural heritage on Kizhi Island and nearby areas. Annually over 160 000 visitors come to Kizhi from all over the world. There are 258 full-time employees in the museum.

Rokua esker region is a sandy esker hill. It is a distinct glacial formation example which has been given a UNESCO Geopark status. The region also has a national park and Natura 2000-sites. Tourism (hotels, entrepreneurs and 2nd homes) and forestry are crucial for the economy of the area. Especially the tourism is dependent on the ecosystem state of the region. The area has more than 60 lakes that are important ecosystems and crucial for attractiveness of the area. In the 2000s the lake conditions have caused concern of the local residents and stakeholders especially concerning the quantitative state of the lakes.

Koli National Park is located about 70 kilometers north of Joensuu, the capital of the province. The park's 80-kilometer-long marked trail network offers excellent hiking opportunities. Wellness, sightseeing, hiking, skiing, and sports are among other nature outdoor activities, important motives that attract visitors to the destination. The favourite place of the visitors in Koli National Park is the peak of Ukko-Koli Hill, which is the main site of all landscape admiration activities in the area. This scenic point is the highest summit in South-Finland, rising 347 meters above the sea and 253 meters above the lake Pielinen (the fourth largest lake in Finland). Since its designation in 1991, notable increase in visitor numbers to the National Park has been experienced and the visitor impacts are becoming more visible mainly during the peak summer months. In 2019, 201, 800 visits were made to Koli National Park.

Petkeljärvi National Parkis situated close to the Finnish-Russian border. It includes bodies of water and wild ridge scenes. The wild nature of the area is underlined by animals that thrive in the park, such as beavers, ravens, and the black-throated diver (the emblem bird of the park). The park's forests have remained untouched by the forest industry with 150-year-old shield bark covered pines as the oldest trees in the park. Petkeljärvi Camping Centre is located at the middle of the Petkeljärvi National Park. It provides visitor information, accommodation, food, sauna, and coffee. There are two ring-marked trails in the National Park. Apart from hiking, one can also paddle and row in the National Park. In 2019, a total of 19,400 visits were made to Petkeljärvi National Park.

1.3. Study methods

Study methods consist of field visits, collecting samples, analyses made by specialists and using DPSIR framework method (more in Chapter 2).

The DPSIR framework (Drivers, Pressures, State, Impacts, Responses) has been widely adopted for understanding links of **different drivers with impacts in environmental questions.** The goal of the DPSIR frameworks is to help local decision makers, inhabitants, and stakeholders understand how different drivers can for example impact their local economies, and how responses influence the current state of environments (Kristensen 2004). It also helps decision makers identify areas needing work and prepare appropriate response pathway.

DPSIR framework assumes a chain of causal links starting with 'driving forces' (economic sectors, human activities) through 'pressures' (emissions, waste) to 'states' (physical, chemical and biological) and 'impacts' on ecosystems, human health and functions, eventually leading to political/management 'responses' (prioritisation, target setting, indicators). Describing the causal chain from driving forces to impacts and responses is a complex task, hence tends to be broken down into sub-tasks, e.g. by considering the pressure-state relationship (Kristensen 2004). DPSIR analysis outcomes can thereafter be used e.g. in discussions with locals to pinpoint the key impact areas in the region or with decision makers on what management actions are needed to respond to impact or potential pressures in a region.

Material and methods for Kizhi and Vodlozersky National Park

The DPSIR framework was updated with field visits and studies by researchers from University of Oulu and Karelian Research Centre of the Russian Academy of Sciences (Fig. 1) with active participation by the staff of Vodlozersky National Park and the Kizhi Museum.

Figure 1. Meeting in Vodlozersky NP. (photo Gulnara Akhmetova)

Researchers from UOulu concentrated on the general hydrogeological conceptual analysis of the waste sites. KarRC RAS researchers studied soil, hydrology, and ecology of the sites. The sites in Kizhi and Vodlozersky NP included waste dump sites. The tourist sites with trampling issues were included into ecological and soil analyses for Vodlozersky NP.

Soil analysis of the sites is presented in chapters 3.3. and 4.3. Hydrological analysis concentrated on the microplastics in the surface waters of the sites (chapters 3.4. and 4.4.), but also included general hydrological conditions of the Onego Lake around the Kizhi site (chapter 4.5.).

Ecological analysis considering the flora of the sites is presented in chapter 4.6. as a general view for both of the Vodlozersky NP and Kizhi sites. The common ecological analysis gives more holistic view of the possible species met at waste sites and risks for invasive species.

Material and methods for Rokua

The Rokua case study representation is based on previous work considering groundwater and land use management conducted in Rokua region. The DPSIR approach in Rokua is based on Multicriteria decision analysis work (Karjalainen et al. 2013) conducted in the case site and modelling on MODFLOW model built for the area (Rossi et al. 2014). Both DPSIR and the numerical modelling demonstration reports of the region are based on scientific publications (Karjalainen et al. 2013, Rossi et al. 2014, Ala-aho et al. 2013, Rossi et al. 2012, Eskelinen et al. 2015).

Material and methods for Koli and Petkeljärvi

The data consists of both primary and secondary sources. The secondary data is mainly sourced through desk research. Google scholar, research articles from University of Finland database, and articles from related journals were sourced (such are journals of sustainability, cleaner production, and sustainable tourism). The primary data consists of regional studies on land-uses, and water quality assessment. The water quality assessment data is from the Centre for Economic Development, Transport, and the Environment and the Finnish Environment Institute. The land-use data was sourced from LIFE IP Freshabit and SHAPE NPA project research from 2017-2019.

The DPSIR framework is used in this research to analyze and understand the links of the different drivers (local-uses ¬– tourism) to waste generation and impacts on environments of Koli and Petkeljärvi National Parks and surrounding areas. The analysis concentrates on land (pressures on forests and forest biodiversity), and water (pressures on waterbodies) inside the National Parks (NPs) and surrounding environments. This is because tourism activities are stressed as dependent upon these, and tourism activities takes place not only within the national parks, but also surrounding areas outside these targets, that lie within the Biosphere Reserve (BR) (UNESCO 2019). The drivers, pressures, state, impacts and responses (DPSIR) areas are investigated, after which recommendations offered for policy and decision makers.

2. DPSIR FRAMEWORK METHOD

The DPSIR framework is based on the idea that there is a chain of causal parts starting from driving forces (human activities, economic sectors) going through pressures (e.g., waste, emissions) to states (chemical, biological, physical) and impacts (on ecosystems, function of society, human health), finally leading to political responses (target setting, indicators, prioritization) (Kristensen 2004). The main idea of the DPSIR framework is defined in the Figure 2.

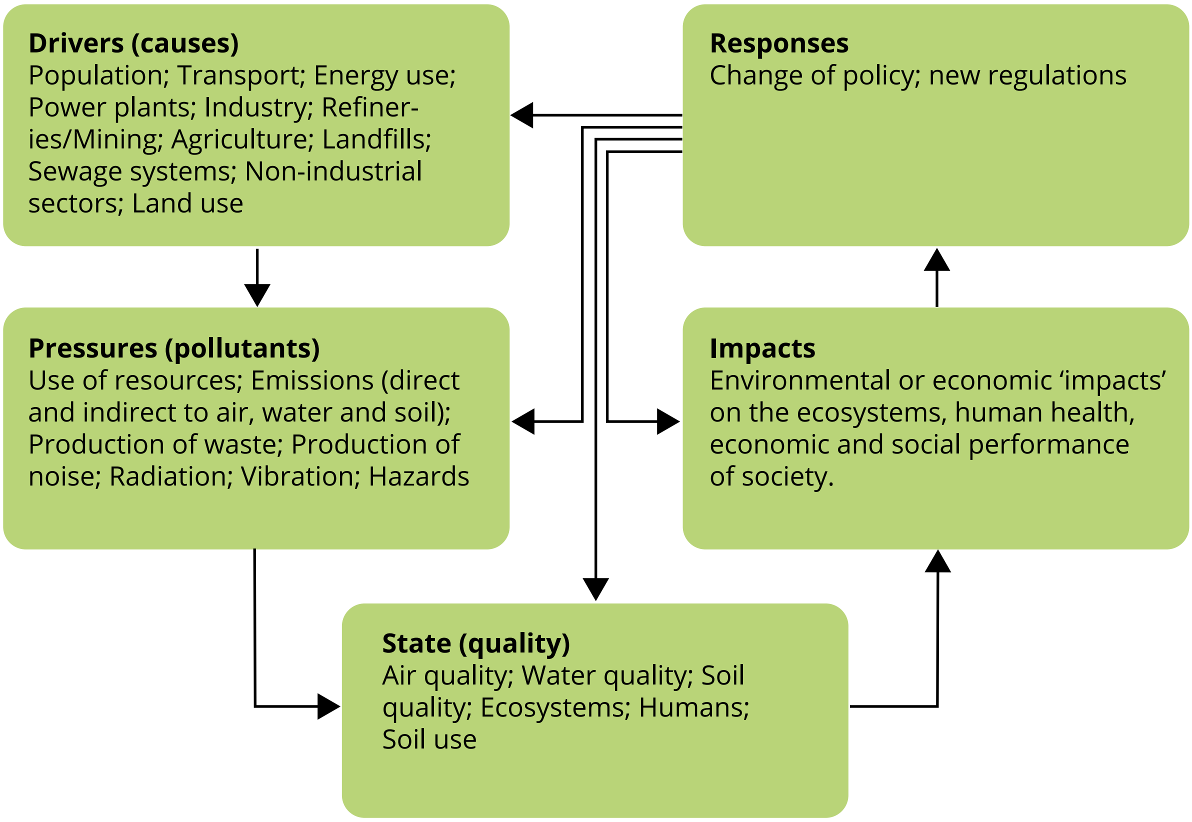


Figure 2. The DPSIR framework (based on Kristensen 2004).

In DPSIR, a need is a driving force. Driving forces are e.g., the need for shelter, food and water; need for mobility, entertainment and culture; the need to produce at low costs. These human activities (production and consumption processes) meeting a need exert pressures on the environment. There are three main types: 1) excessive use of environmental resources, 2) changes in land use, and 3) emissions (Kristensen 2004).

The state of the environment (physical, chemical and biological conditions) is affected due to the result of pressures. The quality of the environment (air, water, soil, etc.) is affected in relation to the functions that these compartments fulfil. The changes in the environment determine the quality of ecosystems and the human welfare. Changes in the state can have environmental or economic impacts on the ecosystems' functions and on human health and on the economic and social functions of society. Society´s or policy makers' response (e.g., policy to change to public transportation, lower CO2 emission levels) is the result of an impact. It can affect in any phase of the chain between driving forces and impacts (Kristensen 2004).

Figure 3. Vodlozersky National Park. Photo by Elena Fedorova.

3. CASE VODLOZERO, RUSSIA

3.1 Site introduction

Vodlozersky National Park is situated on the eastern side of the Onega Lake (Fig. 3.). The National Park covers 4280 square kilometers divided between the Republic of Karelia and Arkhangelsk Region.

Vodlozersky National Park is the second largest national park in Europe after Yugyd Va National Park (also in Russia). Main region of the National Park and services are concentrated on the surroundings of Lake Vodlozero (Fig. 4.).

Lake Vodlozero covers 322 km2 (average depth 2 m) and the main village of the region, Kuganavolok, is situated at a tip of a peninsula on southern part of the lake (Fig. 4.).

Figure 4. Lake Vodlozero. Photo by Pekka Rossi.

Most of the tourists in the National Park region travel through the Kuganavolok village and most of the permanent residents (300 inhabitants) in the region are situated on the Peninsula. Therefore, the Kuganavolok region is the main site of waste management (collection, processing and transferring). In previous decades the waste was collected to a waste site on the southern side of the village (Fig. 5., red square). The waste site has now been closed and the waste transported directly to Pudozh municipality for management.

Detailed information about the existing waste management situation was asked from the personnel of the National Park for the SUPER project. On average, 600 cubic meters of mixed waste is transported from the park each year, plus about 500 kg of sorted waste. The mixed and sorted waste from Vodlozersky National Park is exported by LLC Avtospetstrans to the landfills and waste processing facilities in Pudozh, Medvezhyegorsk and Petrozavodsk. Waste is transported 80 km, 230 km and 400 km respectively, based on its kind and origin, in garbage trucks from Kuganavolok village to Pudozh, Medvezhyegorsk and Petrozavodsk. Separate waste collection is organized by the Vodlozersky National Park. Separately collected aluminum cans, glass, and paper, cardboard and plastic are transported 400 km to Petrozavodsk by truck to LLC UVI-PTZ. At the moment, there are no suitable waste disposal facilities nearby.

About 400 people live on the territory of the Vodlozersky National Park during the winter. The number grows up to 2000 during the summer. During the past several years, the number of tourists in the park has been about 4600-5400 annually. In Kuganavolok village, the only populated area within the National Park`s territory, two shops are located. Waste containers are installed near the shops. There are no cafes, restaurants or any other public catering facilities. Tourists cook and eat at equipped tourist places. Waste is taken to the Kuganavolok

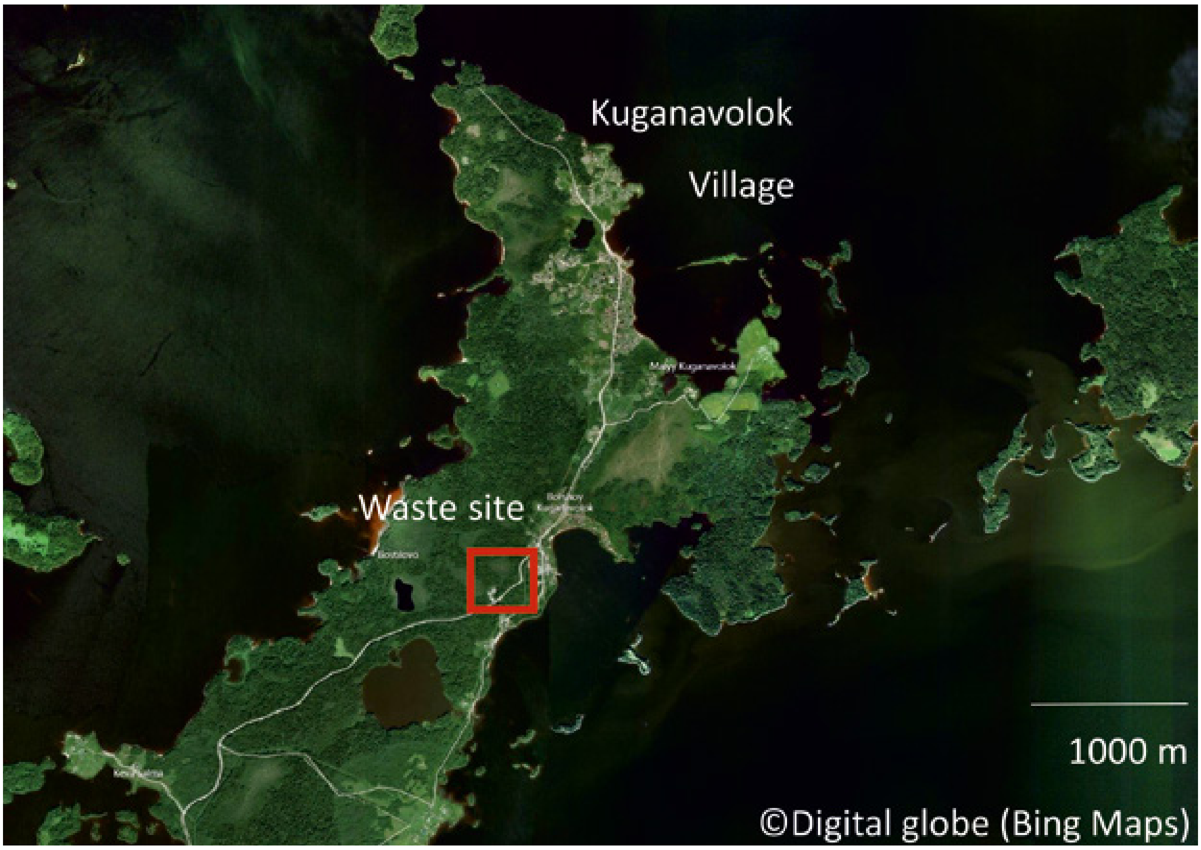


Figure 5. Map of the Vodlozersky NP village peninsula with the Kuganavolok village and old waste site (red square).

village, where the separate waste collection and sorting station for further packing and export is located. For now, there are enough containers for the mixed waste. Mixed waste is generally removed once a week, and twice a week in the summer. The separate waste collection is performed by the National Park only. The park uses modified mesh containers for separate waste collection.

Better waste management in the area and/or cleaning of the old waste dumps would improve the attractiveness of the area for the tourists or social well-being of the inhabitants. The main problems related to waste in the park is the existence of an old unmanaged landfill within the Kuganavolok village area. It is necessary to export and remove the waste accumulated here over the decades. The Park needs also to purchase the hovercraft with the platform for waste containers to export waste from the upper reaches of the Ileksa River, and the garbage truck to export separately collected waste.

The National Park employee, who provides the separate waste collection and keeps order at the waste containers stations in the Park, would also maintain the better waste management in future. Regional operator LLC Avtospetstrans has concluded the contracts on waste removal with each family. The price is calculated on the basis of family members' number and specified standards of waste generation. Vodlozersky National Park pays for the mixed waste removal under the contract with LLC Avtospetstran, as the separately collected waste is exported by the Park.

3.2. DPSIR for Vodlozersky NP

3.2.1. Drivers

The National Park has questions considering the old waste site. Currently the National Park waste management includes assorting of waste in different sites managed by the park (Fig. 6.). Both, the assorted waste from the sites managed by the National Park and the waste from the village are transported outside of the region to the Pudozh municipal center. Considering the old waste site, the impacts are unknown. Managers of the park region have not yet decided on best possible approach for handling the old waste site.

Figure 6. Waste sorting bins at Ohtoma site on the western shore of Lake Vodlozero.
Photo by Pekka Rossi.

The number of residents in the area is rather small, but the visitors easily increase the number, hence, the amount of waste fluctuates depending on the time of the year. Also, local working places are generating some amount of waste. Infrastructure in the area is not the best possible, so in order to improve waste management, and to remove the illegal dumps, the state of the roads requires improvement.

3.2.2. Pressures

As the impacts of the old waste site is unknown it creates pressure to the National Park management. Does the old waste site impact the drinking water? What are the ecological impacts of the waste site? Does the waste site have impacts to the behavior of the tourists or local inhabitants if no action is taken? As the pressures are uncertain, the state and impacts have uncertainties. Although, the waste in old waste sites could be typical Russian MSW (according to Vtorothody 2020; mainly food, paper, plastic, glass, metal etc.), it is not known for sure, so the treatment of old waste site could be done carefully to avoid more harm to environment and people.

To better comprehend the pressures and state of the area, a field visit to the site was conducted during June 3rd to June 5th 2019 by UOulu and KarRC RAS (Fig. 7.). The researchers elaborated the details of the site to better understand what the hydrological, geological and ecological conditions in the area are. They also investigated how the water supply is organized in the area.

Figure 7. Researcher at the closed Vodlozersky NP waste site. Photo by Pekka Rossi.

The first results concerning the pressure considered the organization of water supply. Based on the information, most of the potable water and household water is pumped from the lake straight to use with intake pipes situated further from shoreline in the bottom. The water quality of the lake is acceptable for drinking water purposes, though color values are bit high (probably due to humus from peatlands) based on environmental authorities. Based on our National Park crew some of the people in the village have some problems with the stomach due to the lake water and don't use it as it has low pH. Some wells are situated in the village but not in use. Also, one spring is harnessed for drinking water purposes.

3.2.3. State

During the field visit, a conceptual map of the waste site surroundings was created (Fig. 8.). The waste site surroundings are rather flat, even though somewhat higher elevation is situated on the south side of the waste site. Also, some sandy hills based on the geology are situated on the south and south-east, next to the waste site. Based on site information, the waste site was previously a sand extraction site. As the surroundings are rather flat, the exact hydrological flow paths for the water are tricky to estimate. However, there would be two possible flow paths for the waters flowing from waste site: surface flow or to groundwater.

Considering the surface water flow, there were two main directions of the water flow: there were two lower areas next to the waste site where the water wasn't flowing but the elevation would direct the water through a ditch in the north to small ponds and eventually to wetland. The water in this ditch had electric conductivity of 161 mikroS/cm (compared to 26 mikroS/cm measured from the lake on the same day), indicating that some elements have dissolved to the water. The ditch water had some oily surface, and the odor was strong. On the western side a possible flow path to wetland was visible. If these are the main directions of the surface water, then the water would flow through wetlands before reaching lake Vodlozero. The wetlands might work as a natural purifiers for the waters: e.g., the nutrients would be used by biology and the heavy metals might, at least on some level, bind to organic material. In this case the load to the lake i.e., main drinking water source would have fairly good protection from the waste site, even though the close surroundings might be heavily affected. To monitor this pathway more in detail the wetlands should be checked for possible visible flow routes further from the waste site and the phosphorus/ammonium readings from the waters at different distances from the waste site could be checked.

The second possible pathway for waters from the waste sites is to the sand beneath. This possibility is harder to analyze as the geology and the landforms were unclear. Based on soil study by KarRC RAS, the soil on the southern side of the waste site is sandy (and the area has been used for sand extraction) so there is a fair possibility that the water from the waste site is seeping into the soil beneath. The exact direction of water is hard to define without piezometers as the soil elevation is rather even. Based on the field visit the most probable direction would be to North-East or South, depending on the soil type. In the West the initial check seemed the soil there was clay, which would block the groundwater flow to that direction. However, if the water is seeping to the soil, the groundwater flow might be slow due to small gradients. This can be helpful for the lake water quality but soil in the surroundings of the waste site is probably in a weak condition.

The detailed soil studies did find that some of the rare earth elements (REE) were high in the soil of the waste site (see 3.3. for details), that can create risks to surrounding. Ecological analysis did find that the area had altered flora with some invasive species (see 4.6.).

Based on initial results from the field visit, the highest risk areas of potable water risks were circled in Figure 9. The households in the surroundings should be checked for source and quality. Waste site might have impact to the nearby water quality, but further the peninsula and lake, the impacts most probably diminish as the lake volume is considerable and the topography of the peninsula is rather even. The microplastic studies did not find any higher

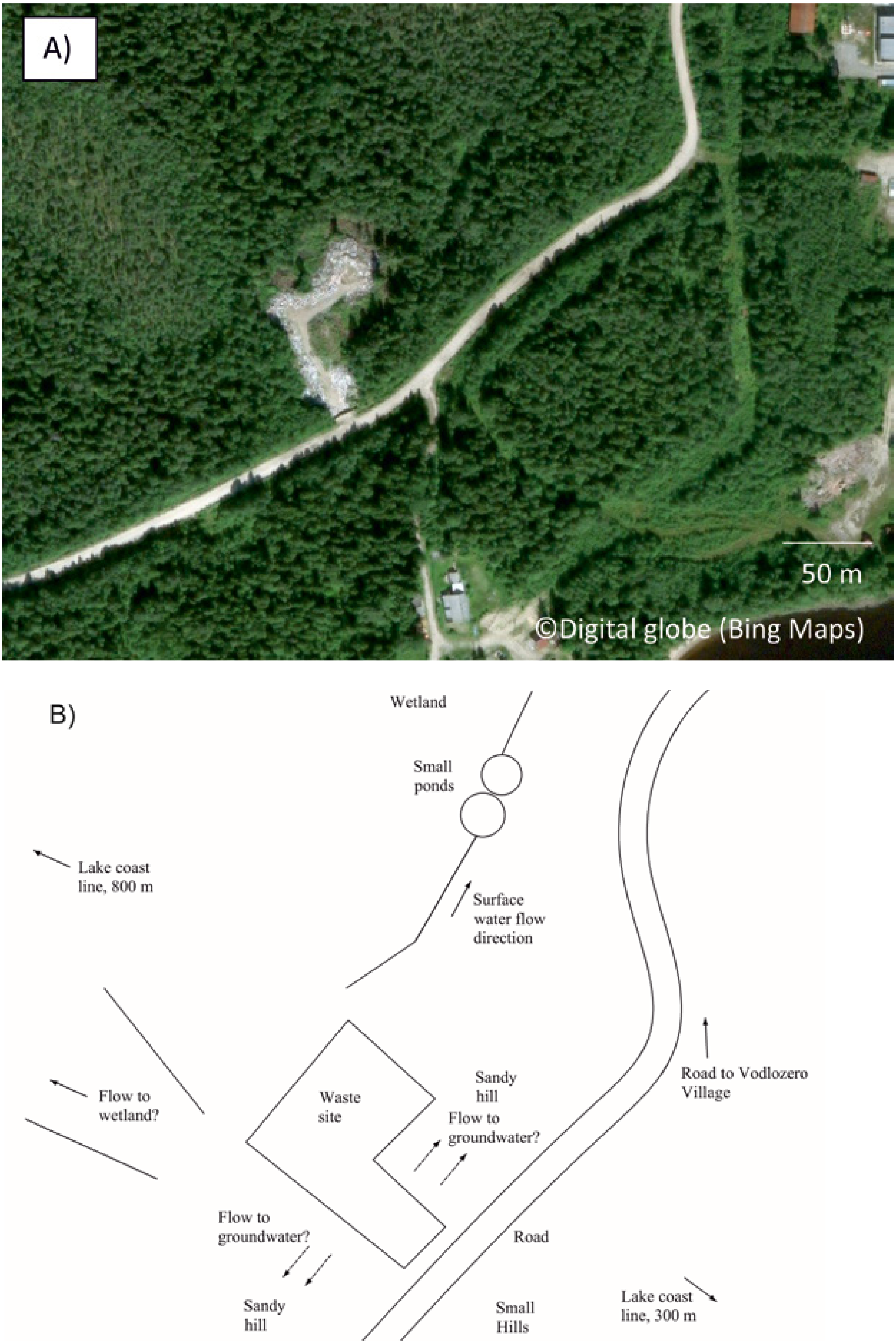


Figure 8. A) Detailed aerial view and B) Conceptual map of the hydrogeological settings of the closed Vodlozersky NP waste site.

amounts of plastic material from the sediments of the lake nearby the waste site (see 3.4.). More interestingly, highest microplastic amounts were monitored in the northern parts of Lake Vodlozero probably due to nearby river inlet.

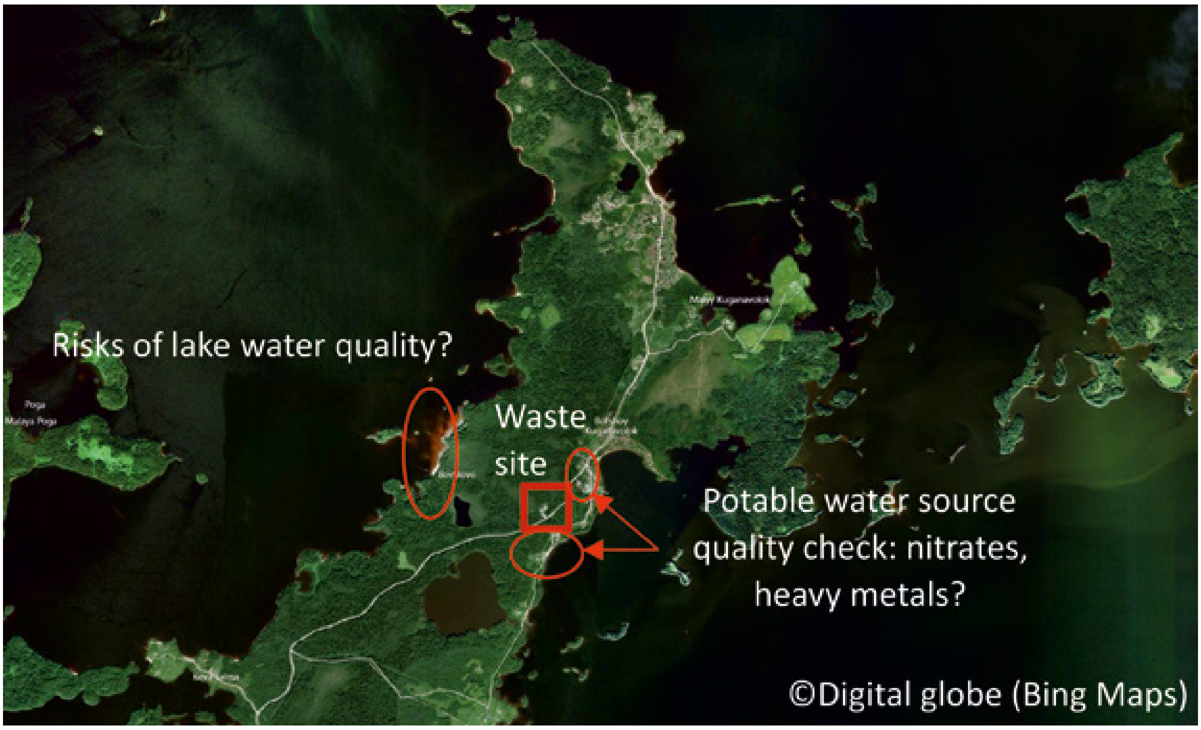


Figure 9. Regions for possible water quality risks and future steps to check possible impacts.

3.2.4. Impacts

Considering the attractiveness of the region, the closed waste site might have negative impact as it is situated on the side of the main road to the region. Considering the waste management impacts to the attractiveness of the region as a tourist destination, it is considered important that the current waste management be functional, and the waste logistics secured (e.g., road conditions). It can be assumed that the old waste sites and poor waste management weaken the social wellbeing of residents and are making those areas less attractive to the tourists and visitors. Considering ecological and environmental impacts of the waste site, the results from KarRC RAS field visit offered more detailed information, e.g., on invasive species and nearby soil quality which enhance the need for site remediation.

3.2.5. Responses

Based on the discussions with the National Park authorities, different options for the old waste site have been considered, including its removal and closing. One option is transporting the material from the waste site to Pudozh and/or Medvezhegorsk municipality and away from the National Park site. This would remove the pressure to the site and would reduce/minimize the future impacts to the site. The state of the area would replenish eventually once the source is eliminated.

Other option that has been discussed would be filling the site. This might diminish the impacts but not remove the source. The key thought in this case would be how the filling is done. If the material placed on top of the waste site has some hydraulic conductivity, the rainwater/snow melt water might still reach the waste and the state of the surroundings might not improve. From visual point of view, the area would look better. From these two responses, the first option would tackle the problem more thoroughly from the National Park area.

Considering these two options, the whole waste management strategy (old waste sites, existing systems, new plans, future possibilities based on studies on waste amounts and types) in general should be considered. The impacts of the waste site to drinking water are limited (as it seems), so no abrupt diminishing of drinking water sources is expected. However, based on the soil (3.3.) and ecological (4.6.) analyses the site does have clear impacts to the imminent surroundings. Considering this, before deciding the solution to the old waste site, the resources are probably more valuable on current waste management. The road condition improvement to the Kuganavolok village might be a good point for waste collection to ensure the good logistics from the region for the waste deportation. This would also encourage the transfer of the old waste material from the peninsula.

The outcome of DPSIR framework for Vodlozersky NP can be seen in figure 10. More detailed conclusions and recommendations for all sites are presented in Chapter 7.

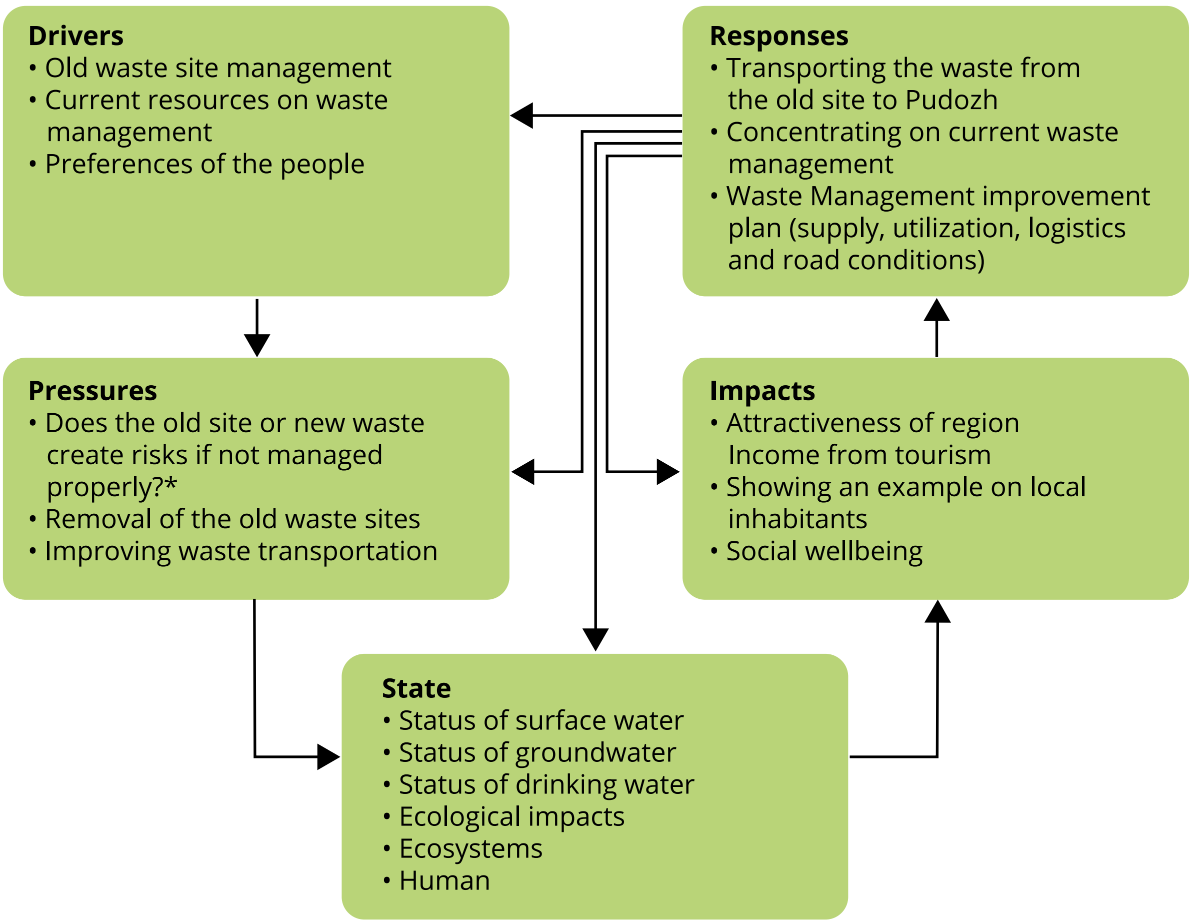


Figure 10. DPSIR framework of the Vodlozero case site. (* refers to potential pressure, + refers to good state, - refer to needing improvement)

3.3. Soil Research and Analysis – Vodlozersky National Park

3.3.1. Need for research

In all stages of their operation and even after closure, landfill areas pose high potential contamination danger, so the ecological and geochemical characteristics of their environmental components need to be assessed. The soil is one of the main natural components affected by waste piling. The technogenic pressure alters the vectors of soil-formation processes, physical and chemical properties of soils, and morphological characteristics of soil profiles (Zamotaev et al. 2018; Nyika et al., 2020). The soil accumulates contaminants, including toxic pollutants – heavy metals (Добровольский, 1997, 1999; Водяницкий, 2005, 2008; Водяницкий и др. 2012; Пляскина, Ладонин, 2009; Мотузова и др. 2011; Barbieri et al., 2020, Федорец и др., 1998, 2008). As a result, there form local-scale geochemical anomalies (Башаркевич, Ефимова, 1992; Roy & Mcdonald, 2015; Zilenina et al., 2017; Othman et al., 2019), which appear even in small waste dumps (Филиппова, Юркова, 2009). Furthermore, high organic pollution of soils in illegal dumps poses sanitary hazard because the environment is favorable for opportunistic and pathogenic microorganisms causing various diseases (Соколов и др., 2014, Wang et al., 2020).

A special issue to be researched is the content of rare-earth elements REE, including lanthanides, in soil. Their latest application in electronic and other technologies has boosted their extraction globally and resulted in their dispersal through the environment (Yasuo & Kamitani, 2006, Ramos et al., 2016) – REE extraction has risen nearly ten-fold since the 1970s. The main anthropogenic sources of REE are ore mining and processing, oil processing, coal combustion, disposal of domestic electronics (Fedele et al., 2008, Long et al., 2010, Gutiérrez-Gutiérrez…, 2015).

The soil is directly exposed to recreational load, so the scope of variation of its properties is a most objective criterion for evaluating the intensity of the impact. The recreational impact begins with trampling down of the ground vegetation and forest floor (Лазарева, Морозова, 1987, Kissling et al., 2009). The forest floor gets compressed and compacted, its components are comminuted, so that eventually the floor gets weathered away and mineral soil layers are exposed. The loss of the forest floor results in a heavier freezing of the soil, changes in its physical properties and hydrological conditions, scarce and poorer development of the ground vegetation, lower forest productivity. The soil deprived of the plant cover and forest floor is susceptible to erosion by wind and water. Also, soil density is substantially increased, the results being lower total porosity, reduced air exchange between the soil and the atmosphere, greater variation of the thermal conditions (Морозова, Лазарева, 1983, Hill & Summer, 1967). Changes happen also in the rate of water percolation, which is a significant factor for plant life. Poor water permeability of the soil reduces air supply into it and leads to greater runoff and evaporation of moisture both from within and from the surface of the soil. The overall outcome of that is gradual degradation of the soil and the environment (Kuznetsov et al., 2019).

3.3.2. Study sites

Surveys were carried out in several areas in the Vodlozersky National Park exposed to diverse anthropogenic impacts – an illegal dumps and tourist campsites (Fig. 11).

Figure 11. Study sites in Vodlozersky NP.

3.3.3. Study methods

The trampled areas were diagnosed by comparisons against reference plots not exposed to human pressure. Bulk density of soil mineral horizons was chosen as the parameter as being the most prone to abrupt change under recreational pressure and easy to determine.

Samples for the analysis of the effect of recreational load on soil water and physical properties were taken by a borer (100 cm2 volume). Samples were taken and measured in 5-10 replicates for each type of surface. The high stone content of soils in the Okhtoma campsite precluded the analysis of recreational effect on their water and physical properties.

Soil samples from waste dumps were analyzed for:
- Soil classification (IUSS..., 2014)
- Soil acidity – potentiometrically, using laboratory pH meter HI-2211-02 (Hanna Instruments, Germany);
- Organic carbon and nitrogen content – with CHN analyzer, 2400 Series II CHNS/O Elemental Analyzer (Perkin Elmer, USA);
- Labile phosphorus – by Kirsanov's method terminated by spectrophotometry with SF-2000 (Russia);
- Total content of the heavy metals Zn, Cu, Pb, Cd, Cr, As, etc. – determined by inductively coupled plasma spectrometry with microwave digestion of samples in inductively coupled plasma mass spectrometer and laser ablation system X Series 2+UP-266 macro Thermo (Ficher Scientific, Germany, USA).
- Labile forms of Zn, Cu, Pb, Cd, Cr, etc. – measured by inductively coupled plasma spectrometry with extraction by pH 4.8 ammonium acetate buffer (AAB). The amount of labile metal compounds in AAB extracts is a measure of micro nutrients available to plants, and of the ecological condition of contaminated soils. The content of labile Cr (III), Mn, Co, Ni, Cu, Zn, Pb in soils is regulated by maximum permissible concentrations (MPC) set in the state standard GN 1.2.3685-21.
- Sanitary microbiological parameters – coliform index, pathogenic bacteria, enterococcus index, pathogenic intestinal protozoan cysts, helminth eggs.

3.3.4. Results

Campsites

Three campsites in Vodlozersky Park were surveyed during the study. Trampling damage in the campsites mostly concentrated around built infrastructure, and the boundaries of the disturbed area depend on the distances between infrastructure elements.

Zones with different degrees of ground cover and forest floor degradation were distinguished within the campsites.

Heavy trampling damage zone is where the ground vegetation cover is absent (Fig 12.). The forest floor is absent, and soil mineral horizons are exposed. Occurs in sites with the heaviest human pressure – fire ring, dining table, at woodshed, around lodges.

Figure 12. Heavy degradation area in a campsite on Isl. Rogunovo.

Medium trampling damage zone (Fig. 13) – ground vegetation is present only around trees, forest floor compacted and worn out (thickness ranges from 1 to 3 cm). This zone corresponds to digression stage III-IV and occupies on average ca. 25% of the campsite area.

Figure 13. Medium degradation area in a campsite on Isl. Rogunovo.

Mild trampling damage zone (Fig. 14) – vegetation in suppressed condition, forest floor only slightly compacted (5 cm thick at maximum). This zone can occupy up to 30-35% of the site area and corresponds to digression degree II-III. Not all the campsites had this zone.

Figure 14. Mild trampling damage zone in a campsite on Isl. Rogunovo.

The physical and water properties of soils were quantified in areas at different stages of digression and with different types of use.

These parameters were found to vary depending on trampling intensity – free moisture content in the soil decreases (Fig. 14a), upper soil layers become slightly denser (Fig. 14b) affecting moisture and nutrients supply to tree roots.

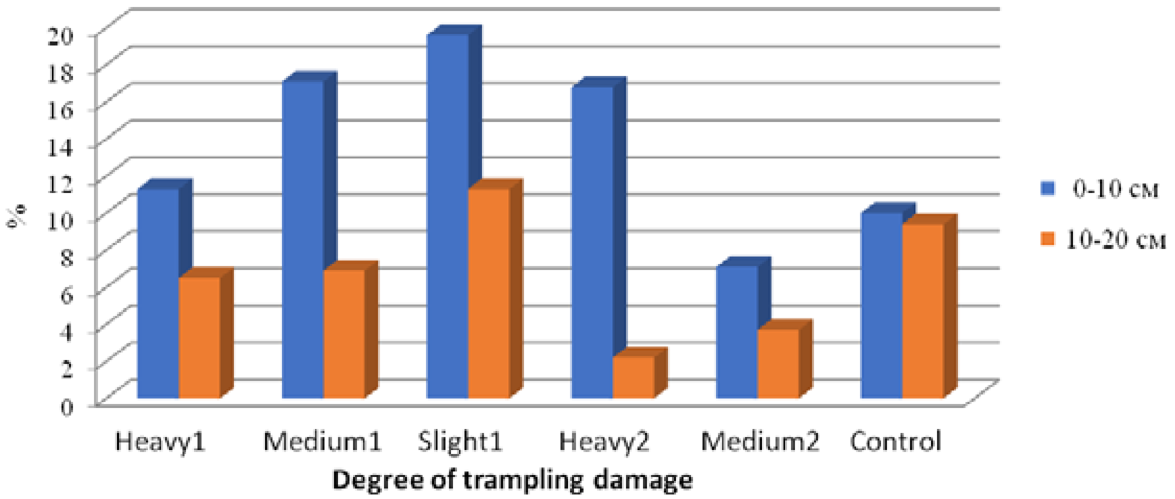


Figure 14a. Changes in soil moisture content in relation to the degree of trampling damage, Isl. Rogunovo

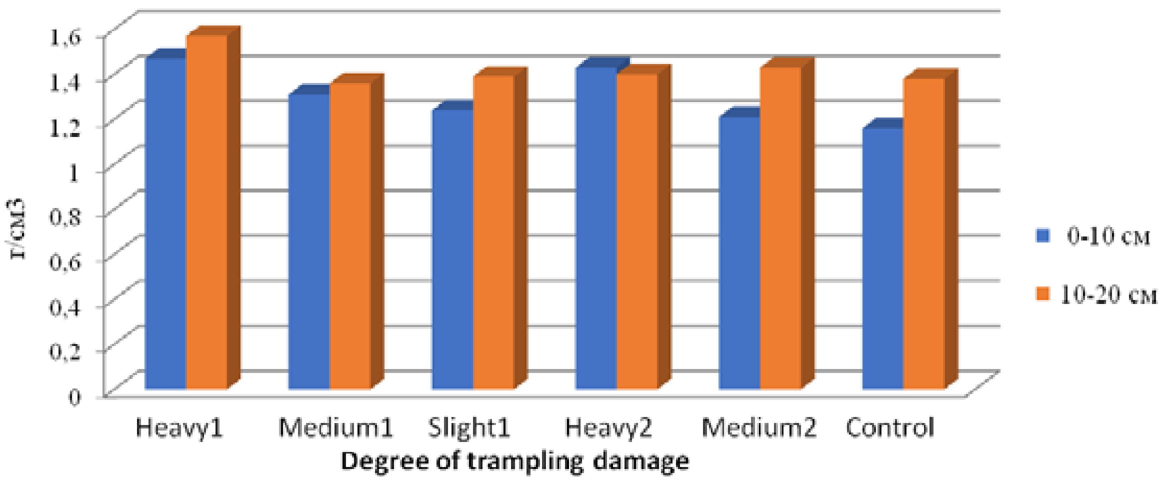


Figure 14b. Changes in soil density in relation to the degree of trampling damage, Isl. Rogunovo

Contrary to what was expected, the acidity of recreation-affected soils did not tend to change towards weakly acidic or near-neutral reaction, even in the parking lot in the Okhtoma tourist facility (Tabs. 1 & 2). The explanations are the short duration of use and not very high tourist traffic.

Table 1. Soil acidity variation in campsites on Isl. Rogunovo

Site	Trampling damage	Depth, cm / Horizon	pH KCl	pH H2O
Rogunovo 1	heavy	0-10	4.18	5.75
	heavy	10-20	3.77	4.99
	medium	0-10	3.86	6.25
	medium	10-20	3.73	5.22
	mild	0-10	4.22	5.76
	mild	10-20	3.69	5.82
Rogunovo 2	heavy	0-10	4.1	4.86
	heavy	10-20	3.58	4.4
	medium	0-10	3.86	4.75
	medium	10-20	3.15	no data
Control		O	3.25	4.4
		BF	3.64	4.45
		B2	4.14	5.5
		BC	4.36	5.51

Table 2. Soil acidity variation in the Okhtoma campsites

Type of use	Depth, cm / Horizon	pH KCl	pH H2O
Road	0-10	4.5	5.34
	10-20	3.51	4.74
	below 20	4.45	5.2
Parking lot	0-10	5.12	5.96
	10-20	5.08	6.33
	below 20	5.26	6.23
Medium trampling damage zone	AdA1, 0-12	4.83	5.8
	B1, 12-23	4.61	5.56
	BC1,23-32	4.21	5.7
	BC2, below 32	4.79	5.87
Control	O, 0-15	3.43	4.36
	E, 15-35	3.18	4.43
	EB, 35-45	3.22	5.43
	BF, 45-70	5.27	6.33
	BC, below 70	5.00	6.77

Waste site

An unauthorized dump is situated near Kuganavolok Village (Figs. 5 and 15), occupying ca. 0.3 ha. The dump emerged spontaneously in a former sand quarry in the 1990s. It appears as several large heaps of diverse garbage – wood, glass and plastic bottles and packaging, domestic appliances, toys, diapers, lots of canisters, aluminum cans, etc.

Figure 15. Unauthorized domestic waste dump near Vlg. Kuganavolok.

There are areas of pine-spruce forest along the road near the dump, growing on sandy Albic Podzols, which were used for reference (Fig. 16).

The soil of the dump can be classified as Spolic Urbic Tehchosol (Epiarenic). It is a mixture of sand and garbage – the result of a recent attempt to cover up the dump without removing the existing waste (Fig. 17)

Soil pits were made in 3 points within the dump, where soil samples were collected from 0-10, 10-20 and 50 cm depths. Also, silt samples were taken from a small overgrowing stream in the forest. Combined soil samples from the upper layer were collected for sanitary-bacteriological and parasitological analysis.

Soil temperature loggers were deployed at 5 and 25 cm depths in three points in the dump and in the reference plot to record temperature variations.

Variation of soil temperature conditions

Figure 16. Reference soil pit.

Figure 17. Soil under the unauthorized domestic waste dump

The data obtained indicates substantial differences in the temperature parameters of soils of the dump and the reference site (Fig. 18.). The primary factor was changes in the ground cover: soil temperatures in nearly barren dump areas (points 1 & 2) were higher than in vegetated dump areas (point 3) and the control (the difference was up to 10-15 degrees). Points 1 and 2 also featured significant circadian soil temperature fluctuations.

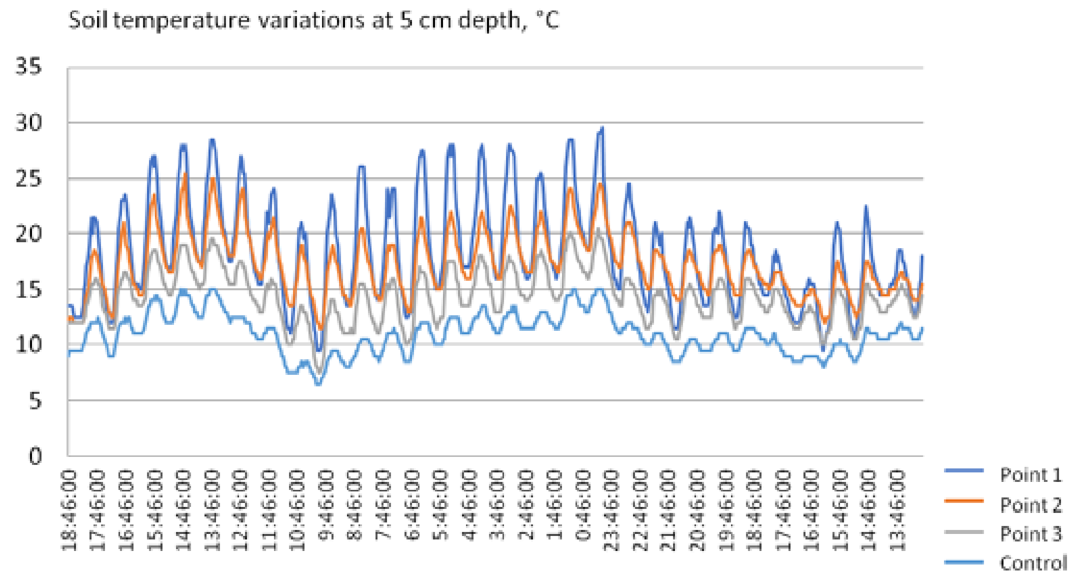


Figure 18. Temperature variations in the soil at 5 cm depth, °C (point 1, point 2, point 3, control)

Soil temperature changed the most significantly in the upper layer, while the tendency in the underlying horizons persisted but was less pronounced (Fig. 19).

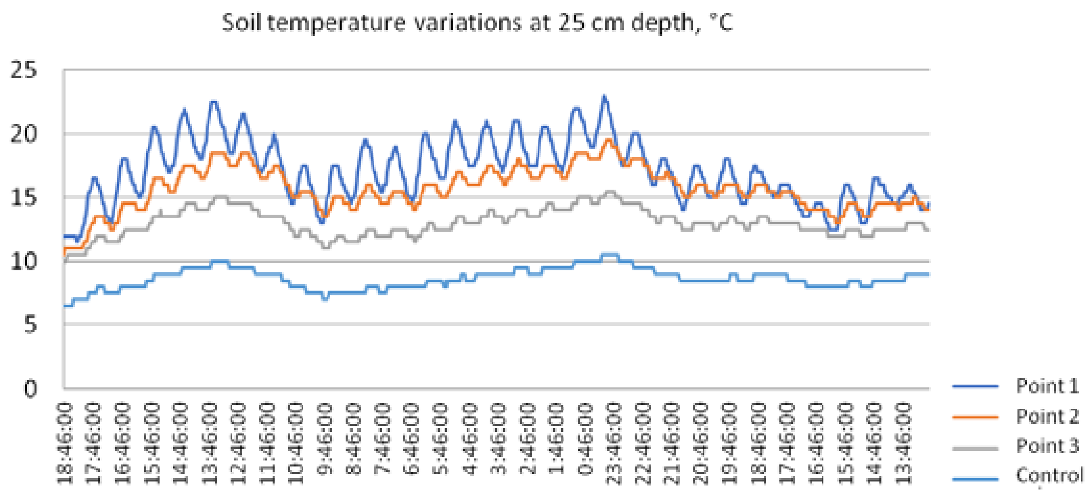


Figure 19. Soil temperature variations at 25 cm depth, °C (point 1, point 2, point 3, control)

Changes in soil agrochemical properties

Soils in the dump, their properties, including physical and chemical properties (Table 3), differ from natural soils in the background.

Table 3. Physical and chemical properties of the soils surveyed (Vodlozersky NP)

Site	soil layer/ horizon	pHKCl	pHH2O	C, %	N,%	Labile P %
Dump	0-10 cm	5.33±.0.49	6.12±0.65	1.4±0.74	0.19±0.12	0.005±0.002
	10-20 cm	4.50±0.59	5.81±0.59	0.16±0.11	0.03±0.01	0.007±0.002
	below 50 cm	4.42±0.89	5.81±0.76	0.07±0.02	0.01±0.004	0.009±0.003
Control	O	3.03	4.24	29.41	1.99	0.0035
	Control	3.06	4.18	0.74	0.10	0.0006
	BF	4.22	4.95	1.06	0.15	0.0003
	BC	4.3	5.39	0.07	<0.005	0.0003

Determinations of the acidity parameters of the soils showed that, as compared to reference soils (pHKCl 3-4, pHH2O 4-5), the parameters have changed slightly towards lower acidity (Table 3). Potential pHKCl varied from 5.33 in the upper to 4.4 in the lower layers, whereas actual acidity was near weakly acidic or neutral reaction – pHH2O 5.8-6.1. This is associated with a transformation of pedogenic processes, absence of acid, slowly degrading litter (needles, tree cones, branches, bark, etc.), dominance of herbs, grasses, etc. in the vegetation, and the composition of the waste deposit, which may contain alkalinizing agents.

Researchers have often observed elevated levels of carbon and mineral nutrients (nitrogen and phosphorus) in landfill soils. In our case, only labile phosphorus content was elevated in all soil layers in the dump, possibly because of the waste composition – food wastes, etc.

Total content of chemical elements

Waste is a key source of the input of various chemical substances and elements to the soil. Hence, geochemical survey of the dump and comparison against a reference would help determine the degree of the site transformation.

Studies revealed the total content and the content of labile forms of a wide range of chemical elements in soils of the dump and the background control sites (Table 4). It is commonly held that the most correct approach to determining the degree of soil pollution with various substances and elements is a comparison against background soils or a control (Добровольский, 1997, 1999, Водяницкий, 2005, Reimann et al., 2005, Reimann & Caritat, 2005, Reimann & Garrett, 2005, Salminen et al., 2004).

Overall, soils in the dump featured a higher content of a majority of the chemical elements studied than the control. The most obvious was zinc contamination in the upper soil layer – up to 300-500 mg/kg, i.e., 6-10 times that of the control. A similar situation, but with a smaller increase, was observed for lead, copper, and cadmium. Arsenic concentration was notably high – its content in soil from the control site was below detectability, in the dump soil it was up to 2-3 mg/kg, and one of the samples contained 4.8 mg/kg. This fact definitely proves that the wastes are a source of high concentrations of this hazardous metalloid. The same tendency, although to a smaller degree, is seen for antimony – a sample from the upper soil layer in the dump contained as much as 4.9 mg/kg, the average level being 1.5 mg/kg. Let us remark that the above elements are usually mentioned as the principal contaminants of soils in landfills (Barbieri et al., 2014, Gworek et al., 2016).

Compared to soils in the control, dump soils contained slightly higher (1.2-1.5-fold) concentrations of the alkaline earth metals beryllium and strontium. Dump soils also showed a tendency to accumulate a majority of rare earth elements (REE), as compared to the control. E.g., for La, Ce, Pr, Sm, etc. this trend is even more explicit – their concentrations are 1.2-1.5 times higher, while for other elements it is less expressed. We can therefore speak of an elevated geochemical REE background in the dump soils, no doubt ensuing from a high content of waste with electronic parts, whose alloys include many REE.

A closer study of the pollution characteristics and directions of element migration downwards revealed the elements had different patterns of distribution across the soil profile. For elements such as Li, P, V, Cu, Zn, Pb, As, Sn, Sb, Mo, Sr, Be, Ba, the highest concentrations are observed in the top 0-10-cm layer and decline with depth (Fig. 20). Hence, the contamination of the dump soils with labile forms of copper, zinc, lead, arsenic, tin, and antimony is only superficial. The higher content of these elements in the upper layer is probably due to their capacity to bind to organic matter to form metal-organic compounds, whereas the sharp reduction in their concentrations down the profile is due to wash-out by precipitation and leaching upon organic matter decomposition.

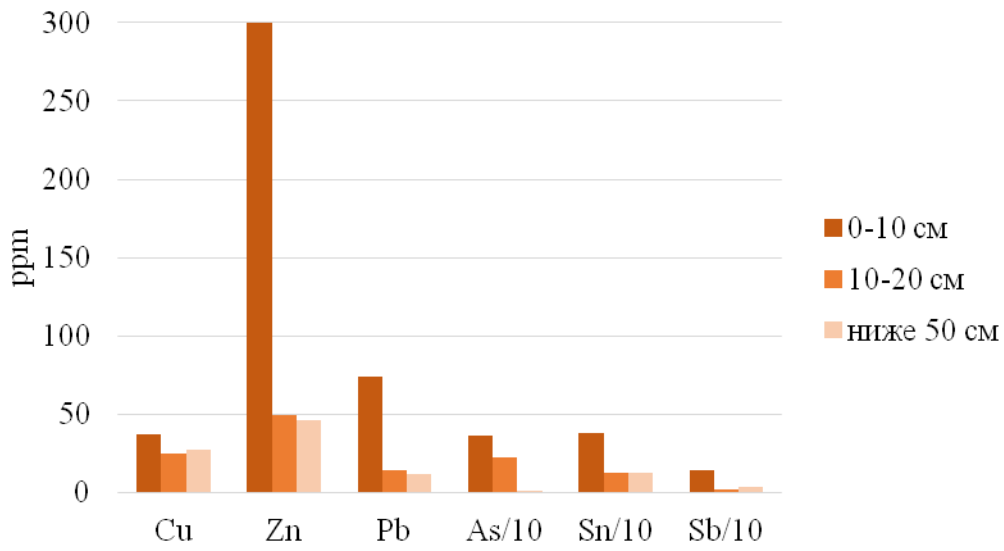


Figure 20. Depth-wise changes in the content of some metals and metalloids in the dump soil.

Meanwhile, the content of a majority of the studied elements, including REE, showed little chance depth-wise, suggesting they were rather inactive in the process of biogenic accumulation. Lanthanides also prove to be relatively inert chemically in soil-formation processes in a humid climate (Самонова, 2013). These elements are reported to form stable complexes and poorly soluble compounds, preventing their leaching.

Table 4. Total content of chemical elements in soils of the dump and the control site, mg/kg

Site	soil layer, cm/ horizon	Sc	Ti	V	Cr	Mn	Co	Ni	Cu	Zn
Dump	0-10 cm	12.2±1.09	2461±216	73.09±5.05	67.7±6.7	415±42	9.6±0.8	31.2±2.53	37.42±3.7	301.4±65.5
	10-20 cm	11.76±0.96	2687±380	67.14±7.84	72.1±11.5	374±62	10.3±1.9	31.7±3.68	25.32±4.69	49.2±6.4
	below 50 cm	11.64±1.91	2464±598	60.72±14.15	70.5±16.6	453±130	10.2±2.4	33.5±5.39	27.06±6.7	46.4±3.9
Control	O	5.12	884	24.97	30.86	343	3.72	18.85	14.13	48.6
	E	8.57	2782	37.02	39.01	169.1	2.47	10.42	6.08	20.3
	BF	12.66	3407	86.46	90.45	353.2	12.75	36.34	18.64	71.5
		10.69	2548	70.37	72.63	343.3	10.01	32.61	17.53	52.1

		Y	Zr	Nb	Mo	Cd	Lu	Hf	Ta	W
Dump	0-10 cm	12.41±1.42	783±148	6.11±0.65	0.72±0.09	0.89±0.23	0.2±0.02	15.84±2.74	0.47±0.05	0.62±0.08
	10-20 cm	12.17±2.55	799±218	5.91±1.15	0.33±0.01	0.53±0.12	0.2±0.03	15.87±3.97	0.44±0.09	0.45±0.09
	below 50 cm	11.79±2.59	869±246	5.72±1.72	0.34±0.04	1.35±0.71	0.2±0.04	17.2±4.62	0.42±0.13	0.45±0.13
Control	O	3.65	517	2.15	0.593	0.52	0.06	8.07	0.09	0.31
	E	8.74	978	6.37	BDL	BDL	0.17	19.22	0.44	0.49
	BF	11.74	561	8.25	0.59	0.36	0.21	11.44	0.54	1.75
	BC	11.29	985	5.42	BDL	0.69	0.17	21.3	0.34	0.37

		Sn	Ga	Pb	Tl	Bi	As	Sb	Te
Dump	0-10 cm	3.84±0.88	14.35±0.52	74.2±34.4	0.5±0.02	0.15±0.02	3.63±0.66	1.46±0.72	0.15
	10-20 cm	1.28±0.12	15.38±2.1	14.5±1.5	0.46±0.03	0.13±0.01	2.26±.01	0.22±0.04	0.42
	below 50 cm	1.29±0.27	12.77±3.62	12.2±0.4	0.47±0.05	0.14±0.03	1.52±0.01	0.36±0.15	BDL
Control	O	1.35	5.37	15.4	0.32	0.12	BDL	0.34	BDL
	E	1.34	15.01	12.2	0.39	0.09	BDL	н.п.о.	BDL
	BF	1.34	17.75	13.5	0.45	0.15	BDL	0.17	BDL
	BC	1.22	17.54	12.9	0.42	0.12	BDL	0.12	BDL

		Li	Rb	Sr	Ba	Be	La	Ce	Pr	Nd
Dump	0-10 cm	23.76±2.33	64.24±3.16	302±34	665±68	3.15±0.9	19.18±2.83	41.07±5.62	4.64±0.65	17.78±2.26
	10-20 cm	21.76±4.67	61.23±4.33	256±2	582±22	1.44±0.47	18.51±4.54	39.78±7.33	4.36±1.09	16.71±4.02
	below 50 cm	21.15±6.47	58.82±4.74	254±5	580±31	0.91	17.4±4.28	40.44±5.66	4.33±1.1	16.55±4.16
Control	O	5.58	22.89	91	243	0.31	5.18	9.97	1.26	4.58
	E	6.66	56.11	265	604	BDL	10.44	20.93	2.41	9.54
	BF	32.92	62.77	228	592	0.99	15.62	30.31	3.6	14.09
	BC	25.38	62.56	243	544	0.95	14.67	26.32	3.33	12.82

		Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
Dump	0-10 cm	3.56±0.45	0.86±0.1	2.94±0.35	0.44±0.05	2.44±0.28	0.45±0.05	1.36±0.15	0.2±0.02	1.37±0.16
	10-20 cm	3.36±0.77	0.82±0.14	2.81±0.62	0.42±0.08	2.41±0.47	0.44±0.08	1.3±0.25	0.2±0.04	1.35±0.24
	below 50 cm	3.39±0.82	0.84±0.17	2.79±0.68	0.44±0.1	2.41±0.54	0.44±0.09	1.35±0.28	0.2±0.05	1.31±0.28
Control	O	0.85	0.24	0.82	0.12	0.71	0.13	0.42	0.05	0.41
	E	2.1	0.59	1.75	0.27	1.63	0.32	0.95	0.12	1.06
	BF	2.93	0.74	2.38	0.42	2.2	0.43	1.26	0.2	1.33
	BC	2.48	0.63	2.29	0.35	2.11	0.37	1.12	0.16	1.22

Note: BDL – below detection limit; colors indicate: – transition metals, – post-transition metals, – metalloids, – alkali and alkaline earth metals, – lanthanides.

Content in labile form

Labile forms of **heavy metal compounds** and metalloids are of particular interest for hygienists and environmentalists. It is believed that the most sensitive indicator of the state of heavy metals and other elements is the content of their labile forms in soils (Пинский, 2013, Мотузова, 1999, Водяницкий, 2008, Водяницкий и др., 2012). Contamination with HM labile forms is the most dangerous, for this is the form in which they can be assimilated by plants and enter food chains.

Our research results revealed a range of elements with an elevated content of labile forms in the dump soils (Table 5), indicating a certain degree of pollution with these elements. Among the elements studied, it is worth noting quite a high, although not exceeding the permissible limit (MPC for labile zinc is 23 mg/kg), concentration of labile zinc in the dump soils – up to 30 mg/kg. Furthermore, the element's lability is high – labile forms account for up to 10% of the total content, possibly suggesting an anthropogenic input. Also, a high content of lead in labile forms was found in some samples – up to 7 mg/kg (MPC being 6 mg/kg). The content of labile copper, arsenic, cadmium, and nickel forms was also elevated, insignificantly exceeding the limits.

Soils of the dump contained notably elevated concentrations of REE labile forms compared to background soils. Their share in the total content was also higher, varying from 1 to 4%.

Table 5. Content of chemical elements in labile forms in soils of the dump and the control site, mg/kg

Site	soil layer, cm/horizon	Sc	Ti	V	Cr	Mn	Co	Ni	Cu	Zn
Dump	0-10	0.03±0.01	0.06±0.02	0.05±0.01	0.19±0.02	4.01±1.37	0.01±0.01	0.11±0.02	0.41±0.09	13.35±0.96
	10-20	0.08±0.03	0.08±0.03	0.07±0.01	0.21±0.02	1.93±0.86	0.02±0	0.17±0.13	0.56±0.17	0.44±0.21
	below 50	0.09±0.05	0.05±0.02	0.07±0.02	0.19±0.03	1.22±0.51	0.02± .01	0.12±0.07	0.35±0.09	0.55±0.35
Control	O	0.02	0.07	0.04	0.15	10.15	0.01	0.02	0.1	0.52
	E	0.03	0.2	0.05	0.18	0.07	0.01	0.03	0.1	0.13
	BF	0.05	0.1	0.05	0.29	0.27	0.03	0.05	0.13	0.18
	BC	0.05	0.09	0.06	0.2	0.13	0.01	0.02	0.15	0.24
		Y	Zr	Nb	Mo	Ag	Cd	Lu	Hf	Ta
Dump	0-10	0.33±0.24	0.01±0.003	$2*10^{-4}±1*10^{-5}$	0.01±0.004	$1*10^{-4}±3*10^{-5}$	0.02± 0.01	$2*10^{-3}±1*10^{-4}$	$0.001±2*10^{-4}$	$1*10^{-4}±3*10^{-5}$
	10-20	0.79±0.72	0.02±0.009	$3*10^{-4}±1*10^{-5}$	0.02±0.001	$1*10^{-4}±3*10^{-5}$	0.004±0.003	$3*10^{-3}±3*10^{-4}$	$0.001±4*10^{-4}$	$1*10^{-4}±8*10^{-5}$
	below 50	0.48±0.33	0.01±0.004	$2*10^{-4}±1*10^{-5}$	0.02±0.001	$1*10^{-4}±2*10^{-5}$	0.002±0.001	$2*10^{-3}±1*10^{-3}$	$7*10^{-4}±1*10^{-4}$	$1*10^{-3}±3*10^{-5}$
Control	O	1*10-3	$6*10^{-4}$	$1*10^{-4}$	0.021	$2*10^{-4}$	0.005	$7*10^{-6}$	$4*10^{-5}$	$3*10^{-5}$
	E	4*10-3	$2*10^{-3}$	$7*10^{-4}$	0.022	$9*10^{-5}$	0.002	$2*10^{-5}$	$8*10^{-5}$	$4*10^{-5}$
	BF	0.03	0.02	$4*10^{-4}$	0.023	$2*10^{-4}$	0.005	$1*10^{-4}$	$8*10^{-4}$	$3*10^{-5}$
	BC	0.1	$6*10^{-3}$	$2*10^{-4}$	0.026	$8*10^{-5}$	0.001	$4*10^{-4}$	$4*10^{-4}$	$4*10^{-5}$

		W	Re	Hg	Sn	Tl	Pb	Bi	B	Ge
Dump	0-10	$1*10^{-3}\pm2*10^{-4}$	$6*10^{-5}\pm2*10^{-5}$	$7*10^{-4}\pm3*10^{-4}$	$2*10^{-3}\pm3*10^{-4}$	$6*10^{-4}\pm2*10^{-4}$	2.77± 0.96	$0.0011\pm4*10^{-4}$	0.32±0.07	0.13±0.06
	10-20	$8*10^{-4}\pm5*10^{-4}$	$7*10^{-5}\pm4*10^{-5}$	$3*10^{-4}\pm1*10^{-4}$	$3*10^{-3}\pm3*10^{-4}$	$0.0012\pm6*10^{-4}$	0.31± 0.23	$4*10^{-4}\pm1*10^{-4}$	0.17±0.01	0.01
	below 50	$5*10^{-4}\pm1*10^{-4}$	$4*10^{-5}\pm1*10^{-5}$	$2*10^{-4}\pm1*10^{-4}$	$3*10^{-3}\pm3*10^{-4}$	$8*10^{-4}\pm4*10^{-4}$	0.06± 0.03	$3*10^{-4}\pm1*10^{-4}$	0.14±0.02	0.01
Control	0	$2*10^{-4}$	$1*10^{-5}$	$8*10^{-4}$	$2*10^{-3}$	$5*10^{-4}$	0.06	$2*10^{-4}$	0.08	$1*10^{-4}$
	E	$1*10^{-4}$	$1*10^{-5}$	$5*10^{-4}$	$2*10^{-3}$	$3*10^{-4}$	0.08	$2*10^{-4}$	0.1	$1*10^{-4}$
	BF	$2*10^{-4}$	$2*10^{-5}$	$8*10^{-4}$	$2*10^{-3}$	$5*10^{-4}$	0.03	$9*10^{-5}$	0.1	$1*10^{-4}$
	BC	$2*10^{-4}$	$2*10^{-5}$	$4*10^{-4}$	$2*10^{-3}$	$5*10^{-4}$	0.03	$9*10^{-5}$	0.12	$3*10^{-4}$

		As	Sb	Te	Li	Be	Na	Mg	K	Ca
Dump	0-10	0.06±0.01	$0.01\pm2*10^{-3}$	$3*10^{-4}\pm1*10^{-4}$	0.02±0.006	$4*10^{-3}\pm2*10^{-3}$	1327±195	75±36	1678±9	1068±389
	10-20	$0.03\pm3*10^{-3}$	$6*10^{-3}\pm1*10^{-3}$	$2*10^{-4}\pm1*10^{-4}$	0.04±0.03	$8*10^{-3}\pm5*10^{-3}$	2632±1526	127±117	1683±51	567±346
	below 50	0.02±0.01	$5*10^{-3}\pm1*10^{-3}$	$2*10^{-4}\pm5*10^{-5}$	0.04±0.025	$5*10^{-3}\pm1*10^{-3}$	1437±554	98±92	1661±63	407±291
Control	0	$4*10^{-3}$	$3*10^{-3}$	$6*10^{-5}$	$2*10^{-3}$	$2*10^{-4}$	622	17.89	1593	145
	E	$7*10^{-3}$	$4*10^{-3}$	$1*10^{-4}$	$4*10^{-3}$	$6*10^{-4}$	614	2.55	1621	9
	BF	$5*10^{-3}$	$3*10^{-3}$	$3*10^{-5}$	0.012	$9*10^{-3}$	612	5.25	1607	8
	BC	$5*10^{-3}$	$4*10^{-3}$	0	0.007	$6*10^{-3}$	583	7.54	1611	12

		Rb	Sr	Cs	Ba	La	Ce	Pr	Nd	Sm
Dump	0-10	0.3±0.08	6.08±1.62	0.0013±0.0003	5.68±1.62	0.49±0.32	0.91±0.56	0.12±0.08	0.69±0.48	0.1±0.06
	10-20	0.620.12	2.09±0.98	$0.002\pm4*10^{-4}$	4.64±1.37	0.96±0.82	1.35± 0.79	0.24±0.2	1.4±1.16	0.2± 0.15
	below 50	0.57±0.17	2.16±1.32	$8*10\text{-}4\pm2*10^{-4}$	3.77±1.11	0.83±0.35	1.71± 0.51	0.22±0.1	1.31±0.57	0.14± 0.06
Control	0	0.82	0.83	0.001	2.27	0.002	0.004	$5*10^{-4}$	0.003	$6*10^{-4}$
	E	0.83	0.1	0.001	2.6	0.005	0.008	0.001	0.006	0.001
	BF	0.94	0.08	0.003	11.89	0.04	0.07	0.009	0.05	0.01
	BC	0.92	0.1	0.003	5.92	0.42	0.4	0.04	0.2	0.04

		Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Se
Dump	0-10	0.015±0.007	0.09±0.05	0.007±0.004	0.052±0.032	0.006±0.0034	0.016±0.01	0.0017±0.001	0.016±0.01	0.009±0.003
	10-20	0.028±0.021	0.19±0.15	0.015±0.012	0.124±0.102	0.0135±0.011	0.038±0.033	0.004±0.003	0.041±0.034	0.012±0.005
	below 50	0.018±0.008	0.13±0.05	0.009±0.004	0.073±0.034	0.008±0.004	0.022±0.011	0.002±0.001	0.022±0.011	0.008±0.003
Control	0	$3*10^{-4}$	$5*10^{-4}$	$4*10^{-5}$	$3*10^{-4}$	$3*10^{-5}$	$1*10^{-4}$	$8*10^{-6}$	$9*10^{-5}$	$6*10^{-4}$
	E	$4*10^{-4}$	0.001	$9*10^{-5}$	$8*10^{-4}$	$8*10^{-5}$	$3*10^{-4}$	$3*10^{-5}$	$2*10^{-4}$	0.003
	BF	0.003	0.01	$7*10^{-4}$	0.006	$6*10^{-4}$	0.002	$2*10^{-4}$	0.002	0.01
	BC	0.006	0.04	0.002	0.02	0.002	0.006	$5*10^{-4}$	0.005	0.008

Note: colors indicate: – transition metals, – post-transition metals, – metalloids, – alkali and alkaline earth metals, – lanthanides, – non-metals.

Microbiological and parasitological studies of the soil

Dumps are dangerous not only because of the chemical contamination of the natural environment through waste degradation, but also because of **biological pollution**. Wastes contain large amounts of microorganisms, some of which may be pathogenic. Sanitary bacteriological analyses showed enterococci to exceed the limit 1000-fold, and the coliform bacteria index was at the threshold of permissible levels. Other parameters conformed to the norms.

The chemical condition of soils in the dumps was studied in detail. Acidity-alkalinity properties have changed towards lower acidity, and elevated phosphorus content was detected, posing **risk of** ground- and surface water **eutrophication**.

Also, surface soil horizons in the dumps were chemically contaminated with some heavy metals. Chemical pollution, as we know, is a "chemical time bomb" (Орлов и др., 2002), and a high total content of heavy metals can undermine the well-being of the area. Even for natural objects that are not yet classified as contaminated, the situation may change if the conditions change – climate, hydrology, geomorphology, vegetation community.

That is why the heavy metals and metalloids demonstrating an elevated and high content – zinc, lead, copper, arsenic, are the most commonly named key soil contaminants in waste dumps (Barbieri et al., 2014, Gworek et al., 2016). We can also speak of an elevated geochemical REE background in the dump soils, no doubt ensuing from a high content of waste with electronic parts, whose alloys include many REE.

According to the regulation "On the procedure of quantifying damage from land pollution with chemical substances", the studied dump soils belong to the **low-pollution category**, in spite of the elevated content of some hazardous chemical elements.

Heavy metal contamination of soils is a degradation process that is hard to reverse. It is virtually impossible to lower the total content of metals in soils, except, perhaps, for well-drained sandy soils, in which case, however, there is a **risk of groundwater contamination**. The solution usually suggested is to make the metals less labile: this reduces their leaching and fixes them in the soil on the one hand and lowers their availability to plants on the other. To do so, several **soil remediation methods** can be applied – liming, fertilization, addition of zeolites or clay, phytoremediation.

Sanitary bacteriological analysis of the soils has shown that, according to SanPin (national sanitary-epidemiological regulations and norms) 1.2.3685-21, the dump soils are extremely hazardous based on the enterococcus index, and if especially dangerous germs are detected in such soils, they should either be remediated or disinfected (with subsequent laboratory control). Hence, the recommendation is to repeat microbiological analyses more thoroughly.

3.3.5. Responses

The recommendation is to eliminate the closed landfill, whereas further remediation actions can be proposed after a more thorough additional sanitary-parasitological analysis of the territory.

As regards the campsites, their well-arranged infrastructure has helped avoid major recreation-induced changes in soil properties. The main forms of recreation detrimental for the forest in the campsites are bivouacking (putting up tents, making campfires, other infrastructure) and treading (making paths, soil compaction, etc.).

To reduce the detrimental environmental impact of recreation, namely soil damage, the following improvements can be recommended for recreational areas:
1. Build decking in sites for tents to avoid soil compaction and trampling down of the ground cover in campsites.
2. Mark out the paths most popular among tourists, as this will notably reduce the number of alternative paths and thus mitigate overall digression.
3. Put up boards with information for tourists about the rules to be followed while staying in the National Park.

3.4. Microplastics in lake sediments of protected areas – Vodlozersky National Park

3.4.1 Introduction

In the past few decades, the problems related to the contamination of the environment with **anthropogenic polymers** have become widely discussed by the scientific community (Moore et al., 2008; Thompson et al, 2004; GESAMP, 2016). **Polymer particles smaller than 5 mm (microplastics)** pose an emerging ecological threat in the opinion of the worldwide scientific society (Moore, 2008; Andrady, 2011). Having a low specific density comparing with other anthropogenic litter, they can be easily transported over long distances in the water environment and float over the water surface or be suspended within the water column (Rilling, 2012; Wright & Thompson, 2013). Because of biofouling and aggregation, MPs are deposited and enter the sediments which have been suggested to be the main sink for MPs (Woodall et al, 2014; Law et al., 2010). MPs are widely dispersed in sedimentary deposits representing an integral record of MPs contamination in the area. Their amount tends to increase several-fold over the next few decades indicating the Anthropocene epoch (Zalasiewicz et al, 2016).

Moreover, because of their small size, they can be presumed as a food by many living organisms posing a harm to them and may lead to lethal outcome (Cole et al., 2014). Particularly dangerous is the ability of plastic particles to absorb persistent pollutants on their surface (Ashton et al, 2010; Endo et al, 2005; Frias et al, 2010) and transport them from garbage dumping sites, sewage tanks, and other sources of pollution to rivers, lakes, and seas. Thus, they form a **new vector for the spread of hazardous pollutants**.

MPs are divided into primary and secondary types. **Primary microplastics** are initially manufactured as small plastic items: these are preproduction pellets (or nurdles), abrasives applied in cosmetics, abrasives for sandblasting etc. **Secondary MPs** are forming directly in the environmental conditions due to disaggregation of large plastic derbies. MPs found in the environment are usually divided into several forms: fragments, beads, capsules and fibers. **Fibers** are thin elongated items with one dimension significantly greater than the other two, **fragments** are pieces of thick plastics of irregular shape with all three dimensions comparable, **films** – sheets of plastic bags and other similar stuff with their thickness significantly less than other two dimensions, **beads** are three-dimensional items of a rounded shape (Zobkov et al, 2020a). **Capsules** are spheres made of plastic material, they can be hollow or contain some filler.

Currently, careful attention is being paid to the studies of MPs in the marine environment while inland waters are being studied to a lesser degree in this regard (Li et al, 2019). In Karelia, the microplastic abundance was **studied in sediments of the central part of Lake Onega and Petrozavodsk Bay** (Zobkov et al, 2020a) which makes it possible to compare MPs contamination in protected natural areas of the Kizhi National Park and the Vodlozersky National Park with unprotected areas.

3.4.2. Sampling and sample processing (both for Kizhi and Vodlozero cases)

Sediment samples were collected using a Box Corer Grab. The 5 cm surface layer was transferred with a stainless-steel spoon into clean plastic bags (samples from Kizhi) or glass vials (samples from Vodlozersky NP). The samples were stored at a temperature of 4 °C until analysis in the laboratory. The samples were analyzed according to the procedure, described in (Zobkov et al, 2020a; Zobkov et al, 2020b). In brief, 400 g of wet sediments were exposed to preliminary wet peroxide oxidation, flushed with distilled water through a cascade of three filter nets with 333, 174 and 100 um mesh size, followed by density separation with potassium formate ($HCOOK$) with a specific density ρ=1.5 g/ml. Then floating solids were exposed to wet peroxide oxidation in a water bath followed by digestion of the chitin fraction with 5% HCl, drying and MPs detection under a stereomicroscope. MPs were classified into four groups according to their shape: fragments, films, fibers, beads and capsules. A subsample was taken to establish dry sediment weight that was analyzed gravimetrically according to the methods generally accepted in the world practice (Hakanson and Jansson 1983). The microplastics abundance was expressed as items per kg of dry sediment weight (pcs/kgDW). Schematic maps are prepared using ArcGis 10.2.2 with Open Street Map cartography.

3.4.3. Study site

Sediment samples were collected at **five sites in Lake Vodlozero** (Table 5a, Fig. 21). The stations were divided into two categories: area of possible direct anthropogenic impact (stations 1vdl, 2vdl, and 3vdl) and background (5vdl and 4vdl), distanced from known point sources of MPs contamination. The 1vdl station was situated at the entrance into the Rebolakhta Bay, 300 m oppose the pier of the Vodlozersky National Park Administration. The 2vdl station was situated near Kuganavolok village, 350 m opposite the village pier. The station 3vdl was situated westward from the Kuganavolok peninsula, 300 m offshore. Stations 1vdl and 3vdl were suggested as the impact zones of the local landfill site, 1vdl and 2vdl stations - as **impact zones of shipping traffic and domestic wastewater discharges**.

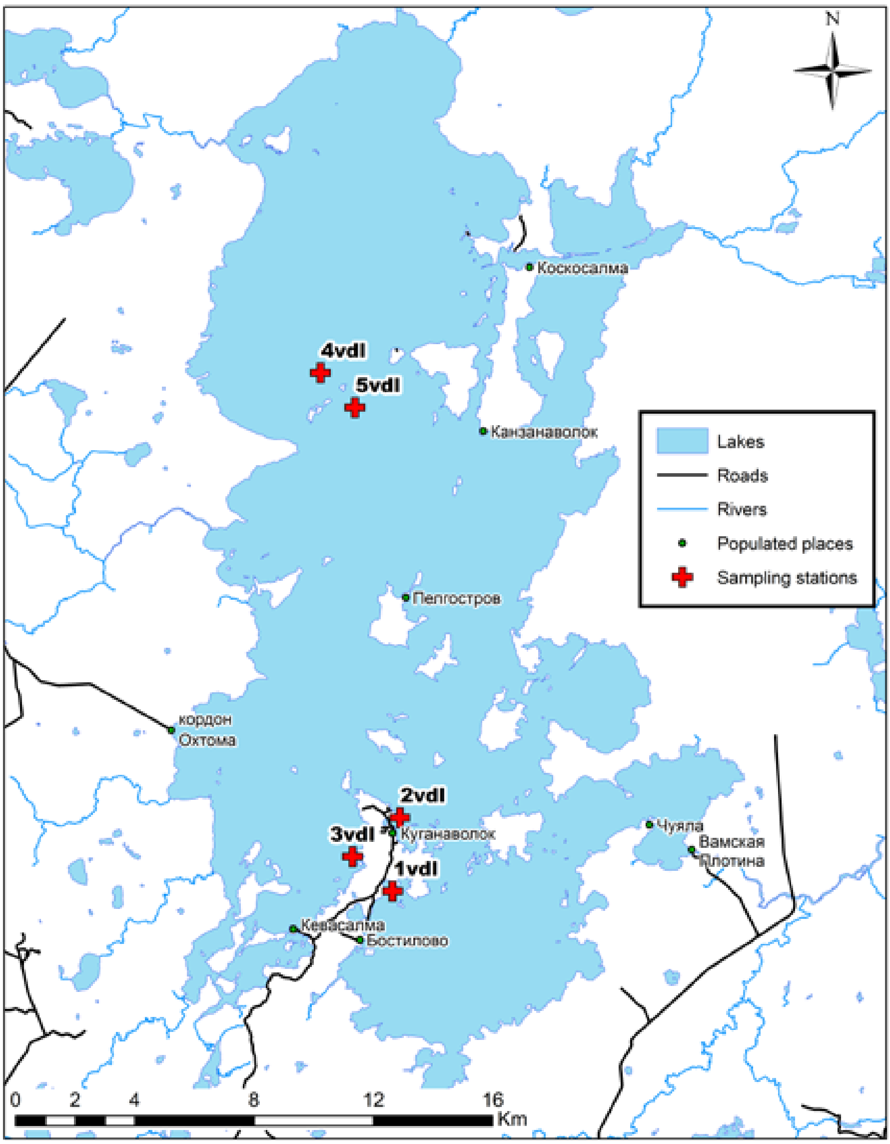


Figure 21. Sampling stations for MPs contamination in Lake Vodlozero

Station	Date	Depth, m	X	Y
1vdl	03.07.2020	3.4	36.88336	62.21789
2vdl	03.07.2020	3.6	36.89086	62.23981
3vdl	03.07.2020	4.4	36.85897	62.22894
4vdl	03.07.2020	4.5	36.85681	62.37472
5vdl	03.07.2020	5	36.87786	62.36369

Table 5a. Sampling stations in Lake Vodlozero

3.4.4. Results and discussion

All sampled sediments were silts with a wetness of 95.0±1.9% and an organic carbon content 8.5±1.0%. In this regard, they differ significantly from Lake Onego sediments (see case Kizhi), having a significantly lower organic carbon content (<5%) and being formed mainly by clastic material (Zobkov et al, 2020a). Thus, it is not correct to compare MPs abundances in lakes Vodlozero and Onega.

The mean MPs abundance in Vodlozero sediments varied from 4719 up to 21905 and was 11048±6139 pcs/kgDW in mean. In almost all samples, hollow capsules (Fig.22 a,b) prevailed over other types of MPs. The **predominance of the capsule-type of MPs is unusual for surface waters**. Microcapsules are a primary type of MPs that are usually applied in the textile industry (Yip & Luk, 2016), drug delivery (Bysell et al, 2011), and coatings (Zhang et al, 2014). Although their **predominance on background stations suggests their natural origin**. Possible natural alternatives can be seeds or algae (Lusher et al, 2020). Raman analysis revealed that the chemical composition of beads was closest to Poly (Diallyl Phthalate) and Diisononyl phthalate with a spectrum match 41.7% and 40.6%, respectively (Fig. 22 c). Although the spectrum match is relatively low, it is not possible to associate those capsules with anthropogenic polymers. In this regard, an additional assessment of their chemical compound with μFT-IR spectroscopy is required. As we are unable to distinguish between the natural or anthropogenic origin of these capsules, they and the films produced during their disaggregation will be excluded from further consideration. The mean MPs abundance in Vodlozero Lake sediments excluding yellow and transparent capsules was 1506±845 pcs/kgDW.

However, even excluding these capsules, the **maximum contamination of the sediment with MPs was observed at the 4vdl background station**. Fibers exhibited the maximum concentration in this site. Although fibers are easily transportable types of MPs, they can represent a zone of sediment accumulation at 4vdl (Zobkov et al, 2020a). However, a large quantity of beads at background stations indicates the proximity to unaccounted point sources of this primary-type MP which may be the **Ileksa river and/or tourist activities on the river** and lake as was suggested previously for the Shuya River in the Lake Onego (Zobkov et al, 2020a).

High contamination of sediment with film-type MPs was also indicated at stations 1vdl – **pier of National Park Administration and 2vdl – pier of Kuganavolok village** (Table 6; Fig. 23). The maximum contamination with fragment type of MPs was also observed at the 2vdl. At stations 1vdl and 2vdl, this may be attributed to proximity to point **sources of contamination:** landfill site, shipping traffic and domestic wastewater discharges and disaggregation of larger plastic derbies on the lakeshore (Fig. 24). However, at the present state of science, it is not possible to identify the relevance of each particular source. Examples of MPs specimens, extracted from sediment samples presented in Fig. 25.

It is noteworthy, that Vodlozero is a dam shallow lake of glacial origin with an average depth only 2.8 m and a mean water level fluctuation 100 cm (Ozera Karelii, 2013). Because of the shallow depth and high fluctuation of water level, MPs can be redistributed over the lake area during water discharges and storm events. This can describe uncertainties in the high level of sediment contamination at background stations. However, **additional studies are required in this regard**.

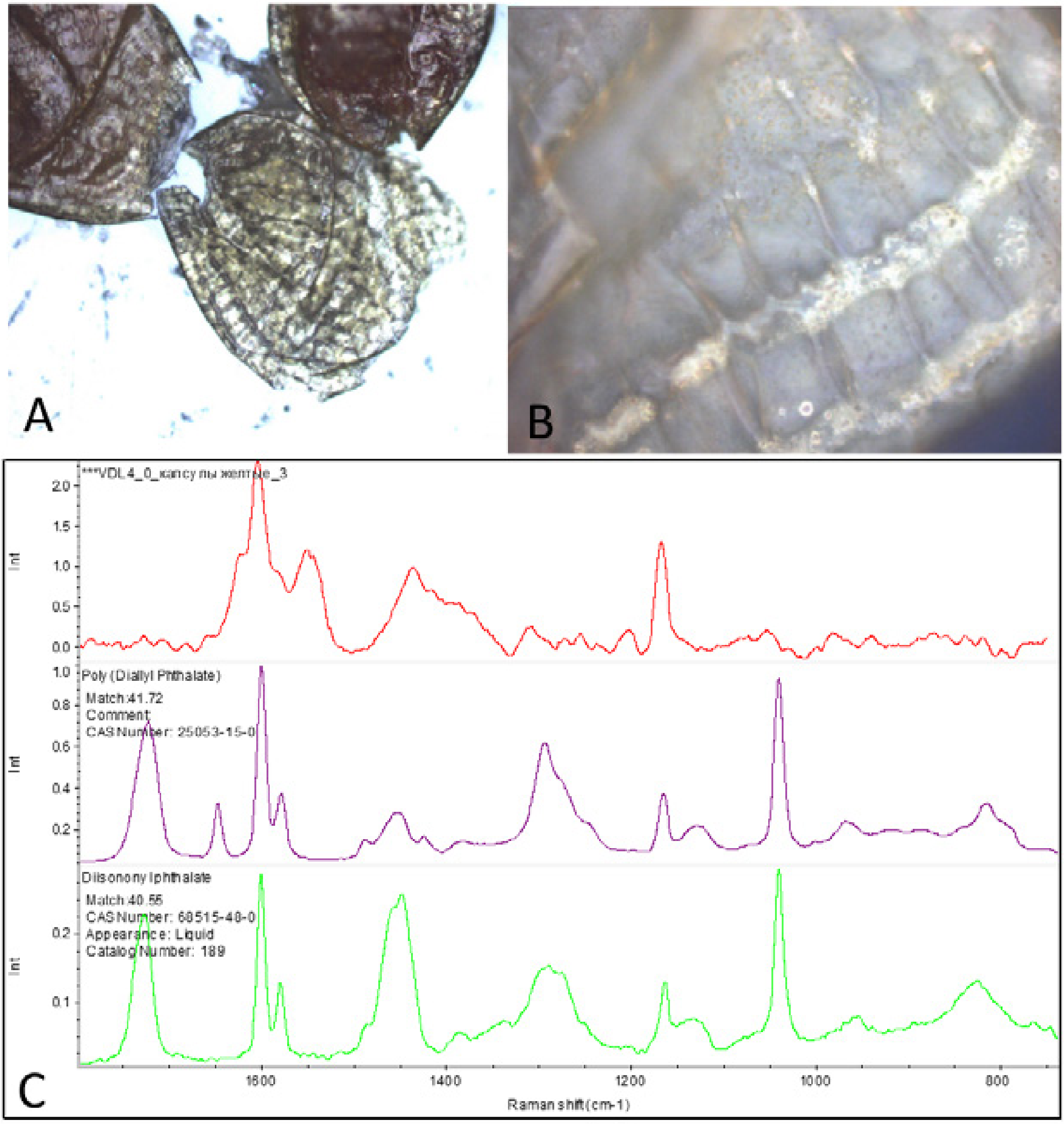


Fig.22. Yellow capsules dominated in Vedlozero Lake sediment samples. A – external appearance; B – surface structure; C –Raman spectrum and closest analogues of polymers.
Photo and Raman analysis made by V.V. Kovalevsky.

Table 6. Microplastics abundance in the sediments of Vodlozero Lake (pcs/kgDW)

Station	Fibers	Capsules[1]	Beads	Films	Fragments	TOTAL[1]
1vdl	62	0	185	**123**	0	369
2vdl	378	**680**	0	**151**	**227**	1435
3vdl	948	146	73	0	0	1166
4vdl	**3175**	0	**317**	0	79	3571
5vdl	127	287	**478**	64	32	987

Station	Capsules[2]	Films[2]	TOTAL[2]
1vdl	2155	2586	4988
2vdl	7666	3097	11367
3vdl	3480	219	4719
4vdl	15397	2937	21905
5vdl	11115	510	12261

[1] – excluding transparent and yellow capsules content;
[2] – including transparent and yellow capsules content

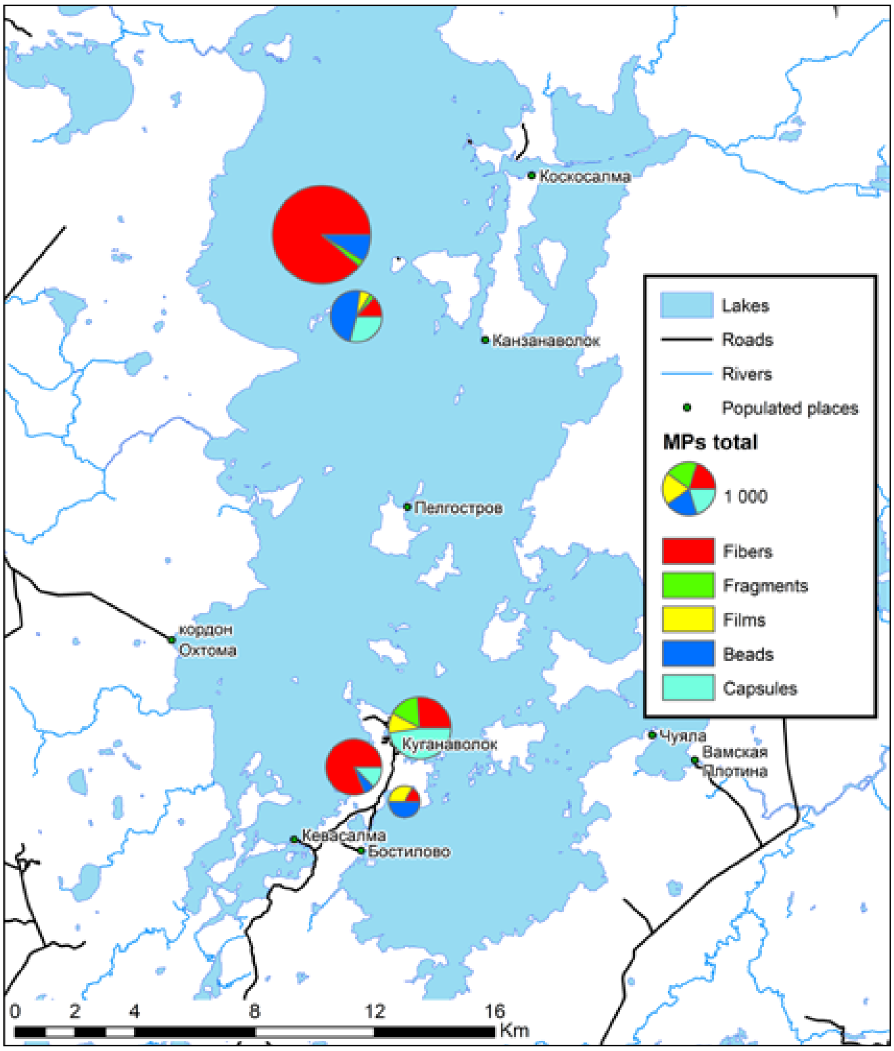


Fig. 23. MPs contamination in the sediments of Vodlozero Lake (excluding the content of yellow and transparent capsules).

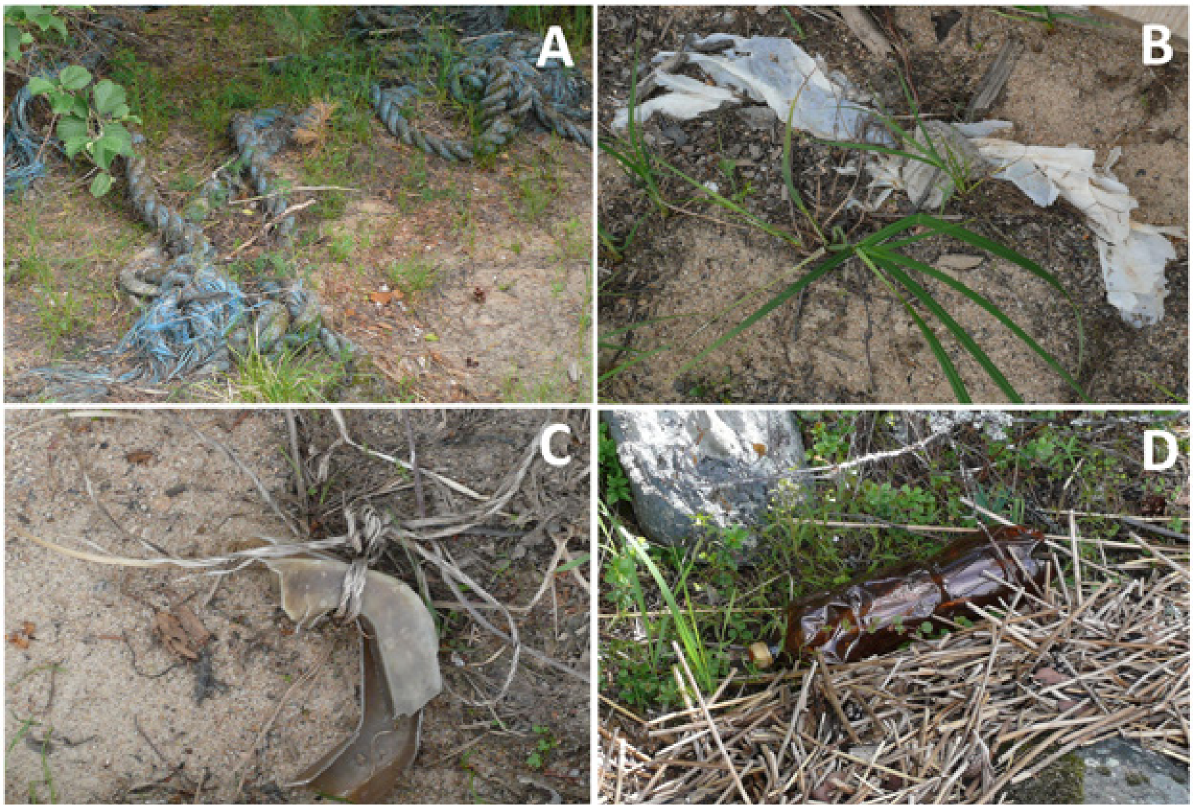


Fig. 24. Disaggregation of plastic litter on the shore of Vodlozero Lake (A – plastic rope; B – plastic sheeting; C – handle of a plastic can with a plastic rope; D – PET bottle).

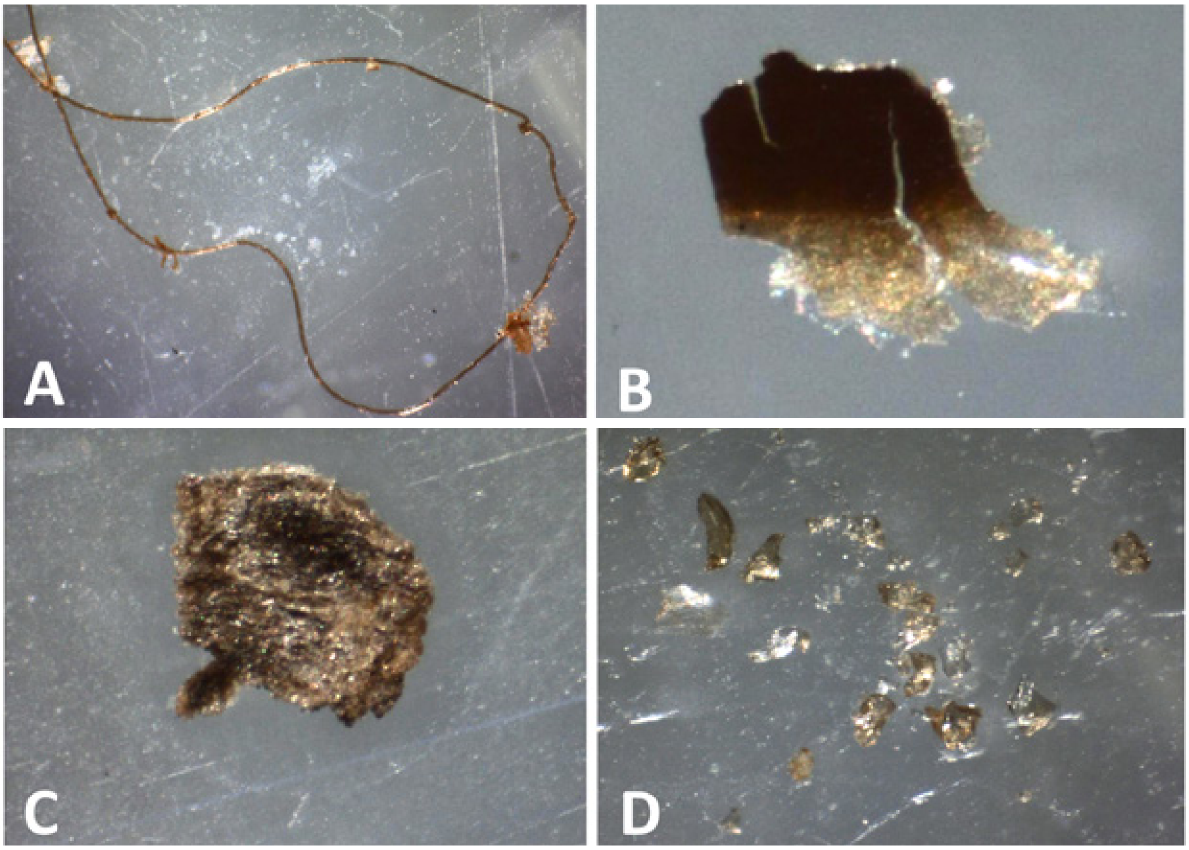


Fig. 25. Microplastic specimens extracted from bottom sediments of Vodlozero Lake.
A – fiber; B – film; C,D – fragments.

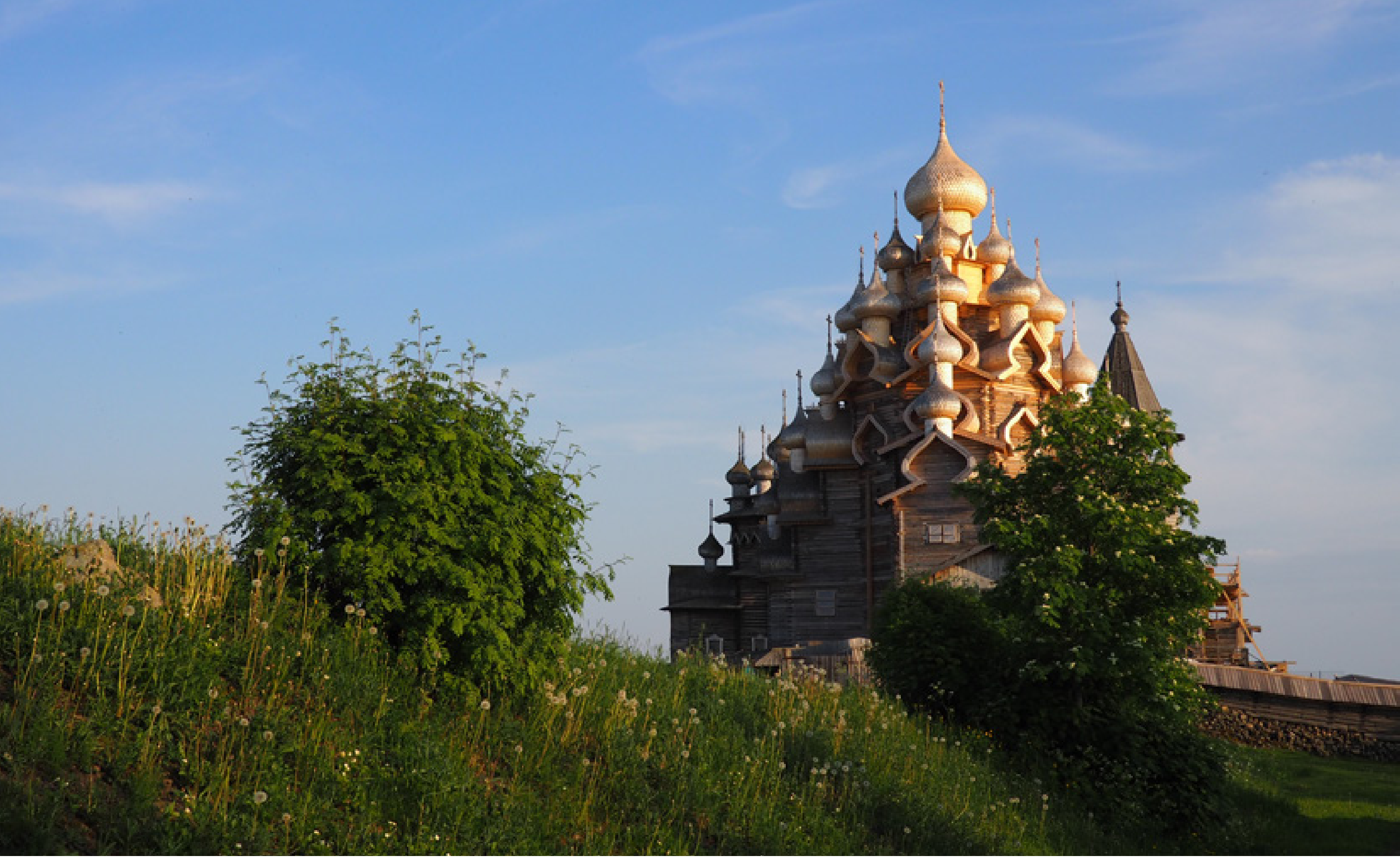


Figure 26. Kizhi Island (photo by Pekka Rossi).

4. CASE KIZHI, RUSSIA

4.1. Site introduction

Kizhi Island is situated in the central part of Lake Onega within an archipelago with different sized islands. Kizhi is a popular tourist destination, harboring the UNESCO heritage site Kizhi Pogost and an open-air museum (Fig. 26). Several fast boats (Meteor) depart daily from Petrozavodsk to Kizhi, and numerous cruise ships visit the island. It is one of the main tourist sites in the Karelia region. Most of the tourists are one-day visitors as longer stay requires a special permission. Several villages are located close to Kizhi Island, on other islands of the archipelago, and on the mainland. These villages have both permanent inhabitants as well as cottage/second-home owners, “dachniks” in Russian.

As regards waste management for the tourist destination and villages, the Kizhi Open Air Museum staff has worked several years to enhance e.g., **waste sorting and waste solutions**. As Kizhi Island is also valued for its nature, visitors join e.g., nature days on the island, where waste management is one of the topics studied by young students, and/or waste is collected in the nearby villages by volunteers coming from all around the country for one or two days. Even though the waste management has been thoroughly considered, still some illegal or old waste sites remain on the island (Fig. 27). These sites are in many cases situated near the lake shoreline, close to villages or on top of sand deposits. Local stakeholders recognize these waste sites as a negative impact on the surrounding nature, local inhabitants, and the pristine-nature reputation of Kizhi Island and the region in general.

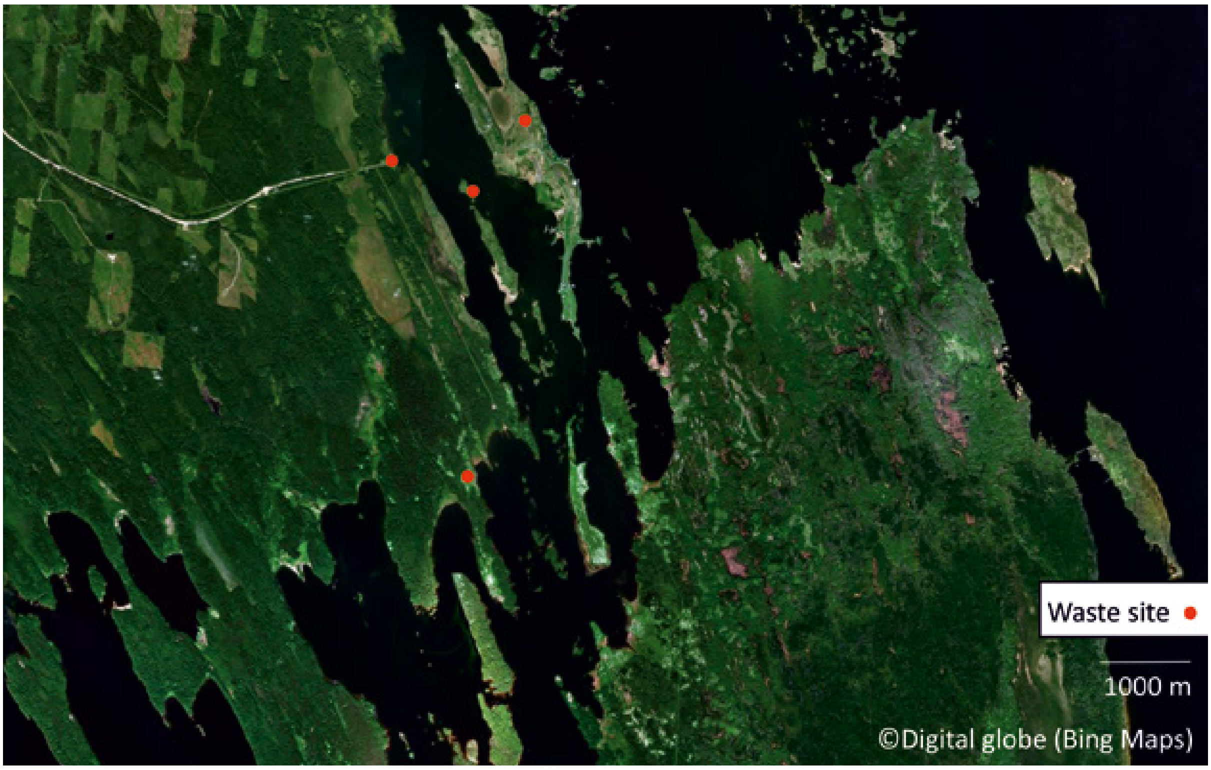
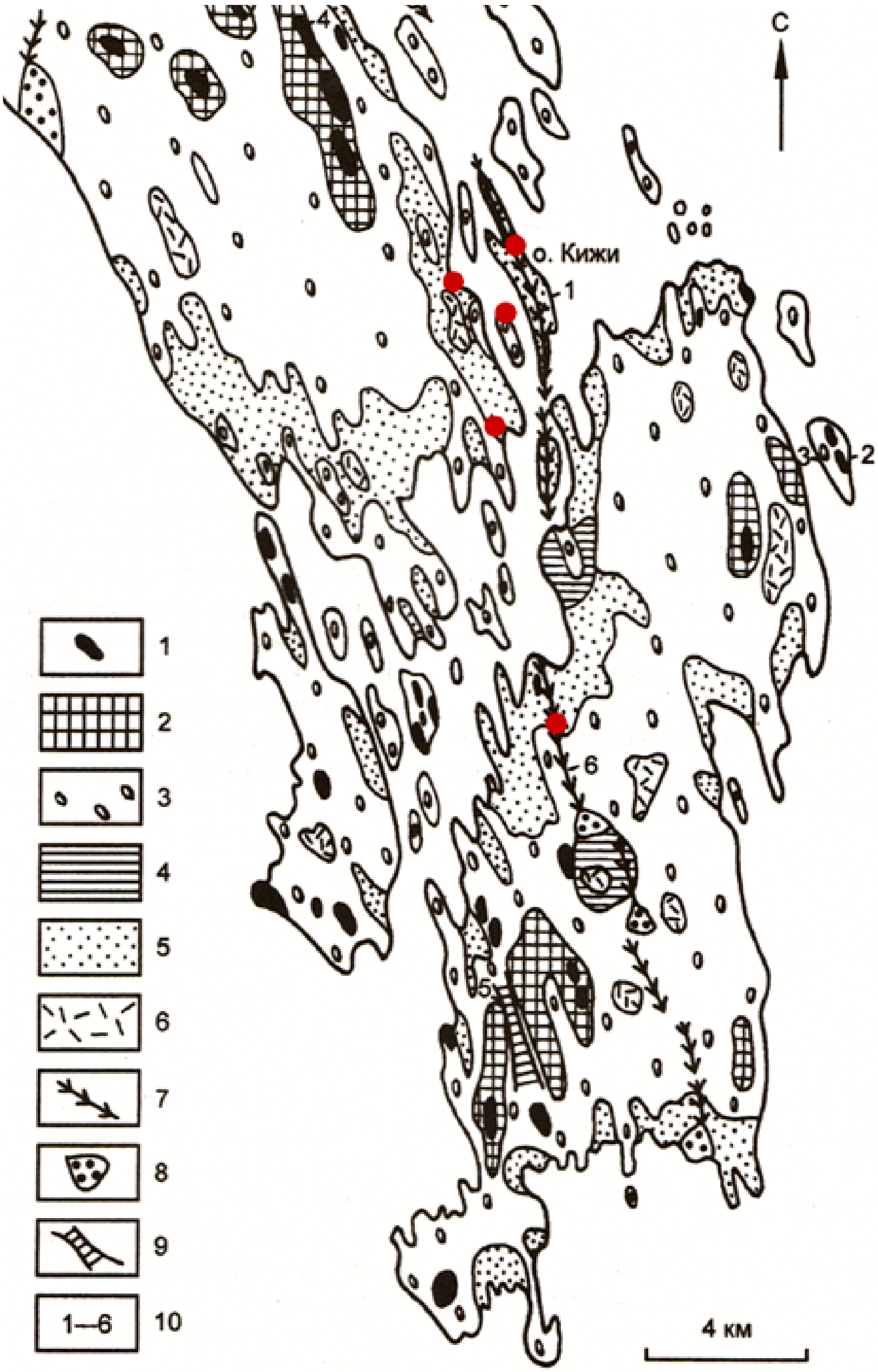


Figure 27. Kizhi archipelago map with some waste dumps (red dots).

Geology of the region is variable and has impacts on how waste sites interact with the environment: harmful substances from the waste sites over sandy substrates more easily migrate to the groundwater than from till or clay, where there is less downward seepage to the groundwater. Kizhi Island itself is a part of a chain of eskers (Fig. 28-29). Eskers are glacial sand and gravel deposits found in regions covered by the last glaciation in Europe and North America. Eskers were formed when glacial meltwater transferred sediment in the direction of ice withdrawal (Banerjee and McDonald 1975). These systems are often shallow, rising 10-100 m above the surrounding landscape, and typically discharge groundwater to springs, rivers, lakes and peatlands. As the esker formations are mainly sand and gravel, substances from the top of an esker can easily migrate to the groundwater. The same esker formation continues onward to Bolshoi Klimenetsky Island, where more villages are situated. The rest of the archipelago mostly has till on top of the hard bedrock.



Schematic map of Quaternary deposits in the Kizhi Skerries Nature Reserve:

1 – bedrock, **2** – areas with a thin (within 1.0-1.5 m) sheath of Quaternary deposits, **3** – glacial deposits – till, **4** – varved clay, **5** – lacustrine and glaciolacustrine sand or, less often, loamy sand and clay, **6** – biogenic deposits – peat, **7** - eskers, **8** – fluvioglacial deltas, **9** – glacial meltwater valley, **10** – curious Quaternary landforms: 1 – Isl. Kizhi - terraced esker ridge, 2 – ancient cobble beach ridges in the eastern part of Bolshoi Olenii Island, 3 – technogenic formations – carbonaceous rock spoil banks and remains of barite mines on Yuzhnyi Olenii Island, 4 – earthquake-collapsed precipice on the western shore of Lake Vekhozero, 5 – structural denudation terrain and a glacial meltwater valley near Lake Obozero, 6 – massive fluvioglacial system made up of esker ridges and deltas

Figure 28. Geomorphological conditions in Kizhi and surroundings (Демидов И.Н. Четвертичные отложения заказника «Кижские шхеры» // Тр. КарНЦ РАН. Серия «Биогеография Карелии». Вып. 1. Петрозаводск, 1999. С. 11-15). Examples of waste sites (red dots).

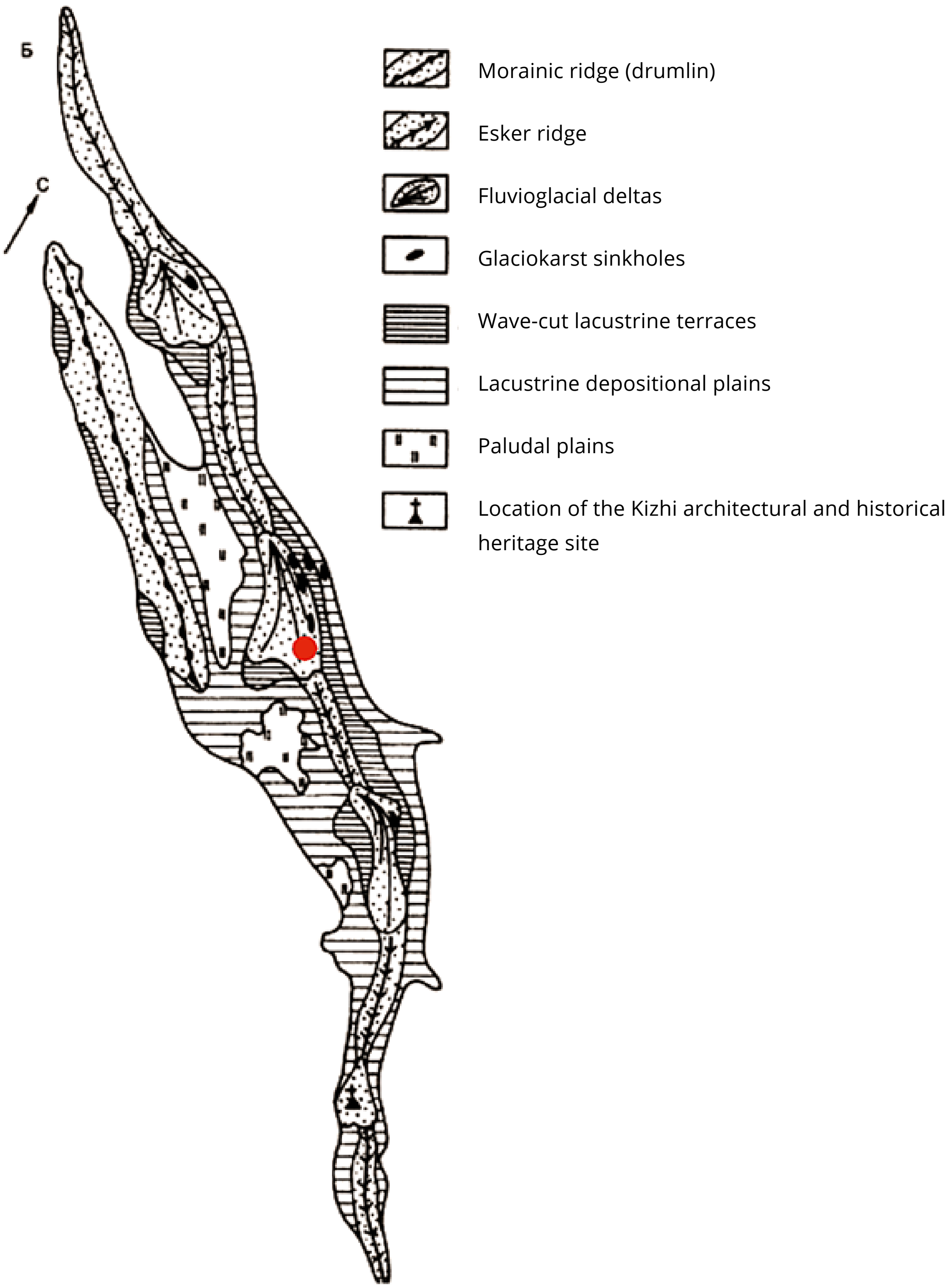


Figure 29. Geomorphological conditions on Kizhi Island (Лукашов, 1999). Closed waste site marked with red dot.

Detailed information about the existing waste management situation was asked from the personnel of the Kizhi Museum for the SUPER project. The mixed waste on Kizhi Island consists of municipal solid waste (up to 95%) and industrial waste (mainly wood, which is mostly burned). The **amount of waste transported from Kizhi Island in 2019 was about 88 tons**. Mixed waste is collected to 240-liter plastic containers at specially designated sites on the island. From these containers, the mixed waste is hauled by garbage truck to 27-m3 containers. When the containers are full, the waste is transported from Kizhi Island. Separated wastes are collected in special containers of various capacities, deployed at the dwellings of Museum employees and contractors – both indoor and outdoor. In 2019, the **amount of separated waste** on Kizhi Island was 610 kg for cardboard, 1791 kg glass, 252 kg PET bottles, 40 kg aluminum cans, and 645 kg for paper. In 2020 this amount increased: 1191 kg of cardboard, 2996 kg of glass, 566 kg of PET bottles, 84 kg of aluminum cans and 300 kg of paper were collected. The separated waste is re-sorted manually and stored in special buildings in the Museum entrance area and Yamka Village.

Kizhi Island chooses the providers of the services of waste transportation and haulage to disposal sites through a tendering procedure. Based on the tender results, Kizhi Museum signs the state contract. Currently, the contractor is LLC KarelStroyUpravlenie. According to the contract, a **garbage truck (or 2 trucks) arrives from Petrozavodsk City to Velikaya Guba Village, where the truck is loaded onto a barge** to be delivered to Kizhi Island (a **distance of 20 km**). On Kizhi Island, the truck is loaded with the waste from the containers by a **hydraulic arm** or by replacement of the filled 27 cubic meter container with an empty one that the garbage truck brings.

Based on the results of commercial quotations evaluation, the Museum signs a contract with a company collecting useful fractions of **sorted waste**. In 2019, these services were performed by LLC EcoBum, and in 2020 the best offers were made by LLC Calypso, with which the current contract was signed. After some fine sorting, the **waste is partially processed directly at Calypso and then sent to St. Petersburg to larger enterprises for the final processing**. The waste from Kizhi Island is transported by a **vessel owned by Kulakovy entrepreneurs**, who are in charge of its delivery to LLC Calypso. The vessel covers a distance of **60 km**. There are no other suitable waste disposal facilities nearby.

There are about **60 people living on Kizhi Island in the wintertime**, and about **300 people in summer**, provided normal conditions for tourism. According to the statistics, the **number of tourists visiting Kizhi Island during 2010–2019 varied from 142 391 to 194 325**. Most tourists visit the Kizhi Pogost ensemble with The Church of the Transfiguration, Church of the Intercession of the Virgin, and the Belfry. Kizhi Museum offers several ecological tours by water and on foot, introducing the visitors to the unique natural objects in the Kizhi skerries and telling about the ecosystems' resistance to the recreational load. Tourist pamphlets and brochures contain maps of nature trails, biking trails, and other routes in the Zaonezhye region.

Shops and a restaurant are located on the wharf, and a grocery store operates in the Yamka Village. They are all equipped with waste container stations and waste collection buildings constructed within the SUPER project. The outdoor eating area near the restaurant on the pier is also supplied with a waste container station. The current number of waste containers is sufficient for now. This was achieved by purchasing the required extra containers, within the

SUPER project as well. The containers are emptied quite often: once or twice a week in summer, and once in a calendar month in winter.

The main issues in municipal solid waste management on the island are:

1. There are a lot of employees and contractors living on Kizhi Island temporarily. Currently, they **cannot wash dishes, so they use various disposable dishes** (plastic plates, knives, forks, spoons, sauce containers, etc.).
2. The restaurant uses **disposable dishes** made of paperboard and plastic, as there is no opportunity to do the dishes either. This tableware is often dumped into the containers for bottles and cans, necessitating post-sorting.
3. Recycling of biowaste from the restaurant is an issue. It is not possible to offer tourists the type of composters the Kizhi Museum staff use.
4. Accessibility issues. The problem is to transport waste from Kizhi Island, since the Museum does not have the appropriate technical capabilities (**no heavy or cargo vessel**), and for the waste collecting company the cost of transportation operations exceeds the profit they can gain from the waste received. Currently, sorted wastes from Kizhi Island are transported to Petrozavodsk by selected contractors.

At four **seminars** held in 2019 within the SUPER project for locals, staff of the Kizhi Museum, emergency services and entrepreneurs working on Kizhi Island, the participants looked into waste management issues. It should be noted, however, that the seminars' educational resources on separate waste collection on Kizhi Island were well received by the participants, who displayed much enthusiasm and concern about the issue.

Better waste management in the area and/or clean-up of the old waste dumps would improve the attractiveness of the area for tourists and the social well-being of the inhabitants. There is no special personnel for waste management improvement. The system operation fully relies on the staff and volunteers involved in it. Waste transportation costs are covered by the federal subsidies allocated to the Kizhi Museum for maintenance of the territory. 240-liter containers are used for the waste container stations, 10-liter containers were purchased for the Museum employees' and contractors' households within the SUPER project. For Kizhi Island, the optimal choice would be soil-colored containers that can be opened hands-free, and the waste would be inaccessible for birds and the action of the wind.

4.2. DPSIR for Kizhi

4.2.1. Drivers

The current waste management system in the open-air museum has been under intense development. Waste management is also a component part of the environmental workshops for young students and environmental volunteers working in the area to clean-up illegal dumps in the surrounding villages during their 1-2-day visits several times a year; and therefore, waste management of the island works as a showcase for a larger audience. There are procedures for waste sorting after which the contents are shipped to the mainland for further handling steps.

However, waste sorting in the villages surrounding Kizhi Island is more variable. Some still have active waste sites, and some of the waste is produced by outside source (e.g., where mainland road ends). Some of the old waste sites, for example on Kizhi Island, have been closed by backfilling the sites: no information is available on the environmental impacts.

The main drivers for waste management in this case will be the village inhabitants and second-home owners. In addition, waste can come from external sources. At the same time, waste management on Kizhi Island has been improved, but the potential impacts of old waste management sites cause uncertainty. Waste-related drivers are quite the same as in Vodlozersky NP; the number of waste producers and the amount of waste fluctuates substantially depending on season. In addition, the infrastructure on Kizhi leaves much to be desired; there is still a need for developing the waste management system for the whole area, as well as for improving the roads and harbor infrastructure as a step to curbing illegal dumping.

4.2.2. Pressures

The pressures from the waste sites on the surrounding water, soil and human health is somewhat understudied. The waste sites do pose some point-source risk to the environment. However, although the type of the wastes is currently not fully known, they are considered regular municipal waste. In such case, the waste causes no massive harm to the environment (e.g., large amounts of hazardous substances) but naturally results in some emissions, leakages, eutrophication etc. However, one important aspect is the question of appearance: how do the scattered waste sites affect the attractiveness of the region and the well-being of its residents?

To better comprehend the pressures and current state of the area, the site was visited by a team from the University of Oulu (UOulu) and Karelian Research Centre (KarRC) on June 7th to June 8th 2019 (Fig. 30). Researchers scrutinized the site to better understand what the hydrological, geological and ecological conditions in the area were. Water supply arrangements in the area were also studied.

Figure 30. A waste site: Sennaya Guba (photo by Pekka Rossi)

The first results concerning the pressure are concerned with the variability of the waste site cases. The surroundings of the waste sites varied. Some were close to the shoreline, some more inland. Some of the dumps had already been cleaned-up or backfilled, while others were in active use. Some were closer to villages, some further away. This variability of sites entails variations in pressure, state and impacts. The response needed would also vary. As to the water supply, the villages mainly drew water from Lake Onega. Some houses also used wells. Therefore, pressure on water quality from the waste sites should also be considered.

4.2.3. State

The condition of the visited sites varied, but they could be generally classified into five categories:

1. Near shoreline/inland
2. Active/inactive/closed/cleaned-up
3. Close to inhabitants and water source/far from housing
4. Geology and soil conditions
5. Ecological conditions

This categorization clarifies both the state and the impacts of each specific site on the surroundings. There are also common aspects between the sites, but these are discussed in detail in Impacts. Below are three examples of sites of different categories. Soil and ecological studies (chapters 4.3. and 4.6.) give more details for the categories 4 and 5.

Active but cleaned-up site near shoreline: Oyatevshchina Village

The dump in Oyatevshchina Village was very near the shoreline, so if there is any leaching or spreading of garbage, it will be seen in Lake Onega. During the field visit three water samples were taken from the lake (Fig. 31, Tab. 7). There was some change in temperature and oxygen level of the water, and the pH was lower near the shoreline, but this kind of variance of water quality can result from the distance off the shoreline and depth of the water. **Heavy metal or nutrient sampling from the lake could give more detailed information on the impacts of the site.** The site had already been cleaned up, so any possible risks to the area are already diminishing. But local stakeholders were unsure whether more waste would be piling up, as the site is near the road.

Figure 31. Oyatevshchina Village waste site (red dot) and water sampling points (blue dots, 5 m, 50 m and 230 m) in Onega.

Table 7. Basic water quality parameters at different distances from the waste site.

	Temperature (°C)	EC (μs/cm)	pH	Oxygen (mg/l)
5 m	23.9	54.4	7.09	10.3
50 m	22.3	53.8	7.3	10.8
230 m	20.5	54.2	7.3	11.3

As the site is near the shoreline and near dwellings, it must be taken into account that, even though no notable impact on basic water quality parameters was detected, this site or a similar kind of sites that have not been cleaned up may pose a risk for potable water. The most common water source for the inhabitants is the lake, from where water is pumped for household use. The waste site can increase the risk of water pollution.

The sediment in the site is till, suggesting less infiltration of water to soil, but more of the water from the waste site will reach the lake as surface runoff (Fig. 32–33).

Figures 32–33. Water sampling at Oyatevshchina village
(photo 32 by Yuri Protasov and 33 by Alex Shveykovskiy)

Active site further inland and away from inhabitants: Sennaya Guba

In the Sennaya Guba case, the dump was still in active use, and people were piling waste to the site. The site was situated on Bolshoi Klimenetsky Island, 1 km from the nearest shoreline and there were no large streams or ditches nearby. The location of the site would seem less risky compared to the Oyatevshchina case, but, based on the geological map (Fig. 28-29), the site is on top of an esker. If this is the case, the most probable direction of water seepage from the waste site is as groundwater flow towards villages Petry and Pleshki on Onega shore (Fig. 34).

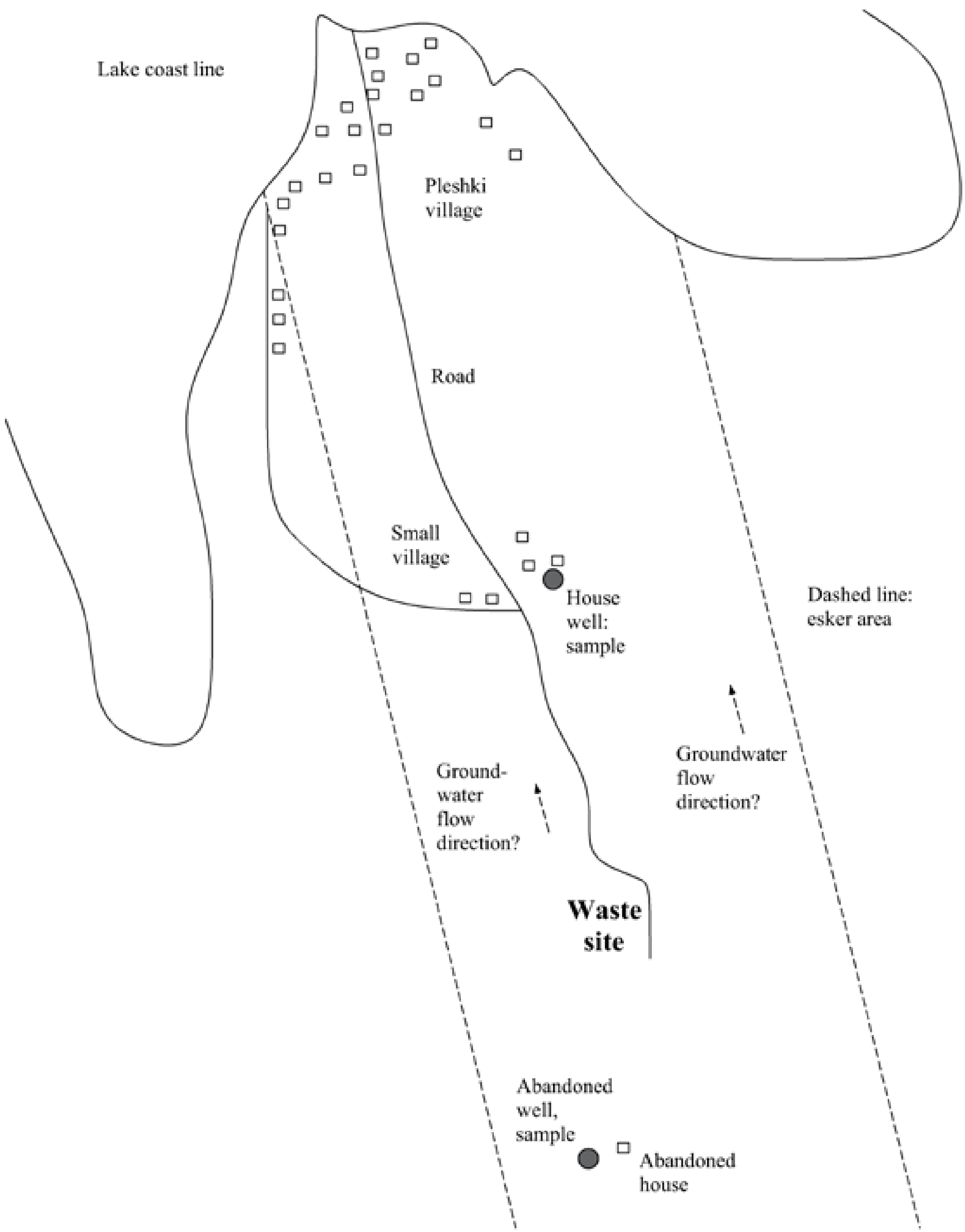


Fig. 34. Sennaya Guba waste site example.

Based on geological maps, the waste site is situated on top of an esker system, with general slope to the lake shoreline. There are some wells in the village (Fig. 35-36), but most of the potable water is drawn from the lake. Active pastures are situated on the esker.

Figures 35-36. Visiting an abandoned well (photo 35 by Yuri Protasov and 36 by Alex Shveykovskiy)

The location of the waste site does create a risk to the groundwater, but can something be found in the water? Two samples were collected from the area, and one of the samples was from a house well in the probable direction of the groundwater flow (Tab. 8). The water did have high electric conductivity, but based on the geological information there can be metal elements in the soil, which can explain higher readings. **Nutrient and heavy metal sampling might bring more information**, but as the soil might contain metals and the esker area was an active pasture, there are also other sources for these substances.

Table 8. Water quality at a well and a spring near the waste site.

	Temperature (°C)	EC (µs/cm)	pH
Spring	8,9	112,2	6,3
House well	18,6*	471	6,49

*Water probably standing in the pipe, warmed up

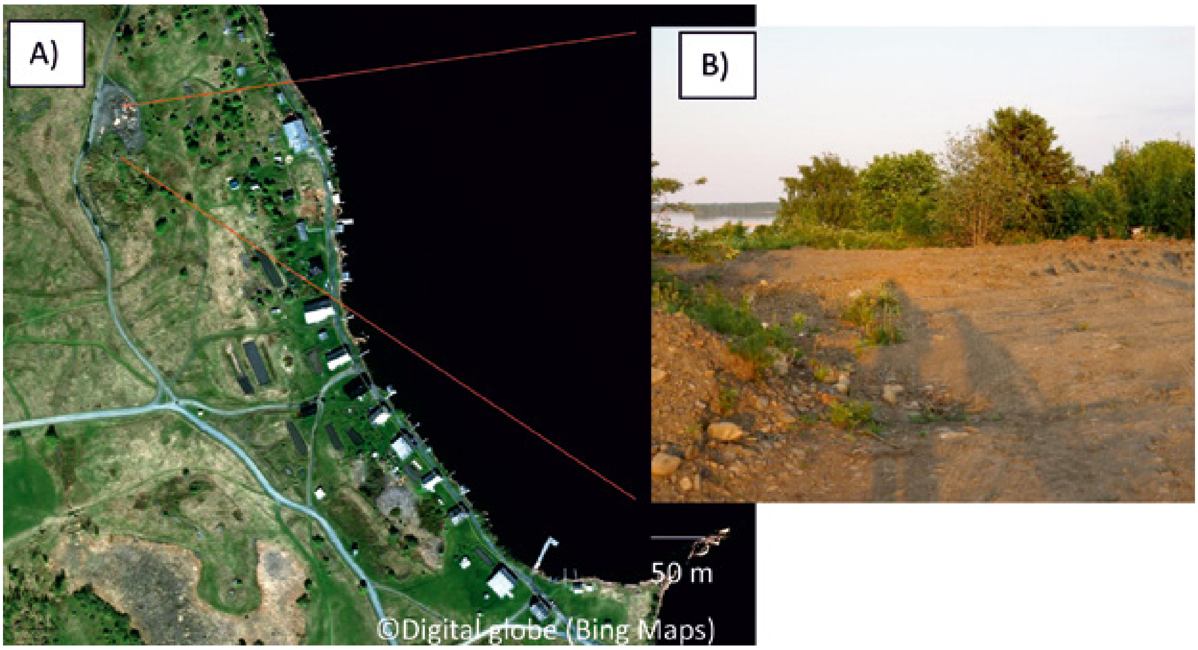
Even though this site was more inland, it can be problematic for the surroundings due to the geological conditions. Even if it may be hard to differentiate the role of the waste site in the groundwater quality, the site does create a risk for the groundwater and for the wells downstream, and in a minor way for the water at the Pleshki village shore: groundwater from the esker will discharge to the lake near the village, and if villagers use lake water, potable water can be affected.

Closed and backfilled site: Kizhi Island

Kizhi Island has all the waste collected to be transported to the mainland. There is an old waste site situated on the top of an esker hill with sand and gravel underneath. The site has been covered up with soil material (Fig. 37), but precipitation can still seep through the soil fill to the waste and finally to the groundwater, depending on the filling material on top. The impacts from the old waste site (e.g., heavy metals and nutrients, depending on waste material) can be monitored by piezometers. Figure 37 B shows the situation around the waste site. Based on the surface elevations, the most probable groundwater flow directions would be to the east, and possibly to the south as a secondary direction. These could be the places for groundwater quality monitoring. However, as the exact geological structure of the esker is unknown, these flow directions are an educated guess. If the esker turns out to have a distinct gravel core, the flow direction will rather follow the core.

Considering water supply and water use, two places are of interest. The first one is the households on the shore, east of the waste site. If these houses use water from the lake, there is a risk that the water is polluted by seepage to the lake shore from the waste site through groundwater. In this case, it might be good to check the water quality house by house. Although the lake's water mass is great and the water can mix easily, the risk of pollution from the waste site is not ruled out. The second point of interest is the well made more than a decade ago in the roadside, south of the waste site. The well was used for drinking water, and analyzed annually. Based on the annual water quality parameters (Tab.9), the water does not seem to have excess ammonium or nitrates, which seem to indicate no impact from agriculture, wastewater or from the waste site (Fig. 38). The electric conductivity in 2019 was above 200 μS/cm, but this could as well be explained by shungite content of the soil (see 4.3). Some chloride spikes were present in 2009 and 2017 (due to agriculture?), but generally the levels are low. Based on the surface elevation, the well would be outside of the possible impact zone of the waste site. More probably, the groundwater feeding the well originates from a southerner area, from another hill in the esker. But, as stated previously, the unknown geological structure does generate uncertainty in the groundwater flow.

The soil, hydrology and ecology study campaign continued in 2020, and the detailed results are presented in 4.3. (soil), 4.4., 4.5. (microplastics and hydrology) and 4.6. (ecology). The soil studies did find that **rare earth elements (REE) were high in some of the sites.** For some of the sites, however, some of the REE content can be explained by the soil material (e.g., shungite). **Microplastics were higher in the Onega lake sediment near some of the sites**, but this can also be due to the tourism activity. **Ecological studies revealed the presence of adventitious/invasive plant species in some of the sites.**



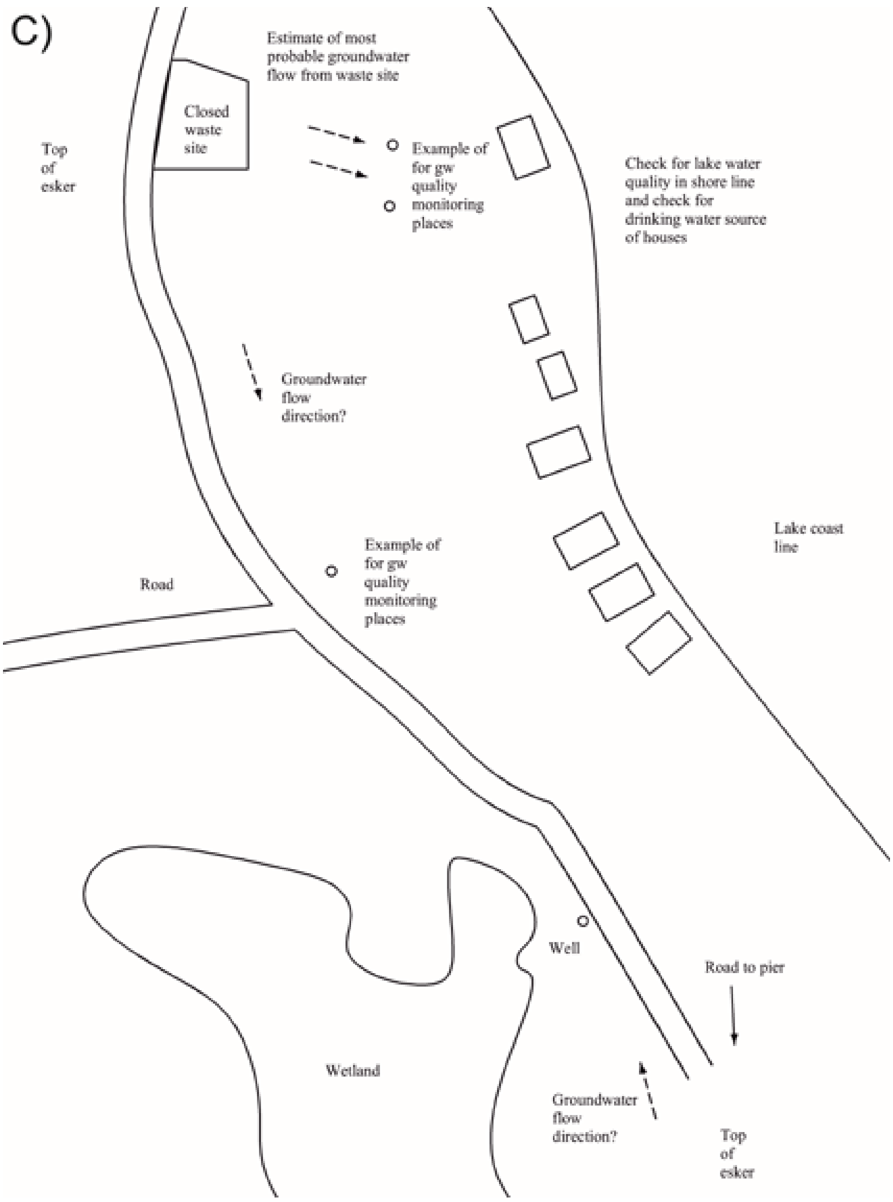


Figure 37. A) Aerial view, B) Land photo, and C) Conceptual map of the hydrogeological settings of the Kizhi Island's closed waste site, drinking water well, and points for groundwater monitoring.

Table 9. Water quality variation in the well near the closed waste site on Kizhi.

	Anions and cations (mg/l)						Metals (mg/l?)									
	NH_4	Fe	Cl	SO_4	NO_3	NO_2	Pb	Co	Cd	Mn	Cu	Zn	E.C.	pH	Color	Turbidity
24.6.2009		0,13	33		0,1	0,012	0,006	-	0,0001	0,02	0,005	0,068	4,8*	7,8	3	0,2
1.6.2010		0,03	1,75		14,2		1E-04		0,0001	0,05	0,005	5E-04	3*	7,1	6	0,1
29.6.2011		0,06	1,1		0,31		0,001	0,001	0,0001	0,09	0,007	0,006		7,61	0	0
19.6.2012	0,02	0,21	1,7		0,88	0,004	0,001	0	0,0001	0,062	0,077	0,024		7,27	5	0
12.5.2013		0,35	3,32		0,988		0,001	0,001	0,0001	0,029	0,044	0,049	2,58*	6,81	42,8	2,16
18.06.14		0,077	2,75	47,2	5,98		<0,001	<0,001	< 0,0001	0,053	0,011	0,021		7,01	9,22	0,86
06.06.15		0,119	1,5	35,6	5,8					0,059			2094*	7,42	<1	<1
15.06.16		0,115	1,5	43,9	5					0,016			280	7,02	10	<1
08.06.17		0,021	56,6	6,4	0,33					0,004			294	6,96	24	<1
27.06.18		0,017	1,4	36,2	4,9					<0,001			172	6,86	11,4	<1
7.6.2019 (Uoulu)													268	6,85		

Figure 38. Sampling from the well near the closed waste site on Kizhi Island (photo by Elena Fedorova).

4.2.4. Impacts

The waste sites would seem to have indirect and direct impacts or risks. The direct risks are of waste itself, diluting material or ecological impacts from the waste sites. The waste material itself can spread to the surroundings. Especially the waste sites near the lake can result in the waste material spreading to the lake, e.g., further producing the risk of lake pollution with microplastics. This can have also indirect consequences for the attractiveness of the region if there is loose waste material on the lake surface.

Another direct risk to humans is connected with drinking water. Household water is mostly taken from the lake. If a waste site is situated near the lake water intake location, this does create a risk for quality. Also, depending on the local geology, water from the waste site can seep to the groundwater and from there to wells (as in Sennaya Guba) or to the shore (risk in Kizhi?). Other impacts are that the old and existing landfills reduce the attractiveness of the area and possibly lower the social well-being of the people.

Some of the waste sites create the ecological risk of alien plants invasions for the Kizhi skerries. This can affect the native environment and, in the long run, diminish the natural values of the region.

4.2.5. Responses

Based on the field visits and the information gathered from the sites, they can be scored and classified in terms of the level of urgency for cleanup or other management options. Similarly to the many multivariate analyses for decision making (e.g., Karjalainen et al. 2013, Kessili & Benmamar 2016), the classification list presented in the State section could be given different weights to define which of the sites are the most vulnerable. Below is a sample scoring system:

1. *Near shoreline, 5 points; inland with stream nearby, 3 points; inland with no streams, 0 points.* The waste can spread to the lake easily. In inland without streams sites, the impacts can be more local.
2. *Active, 5 points; inactive, 3 points; closed, 2 points; cleaned up, 1 point.*
   Active sites are still accumulating and creating growing amounts of waste. Inactive sites still have the waste at the site; closed sites have the waste at the site but covered up; cleaned up sites are taken care of, but is there a risk of new waste accumulation?
3. *Close to inhabitants and water source, 5 points; far from housing, 1 point.*
   If household water is taken either from wells or the lake near the site, the risk for inhabitants is increasing.
4. *Geology and soil conditions: esker and/or polluted soil, 4 points; till and/or some pollution visible in soil 2 points; clay and/or minimal impacts to soil 0 point.*
   Soil has measurable pollution (see 4.3.) and/or different soil conditions create different pathways for water from the waste site to surroundings.
5. *Ecology, invasive/alien plant species: considerable, 5 points; some, 3 points; none, 0 points*
   Based on the ecological survey, the presence and abundance of non-native species in the dump elevates the ecological risks from the site.

Summing up of the score for each site creates points for each site for classification and comparison. The point values above are just examples, and a more detailed listing can be done if more results are available. Factor weights could be elaborated by discussing with local stakeholders. This kind of a scoring system indicates in what order of urgency the waste sites should be managed.

It would be wise to have discussions with the villagers and dacha owners regarding the waste sites, and information campaigns about waste management. The locals can be informed about their waste site risks, e.g., for drinking water. Enhanced knowledge on the impacts of the waste sites can help to collaborate on the waste management. Similarly, to Vodlozersky NP, the MSW management system for Kizhi needs rethinking, so that the management of the old landfills and the new system would be planned simultaneously, and the requisite infrastructures would be improved to suit the purposes.

The outcome of the DPSIR framework for Kizhi Island can be seen in Figure 39. Some of these responses are already in progress. More detailed conclusions and recommendations for all sites are presented in Chapter 7.

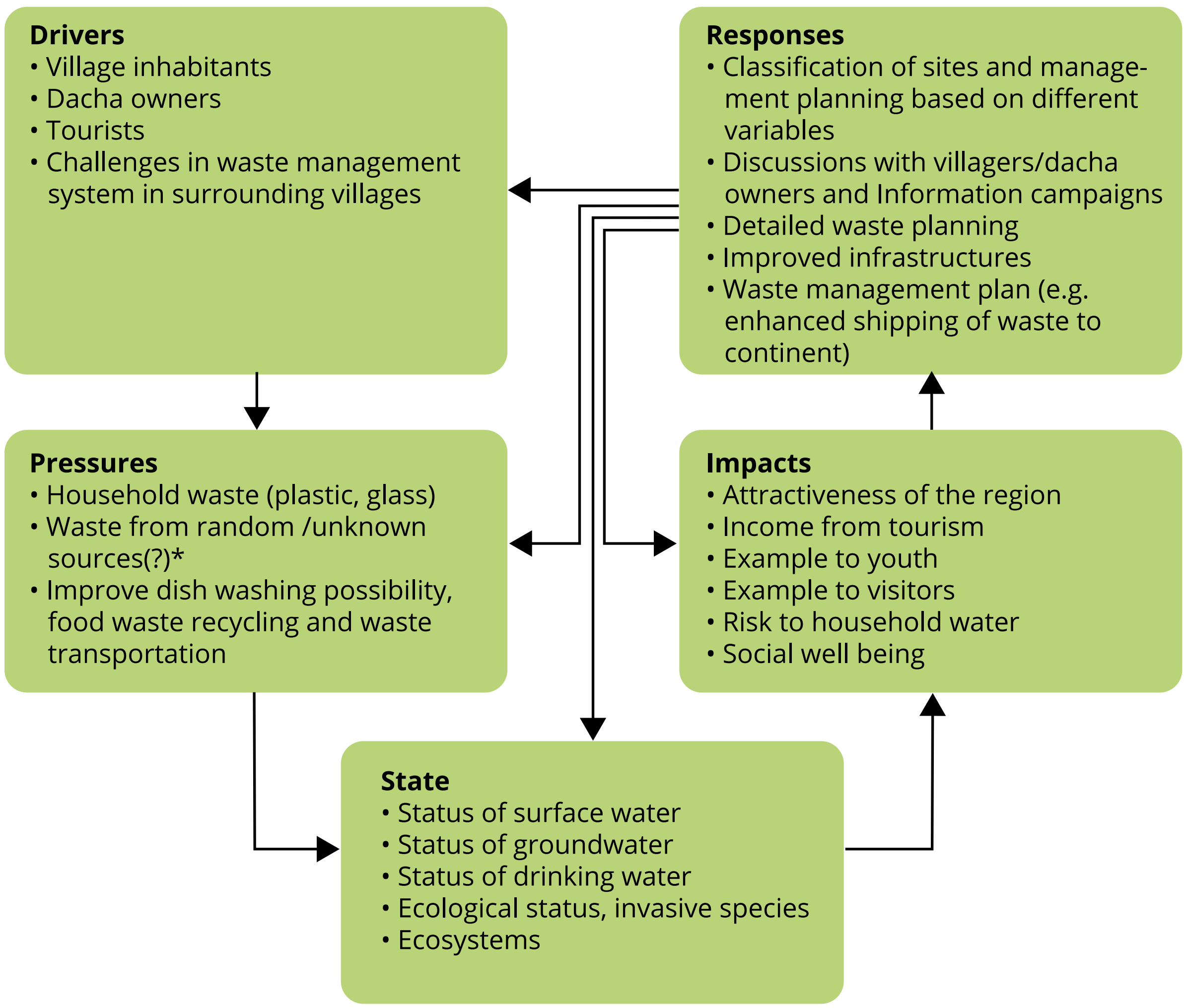


Figure 39. DPSIR framework for the Kizhi case. (* refers to potential pressure, + refers to good state, - refers to need for improvement)

4.3. Kizhi – Soil Research and Analysis

4.3.1. Study sites and methods

Soils were surveyed in illegal dumps formed spontaneously near villages in the Kizhi skerries area (Fig. 40). The methods for the waste sites were the same as in Vodlozersky NP (see 3.3.3)

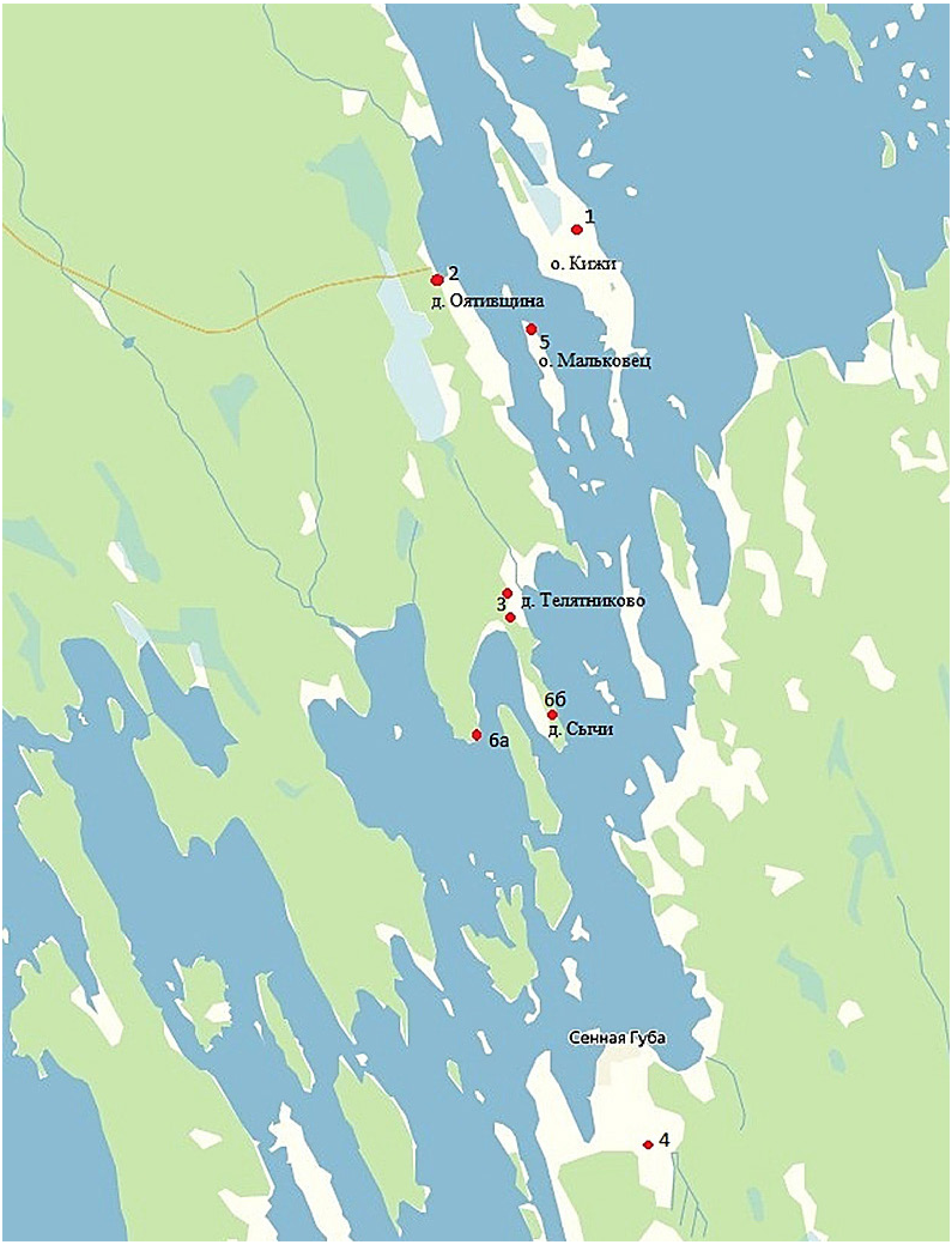


Figure 40. Surveyed waste site locations

Kizhi Island

Since the early 1990's and until 2015 an unauthorized landfill of municipal solid wastes (MSW) ~45 m2 in size had been situated in the Kizhi Island central part (point 1 in Fig. 40). The dump was eliminated with the help of the Kizhi Open Air Museum administration by compacting, incinerating and burying the wastes: all the accumulated waste was moved to a specially excavated pit, burnt and covered up with ground from the excavation heap. The MSW included paper, plastic, glass, old furniture and domestic appliances – TV sets, fridges, etc. This site now looks like a small wasteland partially overgrown with herbaceous vegetation. The top layer of the soil is very dense, composed of spoil heaps with some remains of burnt MSW. Starting with the second stage of soil monitoring (2005) changes in the heavy metal (HM) content of soils in the area have been studied. HM concentrations in soil samples from 0-5 cm depth from the surveyed site across years are shown in the Table. High concentrations of copper (130 mg/kg) and nickel (104 mg/kg) were recorded in 2005. In data from 2011, HM concentrations have changed, zinc and chromium concentrations increased, but the changes were minor. The concentration of a majority of the elements in the top layer decreased after the wastes had been backfilled. This probably happened because the ground used to cover up the wastes had been moved up from the lower natural soil horizons unaffected by the dump.

Oyativshchina Village

A small (3*5 m) waste dump on lake shore was surveyed (point 2 in Fig.40). The woody vegetation is willow thicket; nettle prevails in the ground cover. In spring of 2019 the dump was eliminated, but occasional litter remains on the surface (bottles and cans, wire mesh).

Telyatnikovo Village

Two small dumps situated 100-200 m away from houses in a secondary bird cherry-alder forest were surveyed (point 3 in Fig. 40). One of the dumps was partially eliminated 3 years ago, and now there remain some wooden wastes, cans, asbestos cement sheeting, etc. The other dump is a heap 10*10 m; the waste is composed of old domestic appliances, glass and plastic bottles, cans, etc.

Sennaya Guba Village

An unauthorized dump is situated some 1.5 km away from the village, in an artificial ditch up to 5 m deep in a former hay meadow (point 4 in Fig. 40). Mainly composed of household waste and some construction waste.

Mal'kovets Island

This small island was found to contain several (3-4) household waste dumps 2*2 to 5*5 m in size (point 5 in Fig. 40). The island is covered in secondary tree and shrub vegetation.

Sychi Village (two dumps)

One small dump is on the peninsula shore, not far from the village (point 6a in Fig. 40). Wastes are most probably dumped here by fishermen and locals. Apart from the usual household wastes this dump contained some batteries and storage cells from beacons. The other dump lies in a spruce forest some 100 meters behind the village (point 66 in Fig. 40). It is composed of ordinary household wastes.

3.4.2. Results

The most common soils in the study area are post-farming coarse-humus brown earths (Cambisols) over morainic and fluvioglacial deposits with a high content of shungite, dolerite, and gabbro-dolerite. Soils in the area have a high stone content, a contracted profile with poor differentiation into genetic horizons, and are mostly gray-brown or gray-brown-black.

Figure 41. Soils in the Kizhi skerries.

The reaction of the soils is weakly acidic, pH KCl is within 3 to 5 (Table 10). Acidity variation across the profile is minor, with a slight increase in the lower horizons. Soil carbon content in the control sites and the dumps is highly variable, largely depending on the plant cover, type of use, and presence of different varieties of shungitic rock. Overall, soils under secondary alder stands have a high humus content, with carbon content amounting to 4-7%, while in dump soils it can be up to 8-10%. Soils in the dumps also contain higher amounts of nitrogen, and a very high amount of labile phosphorus, possibly due to their additional input with municipal wastes. Hence, there is a potential risk of surface- and groundwater eutrophication.

Table 10. Physicochemical properties of the soils surveyed in the Kizhi skerries

Site	soil layer/horizon	pH KCl	pH H2O	C, %	N,%	Labile P, %
Sennaya Guba, dump	0-10 cm	4.62	5.76	1.28-4.86*	0.16-0.33	0.01-0.035
	10-20 cm	4.45	5.66	0.94-5.08	0.02-0.32	0.005-0.02
	below 50 cm	4.90	5.87	0.4-3.96	0.01-0.16	0.003-0.013
Parking lot	Ay	4.92	6.36	1.83	0.05	0.012
	Bm	4.77	6.02	0.88	n.d.**	0.011
	BC	4.52	6.11	0.31	0.01	0.0035
Oyativshchina, dump	0-10 cm	6.29	n.d.	0.94	0.02	0.0045
Oyativshchina, control	0-10 cm	5.27	n.d.	0.40	0.01	0.0028
Telyatnikovo 1, dump	0-10 cm	4.71	n.d.	8.65	0.63	0.0056
Telyatnikovo 2, dump	0-10 cm	3.51	n.d.	5.85	0.55	0.0029
Telyatnikovo, control	0-10 cm	3.56	n.d.	4.37	0.28	0.0024
Mal'kovets, dump	0-10 cm	4.44	n.d.	10.22	0.91	0.0031
Mal'kovets, control	0-10 cm	4.5	n.d.	6.88	0.48	0.0039
Sychi 1, dump	0-10 cm	4.9	6.31	2.80	0.18	0.0029
Sychi 1, control	0-10 cm	3.5	4.17	2.05	0.08	0.0024
Sychi 2, dump	0-10 cm	5.75	6.56	6.65	0.58	0.0011
Sychi 2, control	0-10 cm	3.12	4.06	8.94	0.65	0.0030

Ecological-geochemical analysis of soils in the dumps

Changes in heavy metal concentrations in soils of the eliminated dump on Kizhi Isl. (point 1) were studied within environmental monitoring activities in 2005, 2011, and 2016. According to the first surveys in 2005 (the dump not yet covered up), the soils contained high concentrations of copper (130 mg/kg) and nickel (104 mg/kg). Data from 2011 reveal changes in the content of the heavy metals: zinc and chromium concentrations increased, but the changes were minor. The concentration of a majority of the elements in the top layer decreased after the wastes had been covered up. This probably happened because the ground used to cover up the wastes had been moved up from the lower natural soil horizons unaffected by the dump.

Surveys of the small dumps near villages in the Kizhi skerries area proved their pollution characteristics to be largely dependent on the composition of the wastes. A majority of small dumps where the main component is glass and plastic bottles do not cause heavy metal pollution (Table 11) or alteration of sanitary parameters. Soils under a small dump in Vlg. Telyatnikovo, where substantial amounts of cans, nails, springs and other waste containing ferrous and non-ferrous metals were found, featured elevated concentrations of some metals – vanadium, zinc, copper, as well as arsenic.

Soils of the eliminated dump in Vlg. Oyativshchina were found to contain elevated amounts of phosphorus, manganese, cadmium, and lead, but their levels were within the regulatory limits. Zinc concentration was very high - 400 mg/kg, exceeding the tentative permissible concentration (TPC) for acid loamy soils by a factor of four. Arsenic content was twice higher than the maximum permissible concentration – MPC (but the threshold set for this element is highly questionable).

As opposed to the other sites, soils of Mal'kovets Island feature elevated concentrations of a majority of the elements, even in background soils. This probably happened because this island used to serve as the "local dustbin" for the surrounding villages for many years. Among heavy metals, high content was demonstrated by cobalt, nickel, and zinc; arsenic content was very high (ca. 10 mg/kg – exceeding the MPC 5-fold). REE concentration in soils of the dump on this island was also higher than in other dumps surveyed.

Soils of the small dump near Vlg. Sychi (found to contain lots of batteries from vehicles and appliances) had a very high zinc content – over 600 mg/kg, exceeding the TPC 6-fold, and the background level 11-fold. The content of chromium, copper, and lead there was also high, but within the regulatory limits.

The largest among the surveyed dumps (in Vlg. Sennaya Guba) is a major source of soil contamination with hazardous substances. It contains high concentrations of vanadium, chromium, manganese, cobalt, nickel, copper, cadmium, zinc, and other metals and metalloids. The concentrations, however, are comparable with the local background. This means that the geochemical background for many chemical elements is naturally elevated in the area due to characteristics of the parent material – shungitic shales (Reimann et al., 2003, Матинян и др., 2007, Рыбаков, 2020), which are rich in many chalcophile (chemical elements in sulfide form – Ag, As, Cu, Pb, Cd, Bi, Zn, Sb, Se, Mo, Ga, Tl) and lithophile (chemical elements in oxide form– V, Ti, Li, Cr, Mn, Co, Ni) elements, as well as in REE.

Especially high in the studied soils is the concentration of arsenic – 30-50 mg/kg, many times higher than the MPC (2 mg/kg) and TPC (5 mg/kg for acid loamy soils), but the MPC and TPC values set for this element are highly questionable.

Noteworthy is the high concentration of tin in the dump's upper soil horizons, which is 3-3.5 times above the background, and exceeds the MPC 2.5-fold. Antimony content in soils of the dump is also high, especially in the upper horizons – its concentration is twice higher than in the background, and in one sample the MPC was also exceeded.

Table 11. Total content of chemical elements in soils of the dumps and control sites (Kizhi skerries).

Site	soil layer, cm/horizon	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Y
Sennaya Guba, dump	0-10 cm	5319± 516	312± 44	136± 14	906±81	23.03±1.31	71.23± 5.11	92.53± 2.38	333±75	18.94±2.51
	10-20 cm	5148.5±191	340± 26	118±7	857± 126	22.96±1.04	77.5± 8.04	107.98±15.13	224±23	20.46±0.90
	below 50 cm	5280± 428	315±2	117±2	1215± 356	34.04±9.94	105.5± 28.7	146.45±47.05	209±9	19.37±1.06
Sennaya Guba, control	Ay	4335	365	118.3	731	24.16	95.65	118.3	214	23.05
	Bm	4606	355	126.1	911	25.28	80.62	101.5	289	19.81
	BmC	5040	355	126.3	479	22.47	96.92	145.7	204	20.68
Oyativshchina, dump	0-10 cm	2225	61	29.43	1078	10.79	30.64	53.24	442	6.87
Oyativshchina, control	0-10 cm	3312	87	36.27	1273	13.21	28.43	49.74	151	9.85
Telyatnikovo 1,dump	0-10 cm	4037	125	33.15	508	13.35	28.37	63.82	164	10.46
Telyatnikovo 2, dump	0-10 cm	3161	74	34.07	316	8.03	20.33	22.79	83	7.96
Telyatnikovo, control	0-10 cm	4913	151	34.44	636	14.65	26.44	40.47	101	10.22
Mal'kovets, dump	0-10 cm	3641	125	45.9	411	14.25	44.28	43.57	101	10.44
Mal'kovets, control	0-10 cm	4004	136	45.14	541	15.93	47.81	50.37	118	12.06
Sychi 1, dump	0-10 cm	3620	107	55.56	544	12.54	32.56	56.56	641	9.8
Sychi 1, control	0-10 cm	3551	105	55.9	434	13.58	33.59	43.16	57	10.8
Sychi 2, dump	0-10 cm	3868	116	52.77	612	12.12	29.28	37.93	111	10.29
Sychi 2, control	0-10 cm	3277	104	47.19	400	9.53	26.28	37.31	60	9.1

		Zr	Nb	Mo	Ag	Cd	Lu	Hf	Ta	Y
Sennaya Guba, dump	0-10 cm	518±49	10.26±1.05	10.3± 0.71	0.98± 0.09	1.12± 0.4	0.3±0.03	11.22± 1.13	0.61±0.06	1.27± 0.06
	10-20 cm	478.6±3	10.22±0.94	11.74±0.45	1.11± 0.0	0.58	0.35± 0.02	9.58±0.04	0.63±0.03	1.28± 0.07
	below 50 cm	590±39	9.33± 0.31	10.65±0.57	0.51± 0.18	0.74± 0.05	0.33± 0.02	11.75±0.8	0.62±0.03	1.12± 0.01
Sennaya Guba, control	Ay	530	8.92	13.84	0.86	0.65	0.35	10.88	0.6	1.4
	Bm	427	9.09	11.18	1.31		0.35	8.84	0.6	1.26
	BmC	607	9.14	11.15	0.83	0.75	0.39	12.77	0.58	1.3
Oyativshchina, dump	0-10 cm	1083	3.59	1.49	0.41	1.57	0.12	22.71	0.25	0.62
Oyativshchina, control	0-10 cm	889	5.54	1.48	0.32	0.78	0.16	18.72	0.37	0.34
Telyatnikovo 1,dump	0-10 cm	887	5.12	1.16	0.77	0.8	0.16	18.47	0.36	0.39
Telyatnikovo 2, dump	0-10 cm	948	5.13	0.68	0.29	0.63	0.14	20.1	0.34	0.36
Telyatnikovo, control	0-10 cm	889	6.21	1.27	0.26	0.74	0.16	19.56	0.39	0.36
Mal'kovets, dump	0-10 cm	714	6.27	3.31	0.25	0.73	0.18	15.54	0.39	0.81
Mal'kovets, control	0-10 cm	788	7.37	3.61	0.27	0.74	0.19	17.3	0.44	0.75
Sychi 1, dump	0-10 cm	869	4.9	0.97	0.15	0.96	0.17	17.76	0.38	0.34
Sychi 1, control	0-10 cm	914	5.39	0.85	BDL	0.68	0.17	18.15	0.38	0.3
Sychi 2, dump	0-10 cm	765	5.44	0.62	0.25	BDL	0.15	16.05	0.37	0.4
Sychi 2, control	0-10 cm	798	4.48	0.7	0.39	BDL	0.15	16.34	0.33	0.38

		Ga	Sn	Tl	Pb	Bi	As	Sb	Li	Be
Sennaya Guba, dump	0-10 cm	15.16±2.94	6.1± 4.21	0.65± 0.08	49.32± 16.41	0.29± 0.04	32.63± 4.91	2.82± 1.66	35.67± 4.82**	1.56± 0.01
	10-20 cm	16.74±0.64	1.95± 0.14	0.75± 0.03	26.35± 1.71	0.29± 0.01	40.83± 11.08	1.26± 0.15	36.71± 1.83	1.63± 0.37
	below 50 cm	14.64±0.48	1.75± 0.07	0.73± 0.05	38.5± 14.82	0.26± 0.03	37.62± 0.11	1.42± 0.25	34.6± 1.18	BDL
Sennaya Guba, control	Ay	16.69	1.72	0.75	24.88	0.31	49.09	1.41	36.14	1.75
	Bm	17.94	1.87	0.69	24.61	0.31	43.76	1.15	39.65	1.92
		16.1	2.44	1.3	21.57	0.27	53.29	1.25	40.11	BDL
Oyativshchina, dump	0-10 cm	5.43	9.35	0.29	29.54	0.09	3.95	0.51	9.14	0.77
Oyativshchina, control	0-10 cm	9.6	4.25	0.34	26.06	0.09	2.62	0.38	13.88	0.94
Telyatnikovo 1,dump	0-10 cm	10.84	1.85	0.34	22.72	0.1	3.28	0.28	16.9	0.64
Telyatnikovo 2, dump	0-10 cm	10.45	1.98	0.33	17.51	0.11	BDL	0.22	11.44	0.93
Telyatnikovo, control	0-10 cm	11.98	1.49	0.36	14.9	0.09	1.32	0.24	15.28	0.8
Mal'kovets, dump	0-10 cm	10.3	2.32	0.48	14.83	0.13	8.17	1.59	15.02	0.73
Mal'kovets, control	0-10 cm	11.88	1.75	0.54	14.49	0.11	11.85	0.7	18.58	0.73
Sychi 1, dump	0-10 cm	14.06	16.22	0.4	24.28	0.17	BDL	0.91	17.73	BDL
Sychi 1, control	0-10 cm	15.95	1.18	0.41	15.31	0.11	3.96	0.2	17.3	1.15
Sychi 2, dump	0-10 cm	14.28	10.48	0.38	21.61	0.14	BDL	0.3	17.86	0.92
Sychi 2, control	0-10 cm	13.71	1.22	0.41	18.41	0.11	BDL	0.29	14.25	BDL

		Rb	Sr	Sc	Ba	La	Ce	Pr	Nd	Sm
Sennaya Guba, dump	0-10 cm	66.63±6.99	147± 10	18.62±2.61	617±40	17.2±2.49	34.64± 4.68	4.06± 0.6	15.89± 2.37	3.41± 0.56
	10-20 cm	64.33±5.79	149± 16	21.4± 0.67	638±14	19.08±1.2	39.14± 1.36	4.42± 0.32	17.62± 1.20	3.61± 0.1
	below 50 cm	55.55±7.14	148± 3.5	22.01±0.68	576±3	18.4± 1.64	41.53± 7.01	4.33± 0.54	17.29± 2.02	3.61± 0.52
Sennaya Guba, control	Ay	59.03	129	20.04	615	22.32	44.65	5.2	20.4	4.25
	Bm	71.76	136	20.67	668	18.9	37.92	4.17	16.22	3.41
	BmC	52.21	136	21.58	578	16.19	40.74	3.87	15.51	3.34
Oyativshchina, dump	0-10 cm	31.21	151	7.02	405	7.53	15.88	1.81	7.17	1.48
Oyativshchina, control	0-10 cm	45.98	182	9.37	499	9.99	22.14	2.56	10.56	2.3
Telyatnikovo 1,dump	0-10 cm	32.82	147	11.67	350	9.2	19.58	2.34	9.78	2.08
Telyatnikovo 2, dump	0-10 cm	46.62	177	8.67	408	7.68	16.22	1.91	7.99	1.8
Telyatnikovo, control	0-10 cm	58.31	177	11.24	435	8.62	18.48	2.2	8.82	2.05
Mal'kovets, dump	0-10 cm	38.62	129	10.82	347	10.07	21.19	2.52	10.08	2.05
Mal'kovets, control	0-10 cm	51.48	136	11.76	387.5	13.33	27.68	3.23	12.54	2.47
Sychi 1, dump	0-10 cm	48.8	244	13.48	498.2	8.66	20.05	2.19	8.77	2
Sychi 1, control	0-10 cm	50.93	264	14.74	547.6	12	28.93	2.97	11.63	2.43
Sychi 2, dump	0-10 cm	51.55	230	13.02	487.6	9.1	18.47	2.24	8.8	2.02
Sychi 2, control	0-10 cm	48.29	206	12.58	476.1	8.89	18.78	2.18	8.57	1.91

		Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
Sennaya Guba, dump	0-10 cm	0.89± 0.1	3.16± 0.47	0.53± 0.06	3.29± 0.42	0.64± 0.07	2.14 ±0.19	0.28±0.03	2.06±0.27
	10-20 cm	0.96± 0.03	3.44± 0.23	0.55± 0.01	3.48± 0.18	0.69± 0.04	2.13± 0.03	0.31±0.02	2.22±0.1
	below 50 cm	0.98± 0.08	3.41± 0.45	0.55± 0.06	3.5± 0.43	0.72± 0.07	2.12± 0.17	0.31±0.03	2.18±0.16
Sennaya Guba, control	Ay	1.11	4.15	0.69	4.11	0.8	2.39	0.36	2.48
	Bm	0.91	3.12	0.51	3.51	0.68	2.2	0.3	2.25
	BmC	0.93	3.28	0.57	3.75	0.73	2.17	0.34	2.29
Oyativshchina, dump	0-10 cm	0.46	1.34	0.22	1.31	0.27	0.81	0.11	0.76
Oyativshchina, control	0-10 cm	0.67	2.03	0.34	1.96	0.39	1.16	0.16	1.09
Telyatnikovo 1,dump	0-10 cm	0.67	1.99	0.33	2.06	0.41	1.18	0.17	1.15
Telyatnikovo 2, dump	0-10 cm	0.55	1.59	0.25	1.55	0.31	0.93	0.14	0.91
Telyatnikovo, control	0-10 cm	0.66	1.92	0.34	1.96	0.39	1.25	0.16	1.14
Mal'kovets, dump	0-10 cm	0.62	1.95	0.34	1.89	0.41	1.24	0.16	1.17
Mal'kovets, control	0-10 cm	0.72	2.27	0.39	2.19	0.46	1.37	0.19	1.26
Sychi 1, dump	0-10 cm	0.65	1.81	0.31	1.7	0.34	1.05	0.16	1.06
Sychi 1, control	0-10 cm	0.75	2.33	0.35	2.1	0.41	1.18	0.15	1.22
Sychi 2, dump	0-10 cm	0.68	1.85	0.32	1.83	0.37	1.08	0.15	1.1
Sychi 2, control	0-10 cm	0.65	1.83	0.3	1.74	0.33	1	0.13	0.98

Note: BDL – below detection limit; colors indicate: – transition metals, – post-transition metals, – metalloids, – alkali and alkaline earth metals, – lanthanides, – non-metals

Labile forms of heavy metals

According to our results, the content of a majority of the elements neither exceeded the MPC nor was elevated vs. soils in the control sites (Table 12).

Elevated levels were detected for labile zinc (ca. 30 mg/kg) in soils of the dumps at the villages Oyativshchina, Sychi (point 6a), and Sennaya Guba. Labile zinc content was the highest in soils of the small dump near Vlg. Sychi (point 6a) – 37 mg/kg, i.e., 1.5 times higher than the MPC for the labile form of this metal. As mentioned before, soils in this dump also featured an extremely high total zinc content. Hence, these results definitely indicate the wastes contain vehicle batteries with zinc as their main component, considering that we detected no elevated concentrations of other metals.

Locally elevated concentrations were also detected for labile lead in soils of the dump near Vlg. Sennaya Guba – 4 mg/kg, but these values were within current regulatory limits. The same sample also contained slightly elevated (vs. the control) amounts of labile cadmium, tin, and antimony.

Table 12. Content of chemical elements in labile form in soils of the dumps and control sites (Kizhi skerries)

Site	soil layer, cm/horizon	Sc	Ti	V	Cr	Mn	Co	Ni	Cu	Zn
Sennaya Guba, dump	0-10 cm	0.02	0.06-0.17	0.05	0.17	3.16-15.82	0.03	0.2	0.14-0.23	1.72-32.62
	10-20 cm	0.04	0.04-0.25	0.07	0.21	0.18-53.05	0.01-0.23	0.09-0.32	0.4	0.36-3.39
	below 50 cm	0.06	0.17	0.07	0.22	0.38-40.88	0.02-0.25	0.05-0.41	0.47	0.51-2.29
Sennaya Guba, control	Ay	0.07	0.05	0.06	0.21	1.89	0.014	0.26	0.44	0.79
	Bm	0.04	0.05	0.07	0.24	0.25	0.006	0.34	0.38	0.79
	BmC	0.07	0.06	0.07	0.24	0.09	0.014	0.07	0.48	0.53
Oyativshchina, dump	0-10 cm	0.01	0.07	0.03	0.1	1.83	0.004	0.16	0.1	29.11
Oyativshchina, control	0-10 cm	0.01	0.05	0.03	0.11	1.1	0.001	0.1	0.09	4.84
Telyatnikovo 1,dump	0-10 cm	0.02	0.04	0.03	0.11	3.74	0.012	0.12	0.08	11.53
Telyatnikovo 2, dump	0-10 cm	0.01	0.11	0.03	0.11	11.08	0.032	0.1	0.06	7.37
Telyatnikovo, control	0-10 cm	0.02	0.06	0.03	0.11	9.63	0.021	0.16	0.07	3.2
Mal'kovets, dump	0-10 cm	0.01	0.04	0.04	0.13	3.16	0.025	0.32	0.06	2.19
Mal'kovets, control	0-10 cm	0.01	0.04	0.03	0.11	4.44	0.012	0.23	0.07	1.76
Sychi 1, dump	0-10 cm	0.04	0.08	0.07	0.27	21.69	0.021	0.06	0.42	36.84
Sychi 1, control	0-10 cm	0.08	0.44	0.1	0.42	28.23	0.307	0.42	0.49	0.37
Sychi 2, dump	0-10 cm	0.05	0.3	0.08	0.38	50.78	0.04	0.27	0.36	7.82
Sychi 2, control	0-10 cm	0.05	0.79	0.09	0.44	25.58	0.117	0.27	0.46	2.66

Site	soil layer, cm/horizon	Y	Zr	Nb	Mo	Ag	Cd	Lu	Hf	Ta
Sennaya Guba, dump	0-10 cm	0.05	0.006	$2*10^{-4}$	0.03	$6*10^{-4}$	0.02-0.21	$2*10^{-4}$	$3*10^{-4}$	$3*10^{-5}$
	10-20 cm	0.07	0.017	$7*10^{-4}$	0.04	0.006	0.03	$2*10^{-4}$	$7*10^{-4}$	$5*10^{-5}$
	below 50 cm	0.1	0.023	$6*10^{-4}$	0.04	$7*10^{-4}$	0.007-0.05	$3*10^{-4}$	0.0011	$5*10^{-5}$
Sennaya Guba, control	Ay	0.31	0.008	$1*10^{-4}$	0.032	$2*10^{-4}$	0.03	$8*10^{-4}$	$7*10^{-4}$	$7*10^{-5}$
	Bm	0.06	0.006	$1*10^{-4}$	0.033	$2*10^{-4}$	0.02	$1*10^{-4}$	$3*10^{-4}$	$3*10^{-5}$
	BmC	0.1	0.014	$1*10^{-4}$	0.034	$2*10^{-4}$	0.02	$2*10^{-4}$	$7*10^{-4}$	$3*10^{-5}$
Oyativshchina, dump	0-10 cm	0.01	0.002	$1*10^{-5}$	0.001	BDL	0.07	BDL	BDL	BDL
Oyativshchina, control	0-10 cm	0.02	0.002	$1*10^{-5}$	0.002	BDL	0.02	BDL	BDL	BDL
Telyatnikovo 1,dump	0-10 cm	0.06	0.002	$1*10^{-5}$	0.001	BDL	0.04	BDL	BDL	BDL
Telyatnikovo 2, dump	0-10 cm	0.03	0.004	$1*10^{-5}$	0.037	BDL	0.03	BDL	BDL	BDL
Telyatnikovo, control	0-10 cm	0.06	0.003	$1*10^{-5}$	0.002	BDL	0.03	BDL	BDL	BDL
Mal'kovets, dump	0-10 cm	0.04	0.003	$1*10^{-5}$	0.001	BDL	0.03	BDL	BDL	BDL
Mal'kovets, control	0-10 cm	0.06	0.004	$1*10^{-5}$	0.001	BDL	0.04	BDL	BDL	BDL
Sychi 1, dump	0-10 cm	0.01	0.002	$1*10^{-4}$	0.079	$1*10^{-4}$	0.02	$1*10^{-5}$	$1*10^{-4}$	$2*10^{-5}$
Sychi 1, control	0-10 cm	0.21	0.038	0.002	0.052	$5*10^{-4}$	0.01	$5*10^{-4}$	0.0016	$1*10^{-4}$
Sychi 2, dump	0-10 cm	0.09	0.013	0.001	0.104	$7*10^{-4}$	0.04	$2*10^{-4}$	$5*10^{-4}$	$7*10^{-5}$
Sychi 2, control	0-10 cm	0.05	0.014	0.002	0.043	0.0016	0.03	$9*10^{-5}$	$6*10^{-4}$	$1*10^{-4}$

		W	Re	Hg	Ca	Sn	Tl	Pb	Bi	B
Sennaya Guba, dump	0-10 cm	$4*10^{-5}$	$3*10^{-5}$	0.002	1788	0.002-0.02	0.001	0.04-4.12	$4*10^{-4}$	0.26
	10-20 cm	$3*10^{-4}$	$4*10^{-5}$	0.005	1194	0.004	0.002	0.12	$2*10^{-4}$	0.22
	below 50 cm	$3*10^{-4}$	$5*10^{-5}$	0.004	997	0.003	0.002	0.03-2.48	$2*10^{-4}$	0.28
Sennaya Guba, control	Ay	$3*10^{-4}$	$8*10^{-5}$	0.002	1217	0.002	$4*10^{-4}$	0.08	$2*10^{-4}$	0.18
	Bm	$1*10^{-4}$	$3*10^{-5}$	0.001	1457	0.003	$7*10^{-4}$	0.06	$1*10^{-4}$	0.16
	BmC	$2*10^{-4}$	$3*10^{-5}$	0.003	364	0.003	$9*10^{-4}$	0.08	$1*10^{-4}$	0.16
Oyativshchina, dump	0-10 cm	0.001	BDL	0.001	2373	0.002	0	0.09	0.018	0.53
Oyativshchina, control	0-10 cm	0.001	BDL	0	1277	0.001	0.001	0.08	0.001	0.27
Telyatnikovo 1,dump	0-10 cm	0.001	BDL	0.001	1272	н.о.у.	0.001	0.35	0.001	0.18
Telyatnikovo 2, dump	0-10 cm	0.001	BDL	0.001	497	0.001	0.001	0.55	0.001	0.12
Telyatnikovo, control	0-10 cm	0.001	BDL	0.001	723	0.001	0.001	0.15	0.001	0.1
Mal'kovets, dump	0-10 cm	0.001	BDL	0.001	1711	0.001	0.001	0.17	BDL	0.16
Mal'kovets, control	0-10 cm	0.001	BDL	0.001	1279	0.001	0.001	0.13	0.001	0.12
Sychi 1, dump	0-10 cm	$2*10^{-4}$	0.00001	0.024	575	0.004	0.002	0.16	$3*10^{-4}$	0.19
Sychi 1, control	0-10 cm	$5*10^{-5}$	$5*10^{-5}$	0.002	708	0.008	$9*10^{-4}$	1.05	$5*10^{-4}$	0.15
Sychi 2, dump	0-10 cm	$5*10^{-4}$	$1*10^{-5}$	0.002	16020	0.006	$4*10^{-4}$	1.04	$3*10^{-4}$	0.16
Sychi 2, control	0-10 cm	$5*10^{-4}$	$2*10^{-5}$	0.003	923	0.009	$8*10^{-4}$	2.75	$8*10^{-4}$	0.11

		Ge	As	Sb	Te	Li	Be	Na	Mg	K
Sennaya Guba, dump	0-10 cm	BDL	0.04	0.003-0.1	$2*10^{-4}$	0.004	0.003	572	116	1165
	10-20 cm	0.002	0.05	0.004	$3*10^{-4}$	0.003	0.005	575	144	1649
	below 50 cm	0.002	0.05	0.005	$2*10^{-4}$	0.003	0.007	480	131	1667
Sennaya Guba, control	Ay	0.005	0.06	0.004	$3*10^{-4}$	0.003	0.006	428	104	1655
	Bm	0.002	0.05	0.004	0.0002	0.003	0.007	409	76	1682
	BmC	0.002	0.07	0.006	$1*10^{-4}$	0.003	0.011	386	69	1664
Oyativshchina, dump	0-10 cm	0.046	0.06	0.001	$1*10^{-5}$	0.004	0.001	12	310	131
Oyativshchina, control	0-10 cm	0.046	0.02	0.001	$1*10^{-5}$	0.007	0.001	9	143	50
Telyatnikovo 1,dump	0-10 cm	0.12	0.02	BDL	$1*10^{-5}$	0.017	0.003	8	173	55
Telyatnikovo 2, dump	0-10 cm	0.214	0.02	BDL	$1*10^{-5}$	0.014	0.003	6	69	35
Telyatnikovo, control	0-10 cm	0.242	0.01	BDL	$1*10^{-5}$	0.016	0.004	6	84	40
Mal'kovets, dump	0-10 cm	0.161	0.03	0.003	$1*10^{-5}$	0.008	0.003	9	284	37
Mal'kovets, control	0-10 cm	0.122	0.02	BDL	$1*10^{-5}$	0.018	0.003	7	163	34
Sychi 1, dump	0-10 cm	0.001	0.01	0.005	$2*10^{-4}$	0.004	0.002	441	181	1926
Sychi 1, control	0-10 cm	0.012	0.05	0.007	$5*10^{-4}$	0.053	0.016	374	158	1666
Sychi 2, dump	0-10 cm	0.004	0.03	0.004	$2*10^{-4}$	0.013	0.004	315	230	1571
Sychi 2, control	0-10 cm	0.008	0.03	0.004	$6*10^{-4}$	0.021	0.003	305	177	1535

		Rb	Sr	Cs	Ba	La	Ce	Pr	Nd
Sennaya Guba, dump	0-10 cm	1.38	5.74	0.003	16.4	0.05	0.07	0.01	0.06
	10-20 cm	1.36	5.77	0.004	14	0.06	0.11	0.01	0.09
	below 50 cm	1.3	4.05	0.009	10.6	0.08	0.15	0.02	0.12
Sennaya Guba, control	Ay	1.35	6.36	0.005	17.7	0.42	0.6	0.05	0.35
	Bm	1.89	9.14	0.004	32.8	0.08	0.1	0.02	0.09
	BmC	1.46	1.63	0.01	13.7	0.12	0.16	0.02	0.12
Oyativshchina, dump	0-10 cm	0.29	5.99	0.001	8.3	0.01	0.01	0.003	0.02
Oyativshchina, control	0-10 cm	0.29	4.19	0.001	10.5	0.02	0.03	0.005	0.02
Telyatnikovo 1,dump	0-10 cm	0.15	3.57	0.001	10.2	0.04	0.08	0.01	0.05
Telyatnikovo 2, dump	0-10 cm	0.26	1.76	0.001	6.9	0.03	0.07	0.007	0.03
Telyatnikovo, control	0-10 cm	0.59	2.55	0.002	12	0.05	0.1	0.012	0.05
Mal'kovets, dump	0-10 cm	0.08	3.86		8.3	0.03	0.06	0.008	0.04
Mal'kovets, control	0-10 cm	0.33	2.81	0.001	9.3	0.05	0.08	0.012	0.06
Sychi 1, dump	0-10 cm	2.36	2.6	0.004	9	0.01	0.02	0.001	0.01
Sychi 1, control	0-10 cm	2.75	2.9	0.004	20.6	0.42	1.34	0.061	0.33
Sychi 2, dump	0-10 cm	2.23	33.04	0.002	25.8	0.07	0.15	0.016	0.08
Sychi 2, control	0-10 cm	2.15	4.08	0.006	18.9	0.03	0.07	0.008	0.04

	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Se
Sennaya Guba, dump	0.01	0.004	0.01	0.001	0.01	0.001	0.003	$2*10^{-4}$	0.002	0.009
	0.02	0.004	0.02	0.001	0.02	0.001	0.004	$3*10^{-4}$	0.003	0.021
	0.03	0.006	0.03	0.002	0.02	0.002	0.007	$4*10^{-4}$	0.005	0.021
Sennaya Guba, control	0.08	0.017	0.1	0.006	0.06	0.005	0.019	0.001	0.014	0.011
	0.02	0.005	0.02	0.001	0.01	0.001	0.003	$2*10^{-4}$	0.002	0.012
	0.03	0.005	0.03	0.002	0.02	0.001	0.006	$3*10^{-4}$	0.003	0.017
Oyativshchina, dump	0.003	0.002	0.004	BDL	0.002	BDL	0.001	BDL	0.001	0.003
Oyativshchina, control	0.005	0.002	0.006	0.001	0.004	0.001	0.002	BDL	0.001	0.003
Telyatnikovo 1,dump	0.01	0.003	0.014	0.002	0.01	0.002	0.004	BDL	0.003	0.004
Telyatnikovo 2, dump	0.007	0.002	0.008	0.001	0.005	0.001	0.002	BDL	0.001	0.003
Telyatnikovo, control	0.01	0.004	0.015	0.002	0.011	0.002	0.004	BDL	0.003	0.004
Mal'kovets, dump	0.01	0.003	0.011	0.001	0.007	0.001	0.003	BDL	0.002	0.01
Mal'kovets, control	0.02	0.004	0.017	0.002	0.011	0.002	0.004	BDL	0.003	0.004
Sychi 1, dump	0.001	0.001	0.002	$1*10^{-4}$	0.001	$1*10^{-4}$	0.0004	$2*10^{-5}$	$2*10^{-4}$	0.003
Sychi 1, control	0.07	0.012	0.067	0.004	0.047	0.003	0.016	$8*10^{-4}$	0.011	0.013
Sychi 2, dump	0.02	0.005	0.02	0.001	0.015	0.001	0.005	$2*10^{-4}$	0.004	0.011
Sychi 2, control	0.009	0.003	0.011	$6*10^{-4}$	0.009	$6*10^{-4}$	0.003	$1*10^{-4}$	0.002	0.011

Note: BDL – below detection limit; colors indicate: – transition metals, – post-transition metals, – metalloids, – alkali and alkaline earth metals, – lanthanides, – non-metals

Sanitary and parasitological studies

The results of sanitary and parasitological studies conformed to normative levels.

4.3.3. Responses

According to the regulation “On the procedure of quantifying damage from land pollution with chemical substances” (Appendix 1), soils in all the studied dumps belong to the low-pollution category.

That said, even small-size unauthorized MSW dumps are a potential threat to the nature. More attention should therefore be given to environmental education of local people and tourists, building up awareness among authorities, and establishing the infrastructure for environmentally sustainable management of the areas.

Recommendations for clean-up and remediation of unauthorized dump areas are similar to those given for the Vodlozersky NP.

4.4. Microplastics in lake sediments of protected areas – Kizhi

4.4.1. Study area

Samples were collected at **four sites in Kizhi skerries** (Table 13, Fig. 42). Station Z2 was situated near the main pier of Kizhi Open Air Museum, where large tourist vessels arrive. Station Z(OT) was situated near the Coast Guard station, near the shortest waterway from the mainland (Oyativshina) to Kizhi Island. Station Z3 was situated 2.8 km north-east from Kizhi Island, at the northern exit of the navigation passage from the Kizhi skerries. Station Z4 was located along the navigation passage in the skerries, 6 km south from Kizhi Island, near Sychi Village.

Table 13. Sampling stations in the Kizhi skerries

Station	Date	Depth,m	Y	X
Z2	10.09.2019	4.1	62.07317	35.21381
Z3	09.09.2019	9.5	62.101	35.25144
Z4	10.09.2019	6.5	62.02672	35.22064
Z(OT)	18.06.2020	4.0	62.0843	35.2014

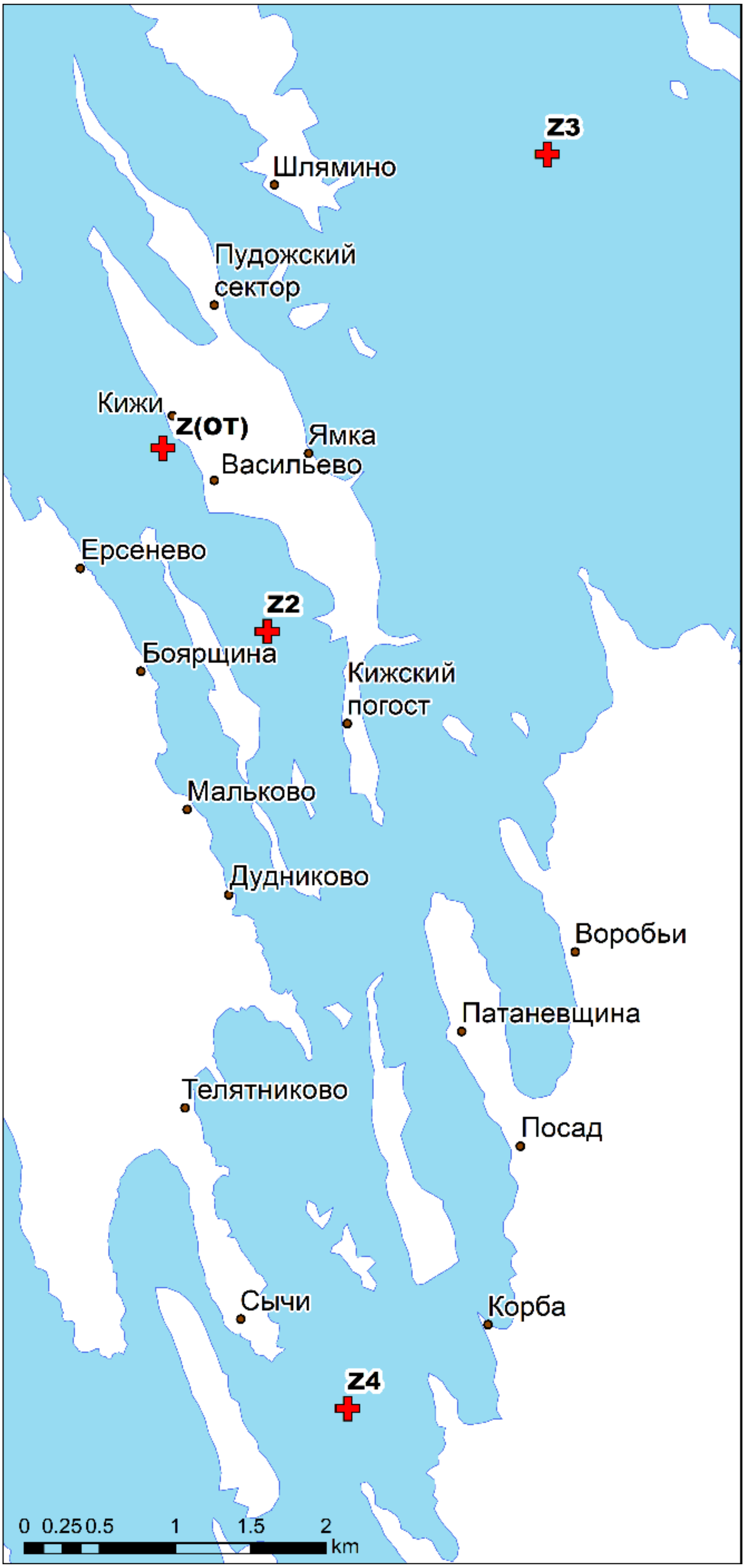


Figure 42. Sampling stations for MP contamination in the Kizhi skerries.

4.4.2. Results and discussion

The mean total MP content in sediments in the Kizhi skerries was 3413 ±1965 pcs/kgDW. The **highest MP content of 6395 pcs/kg DW was observed at the station Z2, near the main pier of the Kizhi Open Air Museum** (Table 14, Fig. 43). The other three stations had comparable total MP abundances, which varied between 2043 and 2643 pcs/kg DW. The highest MP abundance at the station Z2 was mainly due to the **high fiber content (85%)**. It is noteworthy that fiber is the most easily transported form of microplastics (Bagaev et al., 2016). Fiber is able to travel long distances in aquatic environments and cannot be related to the proximity to the MP sources (Zobkov et al., 2020a). The **fiber content at this station was at least 1.5 times higher than in the central part of Lake Onega**, where MPs were mainly of the fibrous type. Meanwhile, this MP content is the **highest detected in Lake Onega so far** (Zobkov et al., 2020a). The possible reason for such high MP abundance is that the sample was collected along the navigation passage: due to the very small depth, currents and stern waves generated by vessels, bottom sediments along the navigation passage are stirred up, and sediment particles together with MPs are eroded and deposited in the adjacent accumulation areas in much larger quantities. However, due to slow water exchange in the enclosed area of skerries, domestic water discharges also can have a notable effect on such high fiber accumulation. As can be seen from Table 14, the total MP content and the content of other fractions at other stations was comparable with other regions of Lake Onega. However, of particular concern is the **increased abundance of films at stations Z4 and Z(OT)**, and fragments at station Z(OT). The increased abundance of these forms can be associated with the proximity of MP sources, such as waste sites, surface runoff, and domestic wastewater discharges (Zobkov et al., 2020a). Examples of MP specimens extracted from sediment samples are presented in Fig. 44.

Table 14. Microplastic abundance in the Kizhi skerries sediments, pcs/kg DW

Station	Fibers *pcs/kgDW*	Beads *pcs/kgDW*	Films *pcs/kgDW*	Fragments *pcs/kgDW*	Total *pcs/kgDW*
Z2	5431	361	318	285	6395
Z3	1548	491	313	238	2589
Z4	1649	251	677	66	2643
Z(OT)	521	375	511	636	2043
Mean for Lake Onega (Zobkov et al., 2020a)	1291±628	454±536	154±159	288±400	2189±1024

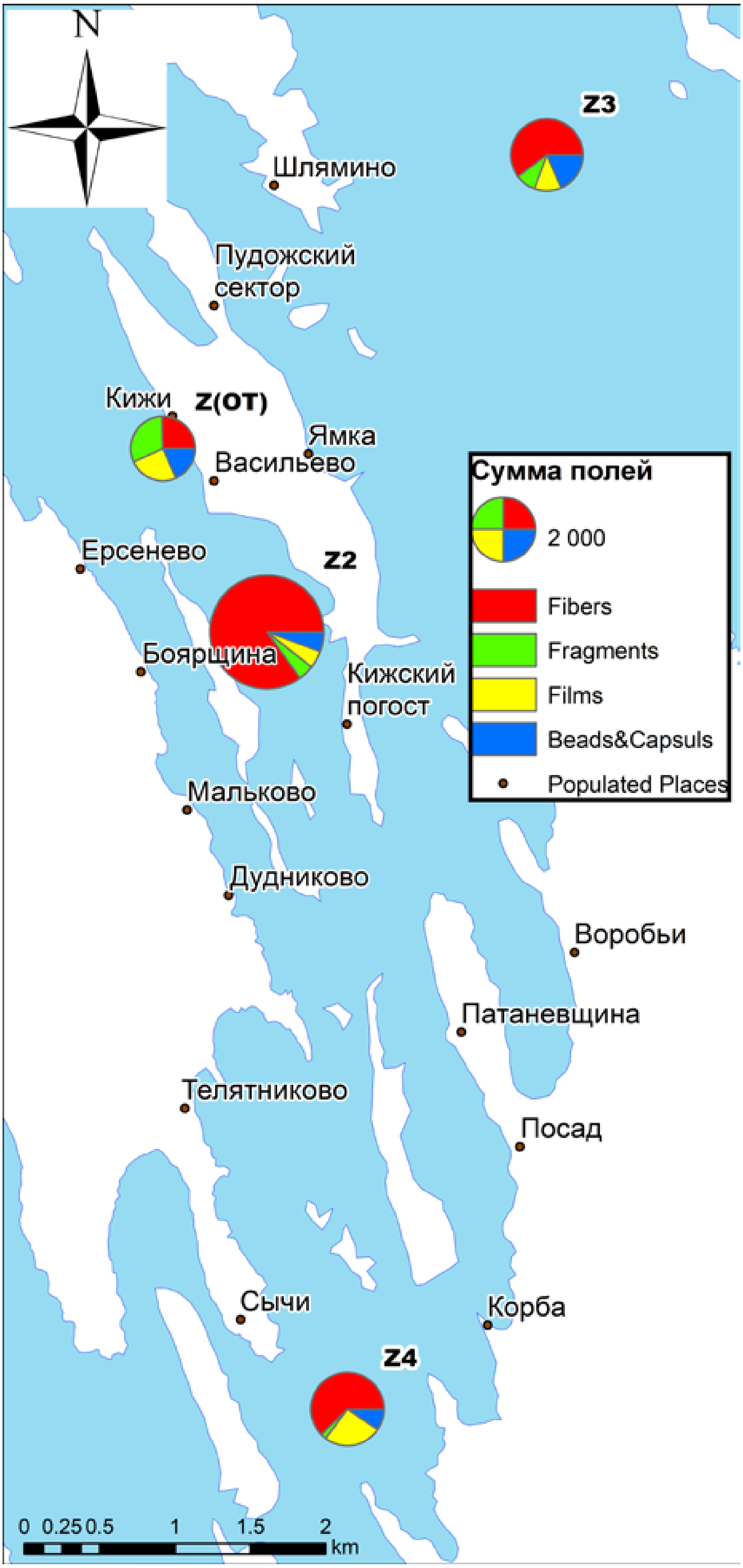


Fig. 43. MPs contamination (pcs/kg DW) in the Kizhi skerries.

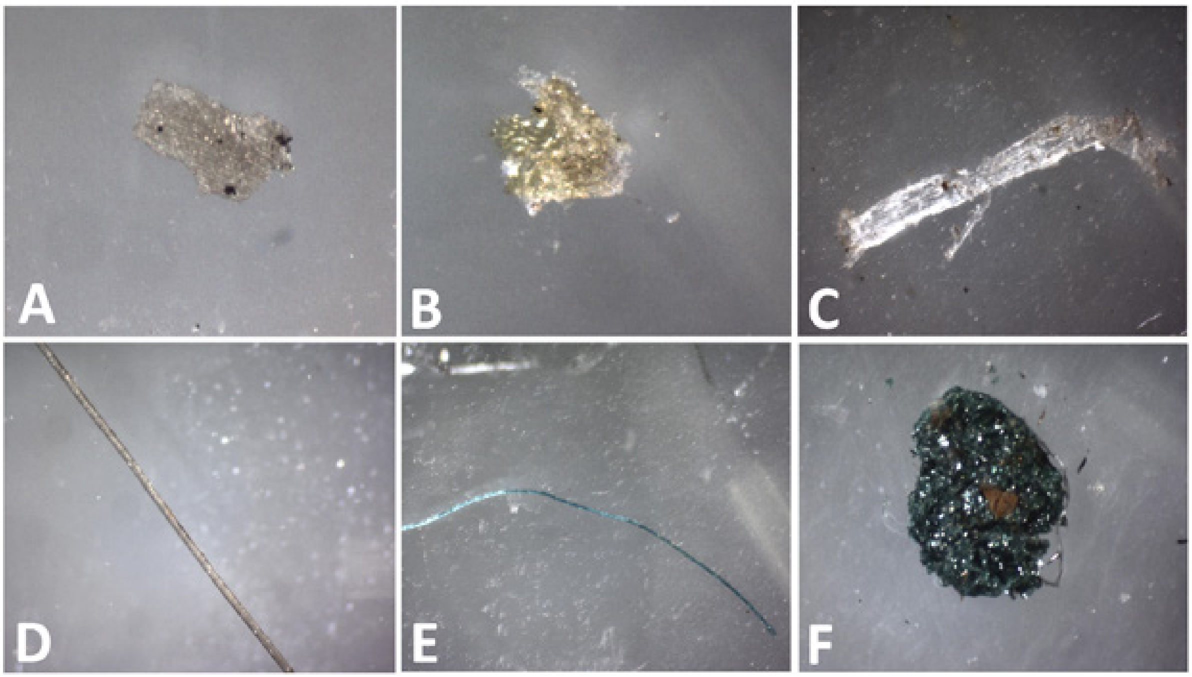


Fig. 44. Microplastic specimens extracted from bottom sediments in the Kizhi Skerries. A, B, C – films; D, E – fibers; F – fragment.

4.5. Hydrological expedition to Lake Onega in Kizhi surroundings

Introduction

Kizhi skerries is a system of islands and straits in the northwestern part of Lake Onega. It features rapidly warmed up shallow water areas and weak water exchange with the open part of Lake Onega. The favorable oxygen conditions in this peculiar region of Lake Onega determine the hydrobiological community development patterns (Diversity..., 2003). The Kizhi skerries area is intensively used for tourism, recreation, fishing, and water transport. Although the territory is sparsely populated, the water area is affected by surface runoff from the Kizhi Open Air Museum, as well as from horticultural, animal farming, and cattle grazing areas.

The hydrological regime of the Kizhi skerries, like that of Lake Onega in general, is characterized by low annual fluctuations in the water level, the prevalence of wind-driven currents during the open water period, and a long ice-covered period (5-6 months) (Lake Onega, 1999). Freeze-up in the Kizhi skerries happens from late November to early December; ice thickness can exceed 0.5-0.6 m in the end of March (Bulletin ..., 2007, 2009). Ice-off occurs in late April-early May (Bulletin ..., 2007–2008).

In the Kizhi skerries, isolated from the main expanses of Lake Onega, sustainable functioning of the ecosystem can be disrupted by an increase in the concentration of nutrients (phosphorus and nitrogen) and the influx of organic substances from household wastewater, water transport, as a result of unorganized tourism and farming. The unstable circulation of water masses in the Kizhi skerries caused by the system of wind-driven currents, especially in the summer, creates the conditions for the migration of eutrophic substances (phosphorus and nitrogen) to central parts of Lake Onega (Onega ..., 2006).

Since 1994, **the chemical composition of the Kizhi skerries waters** has been studied by employees of the Laboratory for hydrochemistry and hydrogeology of the Northern Water Problems Institute of the Karelian Research Centre Russian Academy of Sciences in the framework of the "Environmental Monitoring of the Kizhi Open Air Museum" and under the Agreement on Cooperation between the Kizhi Museum and the Karelian Research Centre, as well as within RFBR and RSF projects (Report ..., 1994; Bulletin ..., 2003-2013; Sabylina, Ryzhakov, 2007; 2016, etc.). Since 2014, the study of the chemical composition of Kizhi skerries waters has also been carried out by specialists from the accredited Center for Laboratory Analysis and Technical Measurements in the Republic of Karelia (TsLATI) (Bulletin ..., 2014, 2015). The main chemical indicators monitored in the Kizhi skerries are: the content of nutrients – mineral and total phosphorus, ammonium, nitrites, nitrates, total nitrogen, permanganate and bichromate oxidation indexes, oil concentration, and also suspended solids.

The hydrodynamic features of the Kizhi skerries were studied in June and October 1994, when direct measurements of currents in bays, straits and open parts of the skerries were taken to evaluate the water exchange between the skerries and Lake Onega open part (Report ..., 1994).

In **June 2019**, within the framework of the international project “Sustainability under Pressure: Environmental Resilience in natural and cultural heritage areas with intensive recreation”, a number of **hydrophysical and chemical-biological parameters** of the water column in the Kizhi skerries were measured from aboard the research vessel Ekolog. **The goal was to study the spatial distribution of environmental parameters that affect the functioning of the aquatic ecosystems.**

During the expedition, measurements of the vertical distribution of temperature, electrical conductivity, turbidity, and chlorophyll “a” were carried out at **12 stations**. The locations of stations are shown in Figure 45. The measurements were performed using a CTD90M Sea & Sun Technology (Germany) multiparameter probe (Fig. 46) with the technical characteristics shown in Table 15.

Table 15. Technical specifications of Multiparameter Probe CTD90M

	Parameters	Range	Accuracy	Manufacturer
CTD90M	Pressure, bar	20 bar	± 0.1 % fs	“Sea&Sun Technology” (Germany)
	Temperature, °C	-2 - +35	± 0.005	
	Electrical conductivity, μS/cm	0-60	± 0.020	
	Turbidity, NTU	0 ... 1000	0.1	
	Chlorophyll “a”, mg/l	0 – 10	0.02	

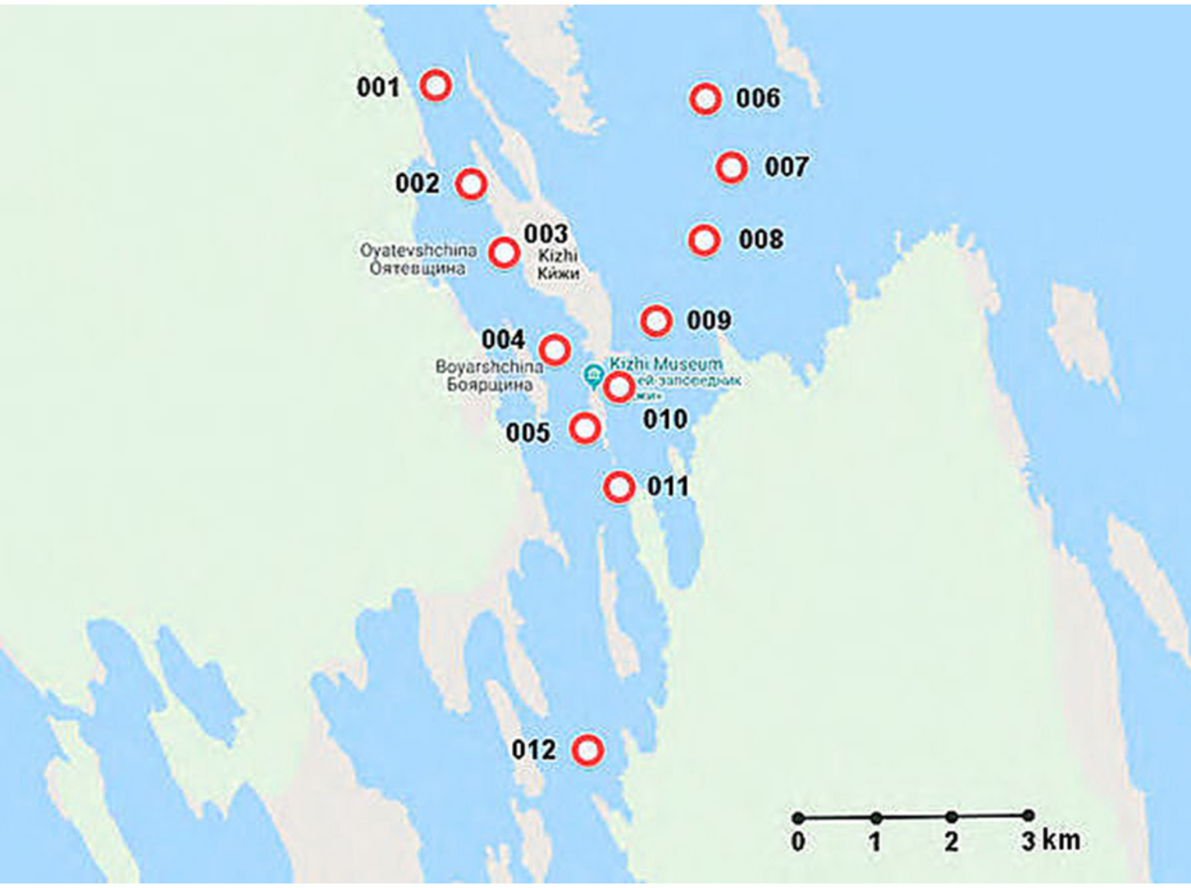


Figure 45. Layout of hydrological measurement stations in Kizhi skerries in June 2019

Figure 46. Multiparameter probe CTD90M Sea & Sun Technology (Germany)

4.5.1. Water chemical composition

The low-mineralized water in the skerries is classified as high-quality water. The main components of the salt composition are hydrocarbonates and calcium, the water reaction is slightly alkaline (pH 6.96–7.9), which creates favorable conditions for the development of plankton (Report ..., 1994; Bulletin ..., 2015). Water transparency increases markedly from spring (1.5–1.9 m) to autumn (2.9–3.1 m) (Report..., 1994). The oxygen regime is favorable; on average, water saturation with oxygen is 85–95%. In the end of June, the oxygen concentration reaches 8-10 mg/L with a saturation of 90–105%, and the respective levels in the fall are 11.4–11.9 mg/L and 90% (Report..., 1994; Bulletin ..., 2007, 2010, 2011).

The watercolor is low (19–39 mgPt-Co/L), as well as the organic matter content (13.7 mg/L, TOC 7 mg/L) (Report ..., 1994; Bulletin ..., 2007, 2015). The interannual range of Corg fluctuations in the Kizhi skerries area is 10–15%, which indicates the stability of the lake ecosystem in this region of the lake (Bulletin ..., 2007). The CODMn in 2000–2012 varied between 6.0–8.5 mg O/l. The seasonal and interannual variability of this indicator is due to the activity of production and destruction processes, closed circulation of water masses, as well as active water exchange with the central reaches of the lake (Bulletin ..., 2013).

According to measurements in the open water period in 1977 and 1978, total phosphorous content (TP) – the main eutrophying agent – in Kizhi skerries water did not exceed 9–12 μg/L. By 1994, it increased to 8–26 μg/L, i.e., approached the upper limit for an oligotrophic waterbody (Report ..., 1994). According to measurements in 1994–2012, the long-term dynamics of the TP content is wave-like, which may be due to the variability of hydrodynamic conditions in the region and the variable phosphorus input from the catchment. **Total phosphorus levels were high in 1994, 1997, 2003, 2004, 2006, and 2007** (17–25 μg/L), and low in 2002 and 2011 (9-10 μg/L) (Bulletin ..., 2008, 2013). In August and September **2008, high concentrations of almost all chemical components were recorded in the Dolgiy Island** area. E.g., the concentration of TP reached a maximum of 77 μg/L, which had never been recorded in the skerries water before (Bulletin ..., 2009).

The average concentration of total nitrogen (TN) in 1994 was 0.60 mgN/L, which was slightly higher than in the lake's central region – 0.55 mgN/L (Report ..., 1994). In the period 1994–2012, the concentration of varied within 0.20–0.80 mgN/L (Bulletin ..., 2008, 2013). The TN concentration of NO_{3^-} has a pronounced seasonal variation – twice lower in late spring (0.09–0.20 mgN/L) than in autumn (0.23–0.28 mgN/L); the concentration of NH_{4^+} in spring was higher (0.06–0.17 mgN/L) than in autumn (0.02–0.05 mgN/L) (Report ..., 1994). Silicium concentration declined from spring (0.55 mg/L) to autumn (0.29 mg/L) (Report ..., 1994).

Total iron content in the skerries water averaged 0.12 mg/l, which is 2.5 times that of the lake's open region. This is due to the geochemical specifics of the region (shungite rocks). The indicated concentration of iron in water is favorable for the development of plankton (Bulletin ..., 2011).

The seasonal variation of nutrients, as well as high concentrations of chlorophyll "A" (up to 2.5 μg/L) and oversaturation with oxygen (up to 106%) with a simultaneous decrease in carbon dioxide concentrations (to 0.28 mg/L) indicate an acceleration of production processes (Report ..., 1994).

In the spring-summer period, due to intensive navigation and tourism, an increased content of **total petroleum hydrocarbons (TPH)** is observed in the fairway: in 1994 to 0.40-0.80 mg/L (Report ..., 1994), in 1998–2003 to 0.20-0.29 mg/L (Sabylina & Ryzhakov, 2007), the maximum permissible concentration (MPC) for fishery-intended waters being 0.05 mg/L. In autumn, the concentration of oil products decreases markedly, but they still occur everywhere. The dynamics of the **average concentration of TPH over the period 2001–2014** is given in the Bulletin ... (2015), where it is shown that the **MPC for fishery-intended waters was exceeded** in 2001, 2008, 2013, and 2014. The **highest content of TPH was observed in August and September 2008** – up to 2.50 mg/l (about 50x MPCs), in the wake of a water transport emergency in this area of the lake (Sabylina et al., 2010; Bulletin ..., 2009, 2015).

Aquatic organisms begin to **accumulate heavy metals** as their concentration increases along the algae - invertebrates - **fish chain**. The toxic effect of heavy metals depends on their form in water. The most dangerous form is ionic. For the Kizhi skerries region, according to measurements in the open water period 2011, heavy metal concentrations were below the MPC values for waters of significance for fisheries: average zinc (Zn) content – 4.4 (MPC – 10.0), lead (Pb) – 0.4 (MPC – 5.0), cadmium (Cd) – 0.03 (MPC – 5.0), and nickel (Ni) – 0.3 μg/L (MPC – 10.0). An exception is the content of copper (Cu), whose concentration in water in this region of the lake varied from 0.7 to 1.8 μg/L, averaging 1.1 μg/L (MPC 1.0). Moreover, the **MPC value was exceeded** in 64% of the eleven samples taken (Bulletin ..., 2012).

The period of the water warming up to 10-15 degrees in the Kizhi skerries is the period of transition to the summer state, when the growth of spring plankton ends. In the seasonal cycle, the spring period accounts for 50% of the annual phytoplankton production, which predetermines the active development of destruction processes in the summer period.

With flood waters in spring, a large amount of organic matter enters the water mass of the Kizhi skerries, resulting in high bacterial activity. When the temperature rises to 10-15 degrees, bacterial biosynthesis and destruction processes are sharply activated. During this period, bacterial destruction can be twice as high as production. Such an excess is typical for waters in which much of the organic matter is of allochthonous origin. In general, the spring period is characterized by high activity of both synthetic and destructive bacterial processes, indicating a high trophic status of this region.

Water cooling to 4–5 degrees in the fall is accompanied by a sharp decline in bacterial activity. As compared to spring, the rate of photosynthesis under the low temperatures and poor light conditions decreases by an order of magnitude. Destruction activity plummets.

The species composition of the algal flora in the skerries region totals 105 species and intraspecific taxa belonging to seven types: cyanobacteria (9), golden algae (10), diatoms (57), yellow-green algae (1), pyrophytic algae (9), euglenoids (2), green algae (17).

In June, maximum diversity and development is displayed by diatoms and chrysophytes, in the fall – by diatoms and cyanobacteria. Diatoms form the bulk of phytoplanktic biomass (up to 80-90%) in Lake Onega.

Thus, **water in the Kizhi skerries can be described as moderately polluted, exposed to anthropogenic impact**. At the same time, the level of pollution **in spring is higher than in fall** because of navigation and the input of pollutants from the catchment area.

4.5.2. Currents in the Kizhi skerries

The water quality of the Kizhi skerries is determined by water exchange with the open part of Lake Onega, where the water is of higher quality. Currents in the skerries are of two types - wind currents and seiche currents. During the open water period, wind currents are unsteady due to the variability of the wind field. The maximum speeds of wind currents do not exceed 20-30 cm/s, and such currents occur in the surface layers of the water column (according to (Report ..., 1994)).

Seiche currents arise as a result of seiche level fluctuations in the open part of Lake Onega and level fluctuations in the semi-enclosed parts of the skerries. The highest speeds of seiche currents are observed in narrowed areas and straits. The period of the main seiche in Lake Onega is 4 hours 20 minutes, the same period dominates in seiche currents. During the freeze-up period, seiche currents are the main type of currents in the skerries.

Thus, Kizhi skerries are characterized by **specific environmental conditions that determine the formation of biological communities**. These conditions include early seasonal warming of shallow waters, overgrowing of coastal areas with higher aquatic vegetation, and the influence of terrigenous runoff, which determines the high productivity of all trophic levels of the biota. Favorable trophic conditions determine the richness of the species composition of planktic and benthic organisms. In general, the development of biological communities in the skerry region is at the mesotrophic level.

Results of the June 6-7, 2019 expedition to the Kizhi skerries from aboard the research vessel Ekolog:
During the measurements on June 6-7, 2019, the water temperature in the surface layers of the Kizhi skerries reached 16-19°C (Figs. 47, 48), decreasing to 11-13°C in the bottom layers. The warmest surface layer was formed in shallow waters near the shore (Fig. 47b). For example, the temperature of the upper 1.5 m layer at station 2 was 18.7-19°C, while the temperature gradient in the thermocline layer at depths of 1.5-2.1 m reached 10 °C/m. In the open parts of the skerries, the surface temperature was noticeably lower (Fig. 47a).

The electrical conductivity of the water was about 0.045 μS/cm over the water column with an increase to 0.05-0.06 μS/cm in a thin layer near the bottom (Fig. 48). At the deep-water station 7, a sharp increase in electrical conductivity to 0.11 μS/cm was observed in a thin 20 cm bottom layer. The turbidity was 2–3 EMFs, sharply increasing in the bottom layer to 7–9 EMFs (Fig. 48).

The distribution of chlorophyll "a" concentration over the water column was fairly uniform — about 1 μg/l, while at most stations a local maximum of 1.5–2.1 μg/l was observed at a depth of about 2-3 m (Figs. 48, 49). In the bottom layers of stations 1 and 7, an increase in the concentration of chlorophyll "a" to 3–6 μg/l was noted.

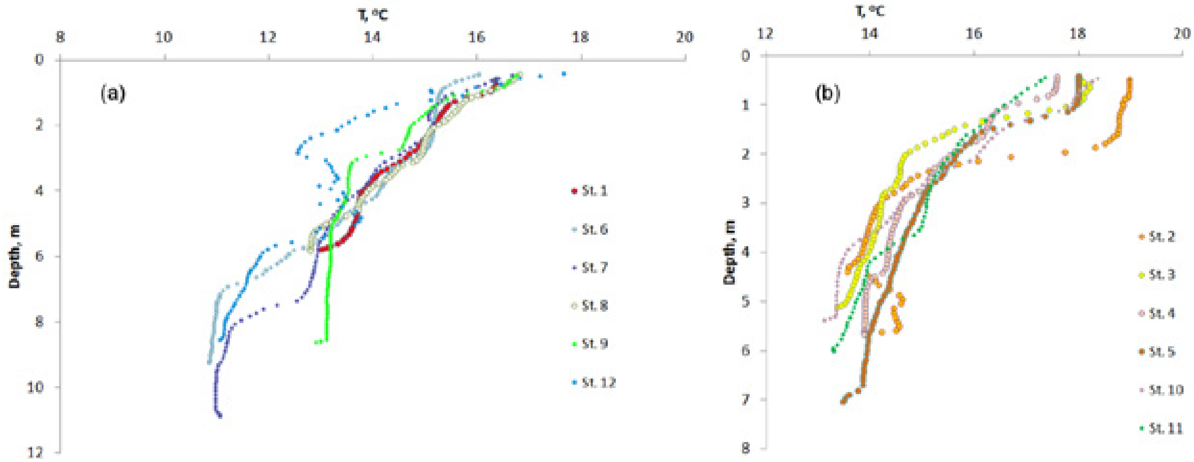
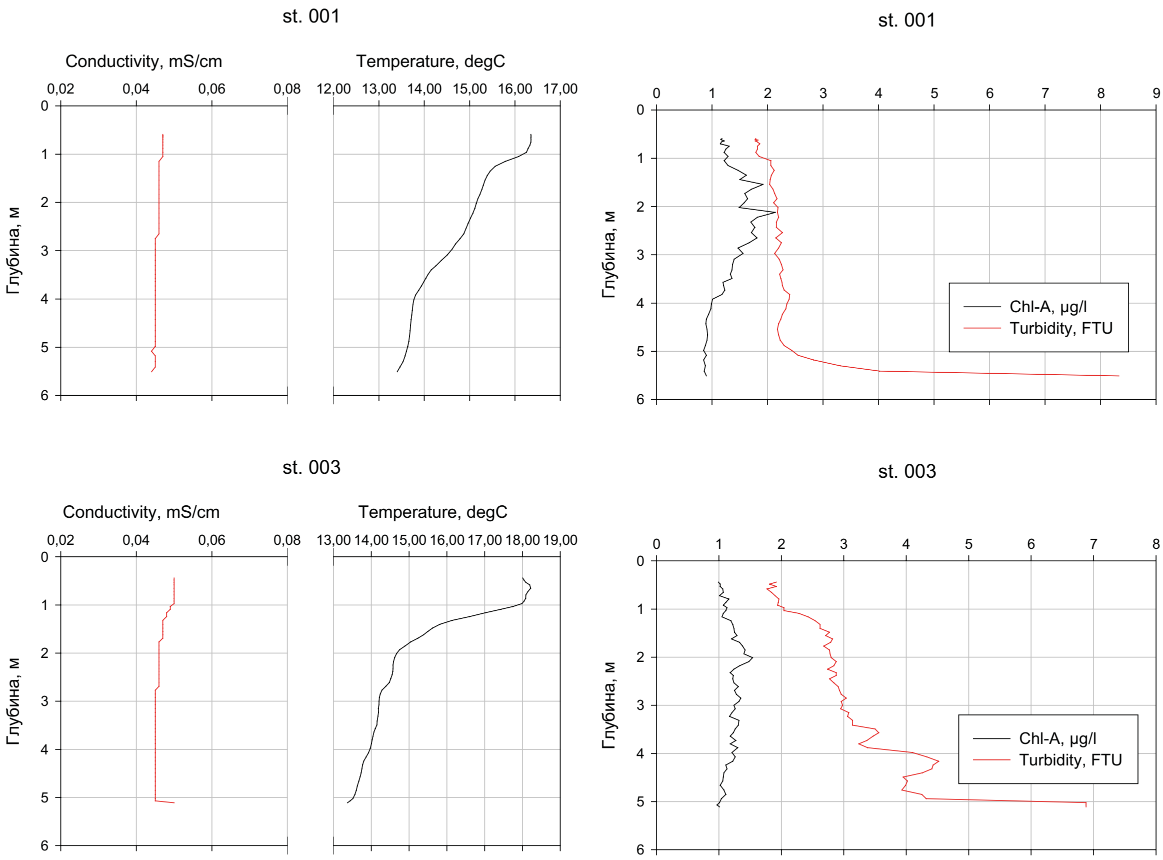


Figure 47. The vertical temperature distribution at the stations in the open parts of the Kizhi skerries (a) and near the shore (b) on June 6-7, 2019



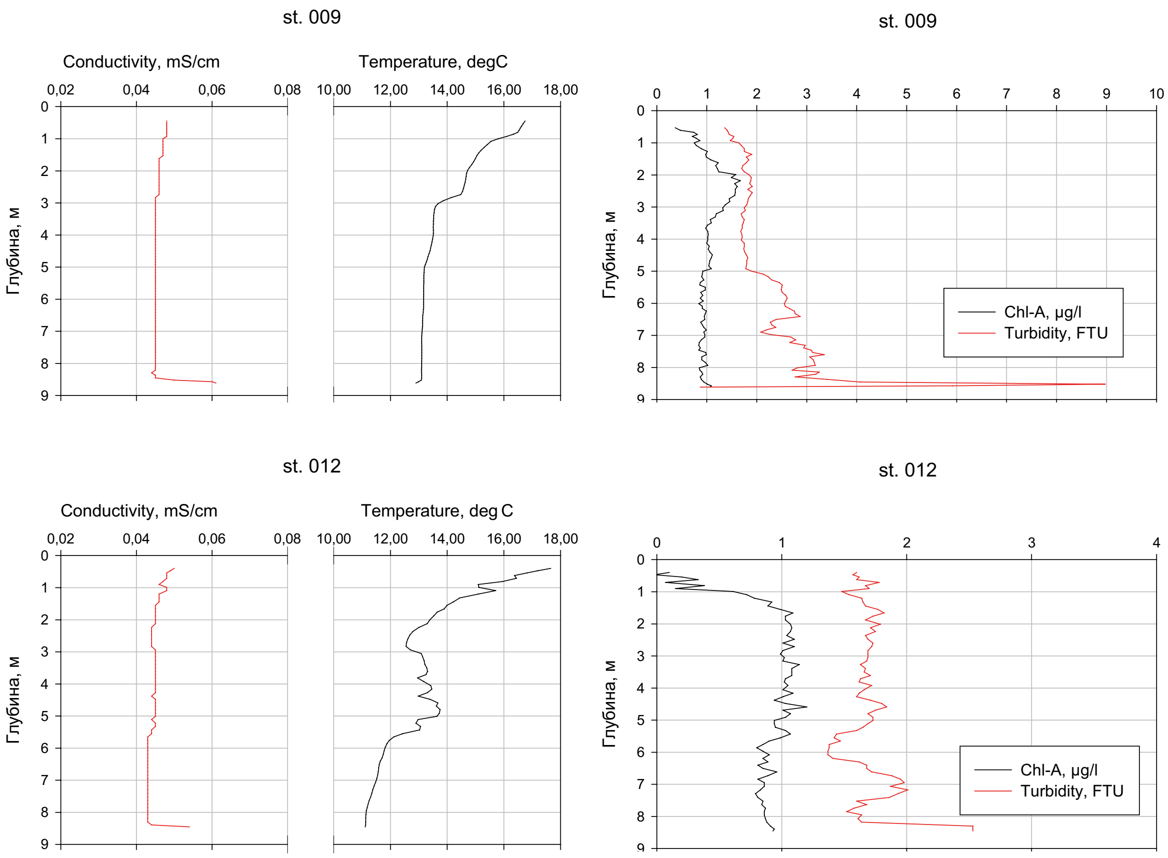


Figure 48. The vertical distribution of temperature, electrical conductivity and turbidity of water and concentrations of chlorophyll "a" on June 6-7, 2019 at stations 001, 003, 009 and 012

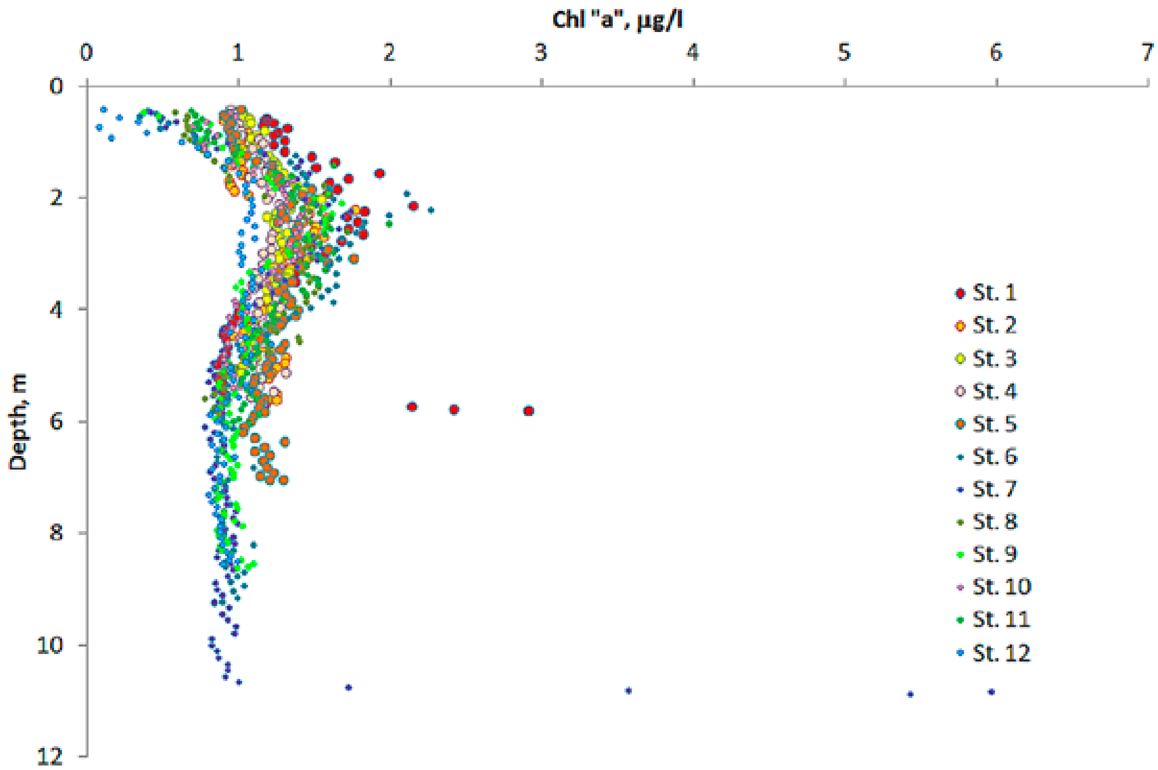


Figure 49. The vertical distribution of chlorophyll "a" concentration across the water column at the measurement stations in the Kizhi skerries on June 6-7, 2019.

4.6. The plant cover of dumps and facilities of the Vodlozersky National Park and Kizhi Skerries

4.6.1. Introduction and study objectives

Vodlozersky National Park and Kizhi Skerries are two of the most attractive and promising areas in Karelia for nature tourism. Although Vodlozersky NP area became populated by humans in ancient times (6th – mid-2nd Ma B.P.), it has preserved unique landscapes with nearly pristine spruce and pine forest (Логинов, 1995). The Kizhi Archipelago, with its centuries-long history of active agriculture in the region (the first settlements were known here ca. 8000-9000 Ka B.P.), on the other hand, experienced an irreversible transformation of natural forest cover, which was replaced by agricultural landscapes of different structural and mosaic qualities (Заонежье..., 2018).

Owing to the functional and developing infrastructure of the national park and the Kizhi Open Air Museum, tourist traffic has been continuously growing, which cannot but affect the natural ecosystems suffering substantial anthropogenic pressure.

The recreational load and waste dumping affect all components of forest ecosystems. The recreational impact is the most tangible for the living ground cover and the soil, in which structural changes caused by trampling (campsites) and pollution (dumps) can be diagnosed visually already in the early stages of recreational vegetation digression and require wise actions to mitigate their effects on the ecosystem.

Objective: To study the effect of the flora in waste dumps on natural plant communities in the Vodlozersky NP and Kizhi. To determine the degree of the plant cover disturbance (degradation) in Vodlozersky NP and Kizhi sites exposed to intensive recreational pressure (tourist campsites).

The research objects were the plant cover (flora and vegetation) in three campsites in the Vodlozersky National Park (NP), and the flora of 9 waste dumps (two in Vodlozersky NP, and seven in the Kizhi Open Air Museum). Most of the dumps were quite small (5 to 25-30 m2), appearing as piles of dry domestic wastes (plastic bottles, construction material, rags, etc.). Two largest dumps in our surveys are situated near Vlg. Kuganavolok (Pudozhsky District), occupying 0.4 ha, and near Vlg. Sennaya Guba, Selga locality (Medvezhegorsky District), occupying 0.3 ha.

The areas in question are situated in two floristic districts – Vodlozersky (NP Vodlozersky) and Zaonezhsky (Kizhi museum), or in the geographical provinces Karelia transonegensis (Kton) and Karelia onegensis (Kon) (Ramenskaya, 1983; Kravchenko, 2007).

4.6.2. Survey methods

Dump areas
Surveys followed the classical transect method: the whole dump area and several tens of meters around the dumps were closely surveyed to detect invasive species capable of invading natural communities. Growth cycles of alien species differ markedly, usually covering three seasons: late spring – summer – early fall. Hence, to identify the floral diversity of the dumps as comprehensively as possible, surveys were carried out in the second half of May, in July, and in early September 2019-2020. **All herbarium specimens are deposited at the Herbarium of the Karelian Research Centre RAS** (PTZ).

Plant cover of tourist sites
Plants in the ground cover are the first to suffer the effects of recreational pressure, the primary impact in such forms of recreation as tourism and outdoor activities being trampling and damage to the tree layer of the forest. When assessing the recreational impact, the tolerance threshold of different forest communities should be determined (Рысин, 1983; Генсирук и др., 1987). The criterion for threshold-level disturbance is the ability of the forest community to recover without assistance under exposure to intensive recreation. Recreational loads can be classified into permissible, maximum permissible, critical, and catastrophic. **Permissible recreational load corresponds to changes in forest ecosystems varying from barely noticeable signs of degradation to the upper limit of stage II digression**. In this category, the ecosystem can handle an increase in recreational load without losing the **ability to restore itself**. A load corresponding to the upper limit of digression stage II is perceived as optimal. Maximum permissible recreational load corresponds to the upper limit of **digression stage III**, in which forest ecosystems are still capable of restoring themselves, but lose some non-essential elements or links (upper canopy and stand regrowth sparsing, loss of typical species from the ground cover). The boundary between the third and fourth stages of digression is considered the tolerance threshold of the ecosystem. Further build-up of recreational load takes the forest ecosystem to **digression stage IV**, in which the overall structure of the ecosystem cannot be recovered without introducing substantial restrictions and sometimes taking forest restoration actions. The final stage of recreational **digression is stage V** – catastrophic, in which links between ecosystem components are broken irretrievably. The stage of the natural environment digression is directly dependent on the recreational load and tolerance of the natural ecosystems. The stage of recreational digression is determined by evaluating the degree of the plant cover disturbance (Table 16).

The degree of digression (disturbance) of the plant cover in the campsites was determined using a method based on mapping the **living ground cover (LGC)** to spot tree layer damage and areas **worn out by trampling**. Campsite boundaries were identified based on the **degree of LGC** disturbance. The boundaries were quite clearly visualized, since “trampling areas” were limited to the main elements of infrastructure: fire sites – shelters, tables – toilet – woodshed, etc., rarely surpassing them.

The following LGC parameters were taken into account in this study: species composition of vascular plants, mosses, and lichens, and their percent cover, both in general and ratios relative to each other. The species composition of mosses and lichens was not fully identified – the descriptions included only the most common boreal species we could identify. The LGC

Table 16. Recreational digression stages for forests

Digression stages	Condition	
	Ground cover and forest floor	Tree stand, regrowth layer and understory
I	Herbaceous cover not disturbed and matches the original forest type. Forest floor not damaged.	Understory and regrowing trees match the site conditions and are not damaged.
II	Herbaceous cover disturbed only slightly. Distinct layers.	Understory and regrowing trees in satisfactory condition. Trees in good or satisfactory condition prevail in the tree stand (75-90%).
III	Herbaceous cover disturbed; ruderal and/or meadow herbs atypical of the community appear. Differentiation into layers still preserved.	Remaining regrowth is poorly differen-tiated. Hardly any saplings of original stand-forming species are present.
IV	Herbaceous cover degrading. Biomass and abundance of ruderal and meadow plants sharply increased. Forest floor in the process of degradation.	The tree & shrub layer is structured as an alternation of patches of understory plants and poorly viable regrowth sepa-rated by openings and paths.
V	Herbaceous cover characteristic of the given forest type has degraded. The per-cent cover of ruderal and meadow plant species vastly exceeds the contribution of forest species, the latter preserved only at trunk bases. Forest floor com-pletely ruined.	Regrowth and understory almost non-existent. Light penetration through the canopy significantly enlarged. Trees have mechanical damage and are dying back. A substantial part of trees has roots exposed.

in the plant communities was described using a standard technique of geobotanical surveys (Полевая геоботаника, 1964, 1976).

Campsites' spaces were conventionally divided into 3 zones according to the degree of trampling damage to the ground cover: heavy (sweeping) trampling damage zone, medium (moderate) trampling damage zone, and mild trampling damage zone (Тимофеева, Кутенков, 2008, 2010; Timofeeva, Kutenkov, 2009):

I. Heavy (sweeping) trampling damage zone. The main trait of the zone is near absence of the living ground cover. 90-100% of the area is worn out by trampling. Recreational digression in this zone is in stage V.

II. Medium (moderate) trampling damage zone. The area worn out by trampling can occupy 30-80%. Living ground cover disturbances match stages III or IV of recreational digression. The ground cover is retained around the trunks of isolated trees and/or within vegetation patches separated by paths. The size of the clumps can vary from 0.5 × 0.5 m to 3.0 × 3.0 m and more. The ground cover is flattened, locally worn-out, but generally consists of species typical of the given forest type. This zone occupies on average ca. 25% of the site area.

III. Relatively slight trampling damage zone. The area worn out by trampling is 1-30%. The living ground cover is retained in much of the area, but is locally heavily flattened (Fig. 61). The network of paths is sparse; vegetation in paths is moderately worn out. Stage II-III of recreational digression. This zone can occupy up to 30-35% of the site area.

Control (reference) plots were established in sites relatively unaffected by recreation (no visible signs of disturbance), representing the same forest types, and with a similar topographic position; their size was 30 x 30 m.

4.6.3. Results: campsites

In total, the shrub and field layers in the campsites were found to harbor 130 vascular plant species, but the diversity of the flora was the highest in the Okhtoma tourist facility, whereas the insular Rogunovo-1 and Rogunovo-2 campsites had 1.3-1.8 times fewer species (Table 17). The paucity of the flora on Isl. Rogunovo can be explained by the originally poor floristic composition of pine and spruce forests in the cowberry- and bilberry groups of habitat types, as well as by a low input of plant diaspores from the mainland.

LGC disturbance is uneven within the campsites. Three zones can be distinguished depending on the degree of trampling damage (Table 17).

Table 17. Number of vascular plant species in campsites and waste dumps

Site	Total number of species	Trampling damage areas					
		Zone 1		Zone 2		Zone 3	
		no of species	%	no of species	%	no of species	%
Okhtoma	101	33	32.7	50	49.5	35	34.7
Rogunovo-1	74	17	23.0	48	64.9	44	59.5
Rogunovo-2	56	19	33.9	37	66.1	22	39.3

Local (native) species predominate in the flora of all the three campsites (82.2% – Okhtoma, 86.5 – Rogunovo 1, 92.9% – Rogunovo 2). The share of alien species is quite low – 7.1-13.5% (Rogunovo 1,2), but much higher (17.8%) in the Okhtoma tourist facility owing to alien species brought in by vehicles.

The shrub layer (understory) is represented by species typical of Karelian forests (8 species), the most abundant ones being the rowan (Sorbus aucuparia) and common juniper (Juniperus communis).

The field layer within the campsites was found to comprise 120 species. The dominants are the bilberry (*Vaccinium myrtillus*) – its percent cover varies among trampling damage zones within 0.1-45%, wavy hairgrass (*Avenella flexuosa*) – 0.1-25, false lily of the valley (*Maianthemum bifolium*) – 1-30%, and highly trampling-resistant species such as the annual meadow grass (*Poa annua*) and white clover (*Trifolium repens*).

LGC disturbance in the campsites is uneven, and spaces inside the campsites can be divided into three zones depending on trampling damage.

Characteristics of the living ground cover in the campsite Rogunovo-1 (Fig. 50).

The campsite is situated on Isl. Rogunovo, on Lake Vodlozero shore, in a cowberry-bilberry-type pine stand (62.282997 N, 36.918739 E).

I. Heavy trampling damage zone is situated by the fire site and table (Fig. 51) and occupies some 30-35% of the total campsite area. The total percent cover (TPC) of the living ground cover (LGC) is 2%; TPC of the field layer is 2%; TPC of the moss layer is <1%. Nearly 98% of the area is trampled down. Occasional plants are *Trifolium repens, Maianthemum bifolium, Avenella flexuosa;* mosses are represented only by fragmentary patches of Pleurozium schreberi. This zone is characterized by stage V of recreational digression of the ground cover.

Remaining trees are few, usually with mechanical damage, or absent (Fig. 64). Regrowth and understory are absent. Forest floor is ruined.

II. Medium (moderate) trampling damage zone. Some 60% of the area is trampled down. The living ground cover is fragmented. LGC TPC is 50%; field layer TPC 40%; moss TPC 2%. This zone occupies ca. 65% of the campsite. Damage to the living ground cover corresponds to stages III or IV of recreational digression. LGC persists around trunks of separately standing trees and/or inside tree patches separated by paths. The ground cover is flattened, somewhat worn out, but generally consists of species typical of this forest type. The prevalent herbs are *Trifolium repens* (25% TPC), and *Poa compressa* (10%). Other species have percent covers <1%. Zone II features the highest diversity of the flora, which is similar in all the campsites, explained by a localized "edge effect" – when competition from forest species is still quite strong, but disturbed areas are already getting colonized by ruderal and meadow vascular plants.

III. Relatively mild trampling damage zone (Fig. 52). Some 15% of the area is trampled down. The living ground cover is largely retained, but heavily flattened in places (Fig. 53), and severely worn out only in several paths. LGC TPC is 55%; field layer TPC 55%; moss TPC 1%. The dominants in the field layer are *Maianthemum bifolium* (PTC 30%), *Poa palustris* (20%), *Trifolium repens, Deschampsia cespitosa, and Oxalis acetosella* (3%). This zone occupies ca. 25% of the campsite. Recreational digression stage II-III.

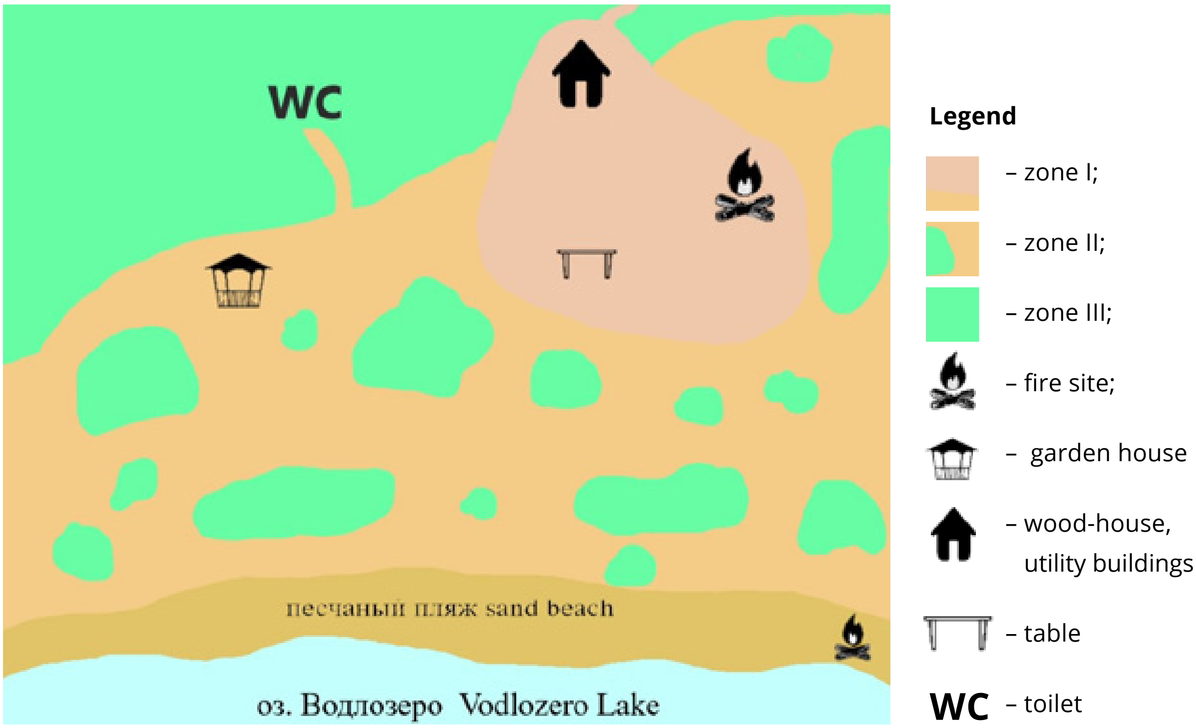


Fig. 50. Layout of the living ground cover in "Rogunovo-1" tourist facility.

Fig. 51. «Rogunovo–1». Zone I

Fig. 52. «Rogunovo–1». Zone II

Fig. 53. «Rogunovo–1». Zone III

Characteristics of the living ground cover in the campsite Rogunovo-2 (Fig. 54).

The campsite is situated on Isl. Rogunovo, on Lake Vodlozero shore, in a cowberry-bilberry-type pine stand (62.285535 N, 36.911529 E).

Only two trampling damage zones can be clearly distinguished in the campsite – I and II. Zone III (mild trampling) is fuzzy, with no clear boundary with the surrounding forest bearing minor traces of LGC disturbance.

I. Heavy trampling damage zone is situated by the tables and fire site (Fig. 55). LGC TPC is 5%; field layer TPC 5%; moss layer TPC 2%. Some 97% of the area is trampled down. Understory is represented by solo specimens of *Salix myrsinifolia, Salix aurita, and Frangula alnus*. The most common herbs are *Maianthemum bifolium and Avenella flexuosa*; mosses are represented only by fragmentary patches of *Pleurozium schreberi.* This zone is characterized by stage V of recreational digression.

II. Medium (moderate) trampling damage zone (Fig. 56). Some 70% of the area is trampled down. The living ground cover is fragmented. LGC TPC is 30%; field layer TPC 25%; moss TPC 5%. This zone occupies ca. 65% of the campsite. The ground cover is retained around tree trunks and/or as isolated patches. The ground cover is worn out, forest species prevail – *Vaccinium myrtillus* (TPC 15%), *Maianthemum bifolium* (10%), *Deschampsia cespitosa, Luzula pilosa, Melampyrum pretense, Convallaria majalis*. There occur singular specimens of meadow herbs – *Pimpinella saxifraga, Veronica chamaedrys*. Disturbances in the living ground cover in different parts of the site correspond to recreational digression stages III or IV.

III. Mild trampling damage zone (Fig. 57) in this campsite is indistinct, occupying a strip several meters wide, beyond which extends the undisturbed forest community. This zone occupies ca. 10% of the campsite, human impact is minor – occasional paths. The prevalent plants in the ground cover are herbs and sub-shrubs typical of this forest type – *Vaccinium myrtillus, Vaccinium vitis-idaea, Carex globularis,* mosses are represented by *Pleurozium schreberi*, *Sphagnum* sp., *Dicranum* sp. Recreational digression is in stage IV.

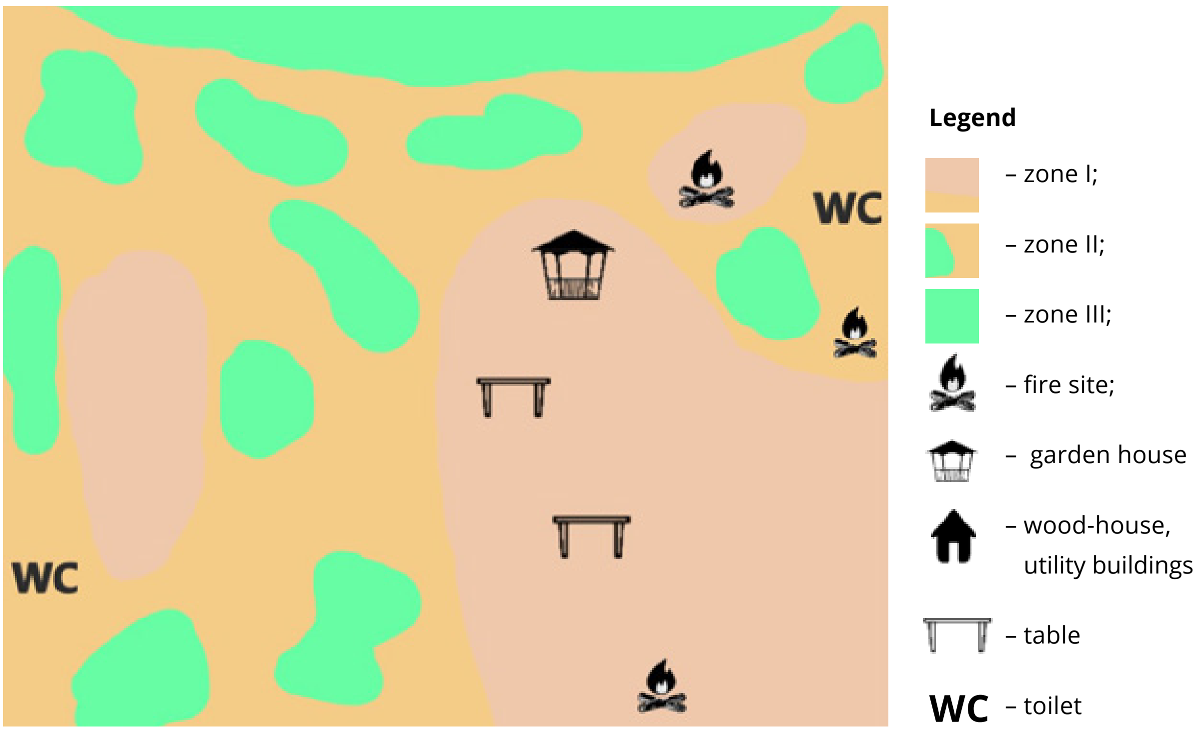


Fig. 54. Layout of the living ground cover in "Rogunovo-2" campsite.

Fig. 55. Rogunovo-2. Zone I

Fig. 56. Rogunovo-2. Zone II

Fig. 57. Rogunovo-2. Zone III

Characteristics of the living ground cover of the Okhtoma tourist facility (Fig. 58).

Okhtoma tourist facility is situated on the south-western shore of Lake Vodlozero (62.270057 N, 36.747714 E) and, unlike Rogunovo-1 and Rogunovo-2 campsites, has the official touristic status – there are 4 guesthouses, a bathhouse, and a separate dining room. Lodges and utility buildings occupy an open meadow-converted site with a dirt road leading to it from the mainland side.

I. Heavy trampling damage zone is situated around two fire sites and the pavilion and occupies vast spaces around the dirt road adjoining the site (Fig. 59). This zone occupies some 1/3 of the total facility area. LGC total percent cover is 10%; field layer TPC 10%; moss layer TPC 1-2%. Around 90% of the zone is trampled down. Ruderal and meadow species prevail – *Deschampsia cespitosa, Plantago major, Leontodon automnalis, Trifolium repens, Poa annua; the only moss present is the trampling-resistant Pholia nutans*. The zone is characterized by stage V of recreational digression.

II. Moderate trampling damage zone occupies around 50% of the entire facility. It is a meadow-converted site accommodating guesthouses and most of utility structures (Fig. 60). The share of trampled-down surface is 10-15%, since guests mostly use boardwalks to move between buildings (Fig. 62). The living ground cover is formed by meadow and ruderal herbs (*Phleum pratense, Alchemilla sp., Lathyrus pratensis, etc*.). LGC total percent cover is 60%; field layer TPC 60%; moss layer TPC 20%. This zone occupies some 60% of the campsite. The forbs meadow in this zone was found to contain a rare native species – *Veratrum lobelianum* (Fig. 63), which mostly occurs on the White Sea coast, less often further inland, and Karelia is the western limit of its range (Кравченко, 2007).

III. Mild trampling damage zone is minor – a small patch of bilberry-type spruce stand neighboring the facility on the north-west. The share of trampled-down surface is ca. 10%. The living ground cover is retained in a substantial part of the territory, being worn out only in the few paths (Fig. 61). LGC TPC is 30%; field layer TPC 80%; moss layer TPC 1%. The ground cover dominants are *Vaccinium myrtillus, Vaccinium vitis-idaea, Maianthemum bifolium* (10%), open spaces are dominated by *Calamagrostis arundinacea* (35%), *Agrostis capillaris* (30%), and *Maianthemum bifolium* (10%). This zone occupies some 60% of the campsite. The forest cover is characterized by stage II-III of recreational digression.

Fig. 58. Layout of the living ground cover in the Okhtoma tourist facility

Fig. 59. Okhtoma. Zone I

Fig. 60. Okhtoma. Zone II

Fig. 61. Okhtoma. Zone III

Fig. 62. Okhtoma. Boardwalks

Fig. 63. Veratrum lobelianum

Fig. 64. Tree damage in campsites

4.6.4. Conclusions and responses: tourist facilities

Assessment of the state of the living ground cover in the campsites Rogunovo-1 and Rogunovo-2, and the Okhtoma tourist facility showed that all these sites have similar disturbance features, no matter for how long they have been used. Each site has areas with heavy, moderate, and mild trampling damage. The spatial scope and characteristics of the disturbance mainly depend on the presence/absence, siting and number of infrastructure elements (fire sites, shelter pavilions, utility structures, etc.) within the sites, as well as on the site's accessibility by transport. In areas exposed to the heaviest human impact (zone I), plant communities are disturbed in very similar ways: the forest floor is ruined, soils are worn out down to the mineral horizon, tree roots are exposed, the field (sub-shrubs and herbs) and ground (mosses and lichens) layers are represented by singular, usually trampling-resistant, species. That said, such heavy disturbance occurs locally, not reaching beyond campsite limits, since trampling is restrained by a wise arrangement of utilities. Disturbance of the living ground cover becomes almost indiscernible to the eye in the very first meters outside the campsites. Zone 1 takes up 30-35% of the campsite area, on average. The living ground cover within zone I is in stage V of recreational digression in all the campsites.

In the moderate trampling damage zone (II), the living ground cover is fragmented, vegetation patches retain traits of the campsite's background plant communities. Forest-dwelling species remain dominant (Vaccinium myrtillus, Vaccinium vitis idaeae, Deschampsia cespitosa, etc.). This zone occupies 50 to 70% of the campsites and has a higher species diversity than the other two – the forest community dominants are joined by ruderal and meadow species, which actively colonize disturbed sites (Plantago major, Poa annua, Trifolium repens, etc.). The ground cover in moderate trampling damage zones may differ between campsites depending on the site conditions and the possibility of diaspore introduction from species alien to the given forest community. Plant communities in zone II are in critical or near-critical stages of recreational digression (stages III-IV or IV-V).

Mild trampling damage zones occupy 10-25% of the campsites' total area, usually along the periphery. The living ground cover is disturbed only in paths; the percent area worn out by trampling in zone III is 10-15%. Plant communities in this zone are usually in stages II or III of recreational digression.

The flora in the campsites is very different in the species diversity from natural undisturbed forest sites, being 5.4-7.6 times richer. On top of retaining a majority of typical forest-associated species, campsite flora is continuously enriched by introductions of regionally common meadow and ruderal species, which usually settle in zones I and II. This is in agreement with data by other researchers who have studied forest plant community transformation under recreational impact (Экосистемы..., 1989). In the future, given the same mode and intensity of use, the disturbed area within the campsites will not grow any significantly. Further changes will probably be connected with the introduction of native meadow species and alien species.

4.6.5. Results: Waste dumps flora

The environment for plants in waste dumps is sharply different from the conditions in natural habitats. They have a peculiar microclimate, soils, hydrological regime, and other environmental features compared, for instance, to forest habitats. Also, there being no tree canopy over such ruderal habitats, so the light and thermal conditions change radically. In contrast to forested spaces, dumps are open, well-warmed habitats. The ambient air temperature and the soil temperature are much higher (because of waste decomposition processes). Another factor for colonization by alien species is the absence of competition from native flora. Essentially, the conditions for the life of plants in waste dumps in Karelia are comparable to semi-steppe or steppe environments, i.e., the characteristics of these limited-size disturbed sites as if move them 600-800 km southwards. Considering that many alien species are capable of migrating hundreds or even thousands of kilometers northwards beyond their natural ranges, finding themselves in our latitudes they can survive and get established only in human settlements and their surroundings, colonizing ruderal ecotopes. That is why dumps often become the first steppingstones for such species.

Surveys of 9 dumps yielded records of 230 vascular plant species (Table 18, for details, see Appendix 2). Although native species prevailed in the flora of the dumps – 165 (71.4%), the share of alien species was high and variable depending on the dump parameters and current conditions (size, time of formation, waste variety, etc.). Expectedly higher (2-3 times higher) diversity was found in large dumps in the villages of Kushnavolok and Sennaya Guba, as well as the former (plowed under) dump on Kizhi Island (Fig. 67, 72).

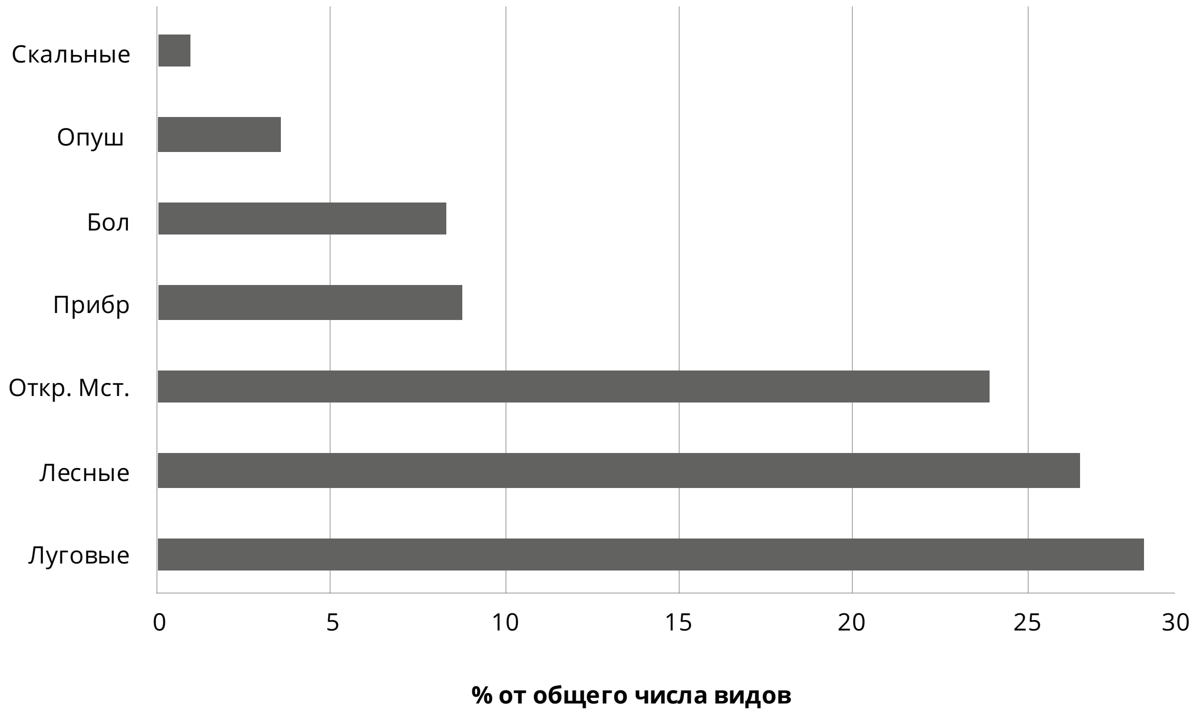
Table 18. Number of vascular plant species in waste dumps

Site	Total number of species	Native species		Alien species	
		No. of species	%	No. of species	%
Dumps in NP Vodlozersky:	143	100	69.9	43	30,1
Kuganavolok	112	71	63.4	41	36,6
Okhtoma	57	51	89.5	6	10,5
Dumps in Kizhi Museum:	169	119	70.4	50	29,6
Kizhi (island)	72	37	51.4	35	48,6
Kushnavolok	37	34	91.9	3	8,1
Mal'kovets	32	30	93.8	2	6,2
Oyatevshchina	43	37	86.0	6	14,0
Sennaya Guba	95	57	60.0	38	40,0
Telyatnikovo 1	29	26	89.7	3	10,3
Telyatnikovo 2	25	22	88.0	3	12,0

Moreover, the flora of waste dumps that are several times smaller (Telyatnikovo Village, Kuganavolok, Mal'kovets Island, etc.) (Fig. 75-79) is characterized by a low representation of alien species (especially exotic invasive elements), the proportion of which is 3-6 times lower than in larger landfills. The number of alien species was the lowest in illegal dumps in the Kizhi Museum territory situated at substantial distance from human communities (Kushnavolok, Mal'kovets).

In terms of habitat type affiliations, species recorded from the dumps were distributed as follows: the diversity of typical local flora species was expectedly high (forest species' share was 26.5% and meadow species contributed 28.3%). The combined share of species associated with other types of natural habitats (wetlands, forest margins, shores and banks, rocks) was 21.4% and varied widely depending on the location of the dump in the terrain. The share of species associated with "open habitats" (secondary biotopes – wastelands, dumps, kitchen plots, roads, etc.) was 23.9% (Fig. 65). This group includes a majority of typical ruderal species ubiquitous in wasteland habitats throughout Karelia (shepherd's purse *Capsella bursa-pastoris*, creeping thistle *Cirsium setosum*, lamb's quarters *Chenopodium album*, etc.).

It is thus obvious that many native plant species (associated with forests, wetlands, and watersides) can tolerate some amount of human pressure and persist as components of ruderal plant communities for indefinitely long. That said, more than a half of all species (52.2%) in waste dumps prefer open disturbed habitats or meadows (Fig. 68, 73, 80).



Legend: бол – wetland, опуш – forest margin, откр. мст. – open habitats, прибр – shores and banks.

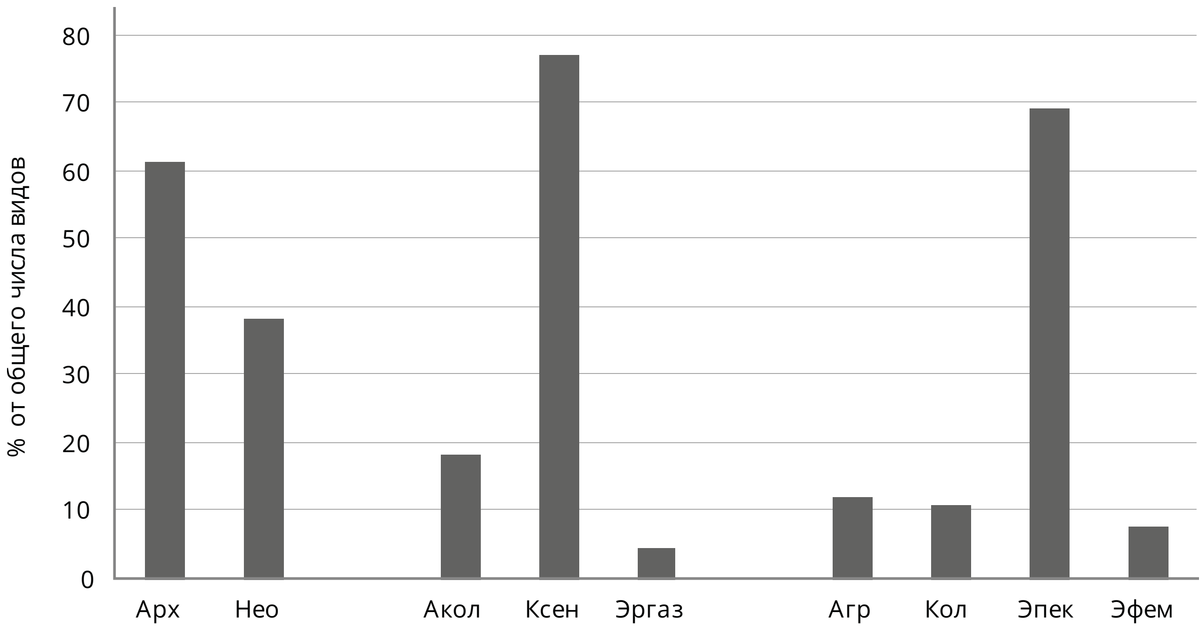
Fig. 65. Distribution of species recorded in dumps by habitat affiliations (% of the total number of species)

The classification of adventitious species by the time and method of invasion and the degree of naturalization revealed the following (Fig. 66):

1. as regards the time of invasion in the region, the leading group is archeophytes (invaded Karelia before the 16th c.) – 61.5%. It includes species commonly occurring in the republic in a wide range of disturbed habitats (common fumitory *Fumaria officinalis*, common chickweed *Alsine media*, common plantain *Plantago major*, etc.). The share of neophytes (later migrants) is nearly twice lower – 38.5% (ground ivy *Glechoma hederacea*, lamb's quarters *Chenopodium album*, wild chamomile *Lepidotheca suaveolens*, etc.).

2. as regards the invasion method, the leader by far is xenophytes (unintentionally introduced by humans) – 76.9% (sand rockcress *Cardaminopsis arenosa*, common orache *Atriplex patula*, oak-leaved goosefoot *Chenopodium glaucum*, etc.). The combined share of cultured species growing feral (ergasiophytes) and species dispersing without human assistance (acolytophytes) is 23.1%. One can name ornamental and food plants popular among second-homers, the usual dump "satellites", such as Allium *cepa*, *Anethum graveolens, Cosmos bipinnatus, Solanum tuberosum* (Fig. 69, 70, 74).

3. as regards the degree of naturalization, the most numerous are the adventitious species that have already become naturalized in the Karelian environment and are successfully colonizing secondary habitats (epecophytes) – 69.2%. This group includes many regionally widespread ruderal species that are usually abundant in habitats transformed by human activity (prostrate knotweed *Polygonum aviculare*, large-flowered hemp-nettle *Galeopsis speciosa*, hedge bindweed *Calystegia sepium*, etc.). Other groups contribute a total of 30.8%.



Legend: агр – agriophytes, акол – acolytophytes, арх – archeophytes, кол – coloniophytes, ксен – xenophytes, нео – neophytes, эпек – epecophytes, эргаз – ergasiophytes, эфем – ephemerophytes.

Fig. 66. Distribution of adventitious species by invasion time and method and the degree of naturalization (% of the total number of species)

Owing to specific azonal conditions (disturbed ground, elevated temperature and microelement content in the soil, lack of shadow, etc.) different from natural habitats, waste dumps often act as source areas for dispersing invasive vascular plant species (alien species whose dispersal may threaten the region's biological diversity). The dumps surveyed were found to contain several species classified as invasive in Karelia: *Sambucus racemosa* (Kizhi), *Epilobium adenocaulon* (Kuganavolok, Okhtoma), *Impatiens glandulifera* (Kuganavolok) (Fig. 71), and *Malus domestica* (Kizhi, Kuganavolok).

4.6.6. Conclusions and responses: Waste dumps flora

Studies have shown that the flora of the waste dumps features a far greater (2-8-fold) diversity compared to the surrounding undisturbed forest communities. The number of species in the largest dumps (Kuganavolok, Sennaya Guba) is expectedly higher, whereas the number of species in the micro-dumps far away from human communities is 2-3 times lower.

The flora composition in all the dumps is mainly made up of native species, while the share of alien species can be 3-6 times lower, depending on the dump size, waste fractions and amount. Plant communities in the dumps are mostly composed of boreal meadow and forest species. The percent-cover dominants in smaller dumps (Oyatevshchina, Telyatnikovo, etc.) are *Filipendula ulmaria, Urtica dioica, Aegopodium podagraria*, quite frequent are *Geranium sylvaticum, Knautia arvensis, Rubus saxatilis, Lathyrus pratensis*. Apart from native species, a significant group in the largest dumps (Kuganavolok, Sennaya Guba) in terms of both species number (around one-fourth of all species) and spatial coverage are open-habitat pioneers. Most of them are alien species very common in the region, such as *Cirsium setosum, Chenopodium album, Alsine media*, etc. In addition to the ruderal species that are widespread in the region, other usual inhabitants of waste dumps are so-called "escapees" – ornamental and food plants people commonly grow in their subsistence plots: *Anethum graveolens, Solanum tuberosum, Allium cepa, Allium sativum, Cosmos bipinnatus, Chelidonium majus*, etc.

The dumps were found to contain four species classified as invasive in Karelia: *Sambucus racemosa, Epilobium adenocaulon, Impatiens glandulifera,* and *Malus domestica*. It is obvious by now that these species have become quite common across southern parts of Karelia; some of them spread actively and aggressively to secondary habitats, often displacing native species, and forming thick single-species stands. Regular monitoring of habitats such as waste dumps and other ruderal habitats is needed to be able to adequately predict how the situation with invasive species will develop and understand the strategies of their potential future behavior in the republic.

When large source areas of invasive species are detected in the region, the recommendation is to eradicate them as soon as possible, before massive dispersal has occurred. Since waste dumps often act as starting points from where invasive species spread across the region, the first key step to take is to remediate them (for large official landfills) or to sort and recycle the wastes (for illegal micro-dumps). As applied to the Himalayan balsam – one of the most aggressive invasive species in the republic today, the control measures are total eradication of populations, and prevention of seed formation and dispersal (Виноградова и др., 2010). The recommended time for eradication (by weeding, mowing, trimming) is late July, when the first flowers appear, to be repeated during 2-3 years, until new plants stop re-growing. Another key action for preventing massive spread of alien vascular plant species is monitoring of potential introduction sites. Regular check-up on first findings or established populations of such species enables monitoring of changes in their status and predicting future behavior of alien flora elements in the region.

Fig. 67. General view of the Kuganavolok dump

Fig. 68. Fragment of weed-meadow vegetation in the dump in Kuganavolok

Fig. 69. Onion Allium cepa

Fig. 70. Cosmos bipinnatus in the Kuganavolok dump

Fig. 71. Thickets of Impatiens glandulifera in the dump in Kuganavolok

Fig. 72. Waste dump at Sennaya Guba Village

Fig. 73. Fragment of meadow vegetation in the waste dump in Sennaya Guba Village

Fig. 74. Solanum tuberosum

Fig. 75. Waste dump at the Okhtoma camp site

Fig. 76. Waste dump on Mal'kovets Island

Fig. 77. Waste dump 1 in Vlg. Telyatnikovo

Fig. 78. Waste dump 2 in Vlg. Telyatnikovo

Fig. 79. Waste dump at Vlg. Oyativshchina

Fig. 80. Common moonwort Botrychium lunaria

5. CASE ROKUA, FINLAND

5.1 Site introduction

The Rokua esker aquifer is one of the largest groundwater bodies in Finland with an area of 139 km2, of which 92 km2 is groundwater recharge area (Fig. 81). Aquifer thickness varies from 30 m to 100 m and consists of sand and local deposits of gravel. The esker is protected under the European Union's Natura 2000 network and contains a national park. The Rokua esker aquifer is an example of unique dune formations caused by the wind and fluvial and coastal currents, as well as deep depressions and kettle lakes formed by the preferential melting of ice. Among the area's key ecosystems are the crystal clear, oligotrophic, groundwater-dependent kettle lakes (Fig. 82). Rokua was also introduced as a member of the UNESCO Geoparks Network. It is a popular recreation area and holiday resort with hotels and second homes. The economic impact of the annual 120,000 tourists on the local economy is significant (Jurvakainen, 2007).

As in most inland eskers in Finland, the Rokua groundwater system is unconfined in the recharge zone. It discharges groundwater into the surrounding peatlands, where peat partially confines the groundwater. These peatlands have been used for forestry, peat mining and, on a smaller scale, agriculture. In the past, Finnish water management did not consider drainage in the groundwater discharge zone as a threat to the esker aquifer. Drainage for forestry was supported by government subsidies and conducted on a large scale from the 1950s to the 1980s. Possible environmental impacts of this practice were studied and noticed only later. Currently, drainage of pristine peatlands is rare, but poorly functioning drainage systems are enhanced by drainage improvements (i.e., the reopening of filled ditches).

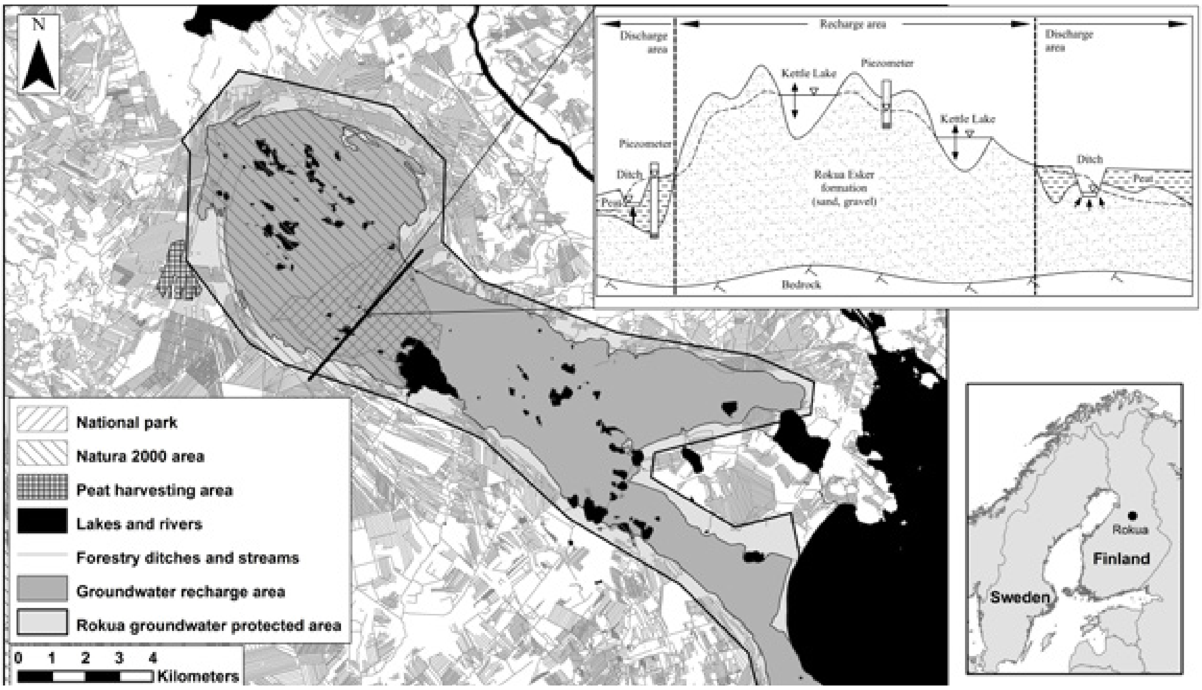
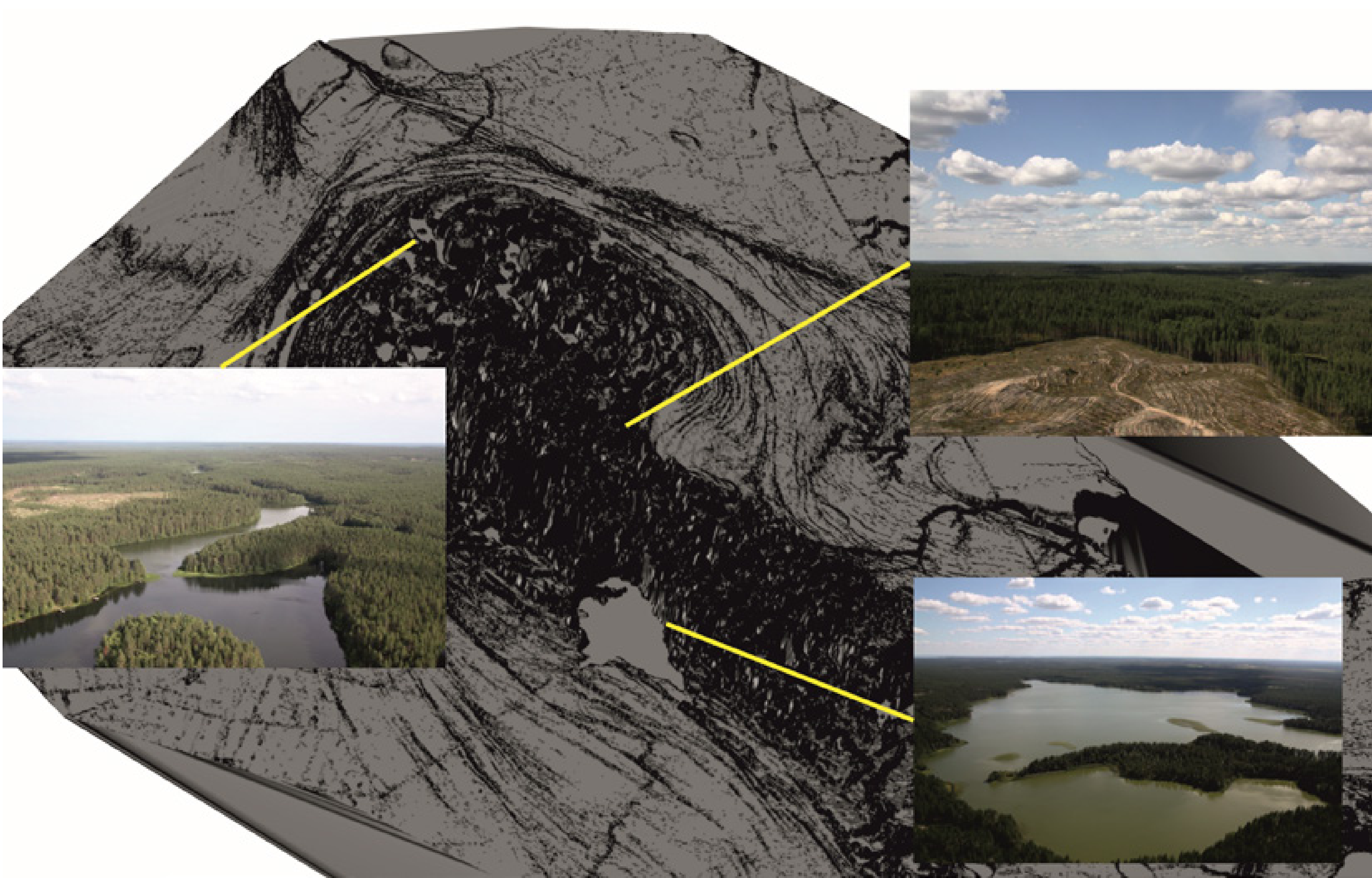


Figure 81. The Rokua esker area and a cross-section sketch of the esker with recharge and discharge areas (From Karjalainen et al .2013).

Figure 82. Rokua landscape and surroundings based on digital elevation model (National land survey of Finland 2014). (photos by Pekka Rossi)



5.2. DPSIR for Rokua

5.2.1. Drivers

At Rokua, groundwater-dependent lake levels were observed to decline after a drought period in the 1980s, and the same decline was also repeated after later dry seasons. The need for research in the Rokua area was catalyzed by a dry period in the 2000s, when the water level of the Rokua lakes and groundwater were, as in the 1980s, again substantially declining. At this point, the decline was attributed to several factors, including forestry ditches (Fig. 83) and the nearby peat harvesting area: the land use surrounding the groundwater area.

Intensive hydrogeological studies of the Rokua groundwater system started in 2008. The studies have shown that the groundwater level and the dependent lake levels are closely related to annual changes in precipitation and evapotranspiration. After a dry period, the groundwater levels declined for several years, whereas high precipitation periods again gradually raised the water levels. However, initial studies also showed a slower, longer-term decline in the Rokua water levels. This decline could not be explained by climate conditions, as effective precipitation (precipitation−evapotranspiration) has increased during the 30-year reference period from 1980 to 2010.

As there are hundreds or even more than a thousand kilometers of forestry ditches and also peat harvesting in the area, the land use was of interest to understand the reasons, i.e the drivers, for the variation in groundwater quantity at Rokua.

Figure 83. Forestry ditches at Rokua (photos by Pekka Rossi).

The EU Groundwater Directive states that the quantitative and qualitative deterioration of groundwater should be prevented. However, public awareness of the problems relating to the decline in groundwater level is in many cases poor among the EU member states (Kløve et al., 2011a and b). The same problem concerns the Rokua esker area, as public knowledge of groundwater was limited. In Rokua, groundwater is the connecting factor between the surface waters, i.e., the esker lakes and the streams and ditches within the peatland discharge area. Accusations among various stakeholders concerning the reasons for the water level decline during the 2000s raised increased tensions between the different stakeholder groups in the area. To open discussions between the stakeholders on the role of different land uses and their impacts on the Rokua water levels, up-to-date knowledge on groundwater will be distributed.

5.2.2. Pressures

According to a study by Rossi et al. (2012) and the initial groundwater flow models, the anticlinal Rokua esker groundwater discharge zone conditions are dependent on land use. Therefore, drainage (either for forestry, peat extraction or agriculture) of peatlands might be one of the reasons for the long-term decline of the Rokua groundwater level. As the study results were uncertain concerning how much the discharge zone conditions actually affect the esker groundwater level, precautionary principles should be applied in the Rokua area until more exact scientific evidence becomes available.

Study by Rossi et al. 2012 revealed that the ditches have distinct connection to the aquifer. The groundwater can discharge into the ditches as the ditches disturb the confining peat layer (Fig. 84). The risk for these discharges in the surrounding ditches could be estimated with a GIS analysis by Eskelinen et al. 2015 (Fig. 85). This showed that there is a wide risk for groundwater balance due to land use that should be taken into account. The exact dynamics were studied in the modelling tasks (Chapter 5.3).

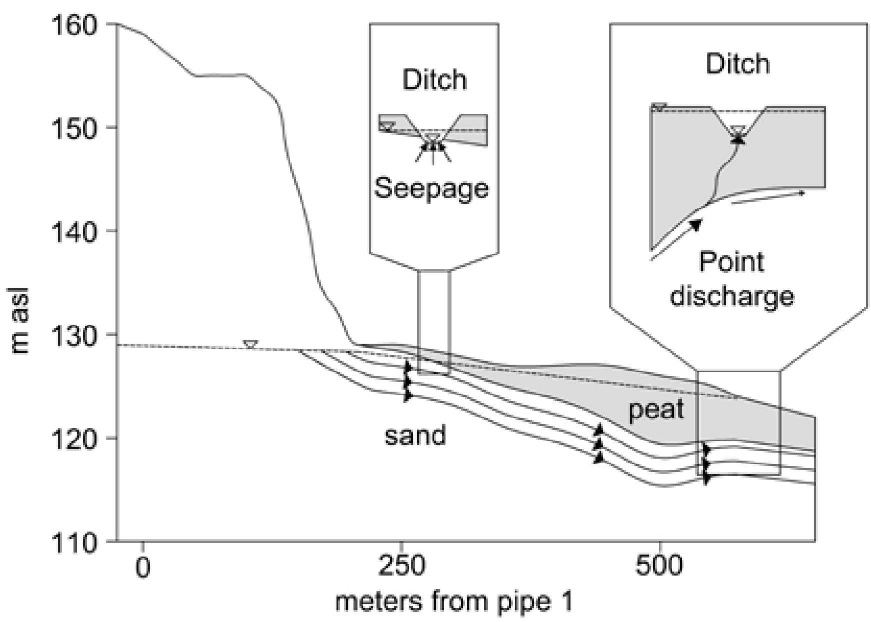


Figure 84. Example of effect of land use in peatlands on groundwater discharge from the esker aquifer (From Rossi et al. 2012).

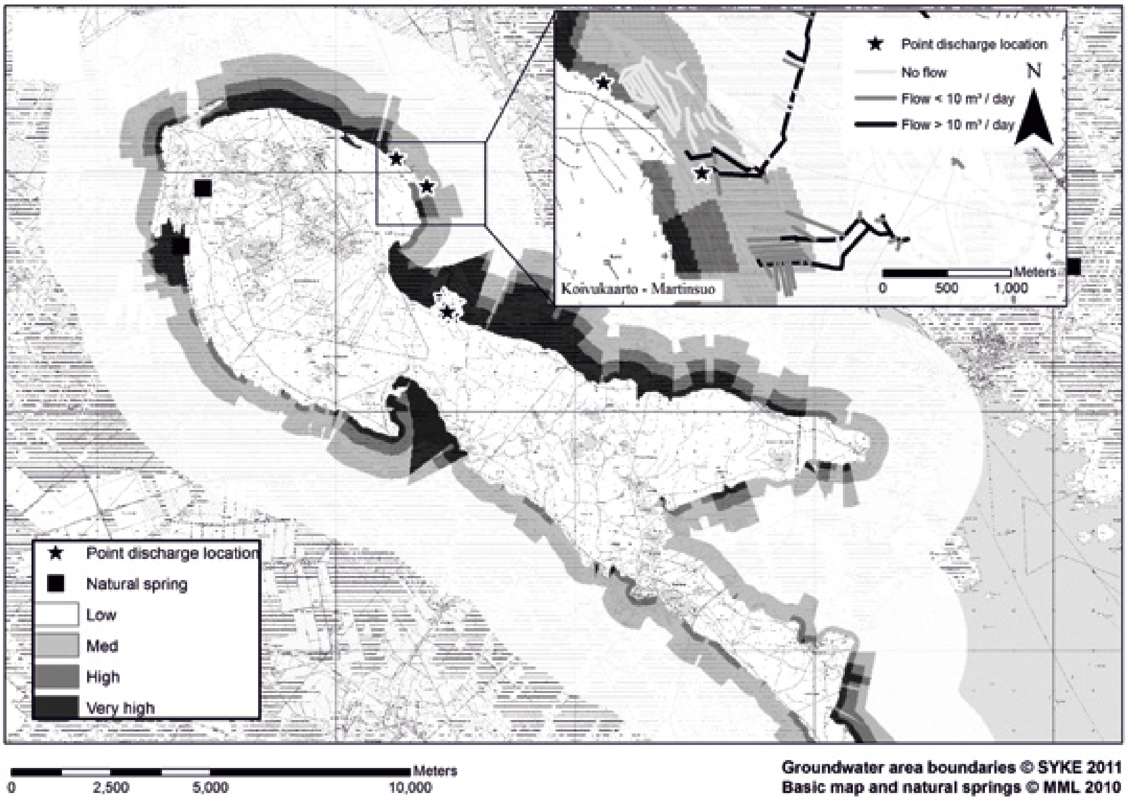


Figure 85. GIS analysis of the risk for groundwater seepage to the forestry ditches in the surroundings of Rokua (From Eskelinen et al. 2015).

5.2.3. State

Water levels of Rokua

Forestry ditches have changed the groundwater exfiltration patterns of the Rokua groundwater discharge area. How much these changes have actually affected the Rokua water levels was modeled. Initially the water levels in the early 2010s were low (Fig. 86) and concerns about the state of the lakes were high.

Figure 86. Lowered lake level at Rokua (photo by Pekka Rossi).

Ecological state of lakes and springs

Preliminary studies of groundwater-surface water interactions in Rokua have shown that phosphorus is leaching into the groundwater from the sandy soil, especially when the groundwater has a long contact time with the sand (i.e., old groundwater). This can be seen in the lakes that are situated lower in the esker surroundings having distinctly higher phosphorus levels (Fig. 87).

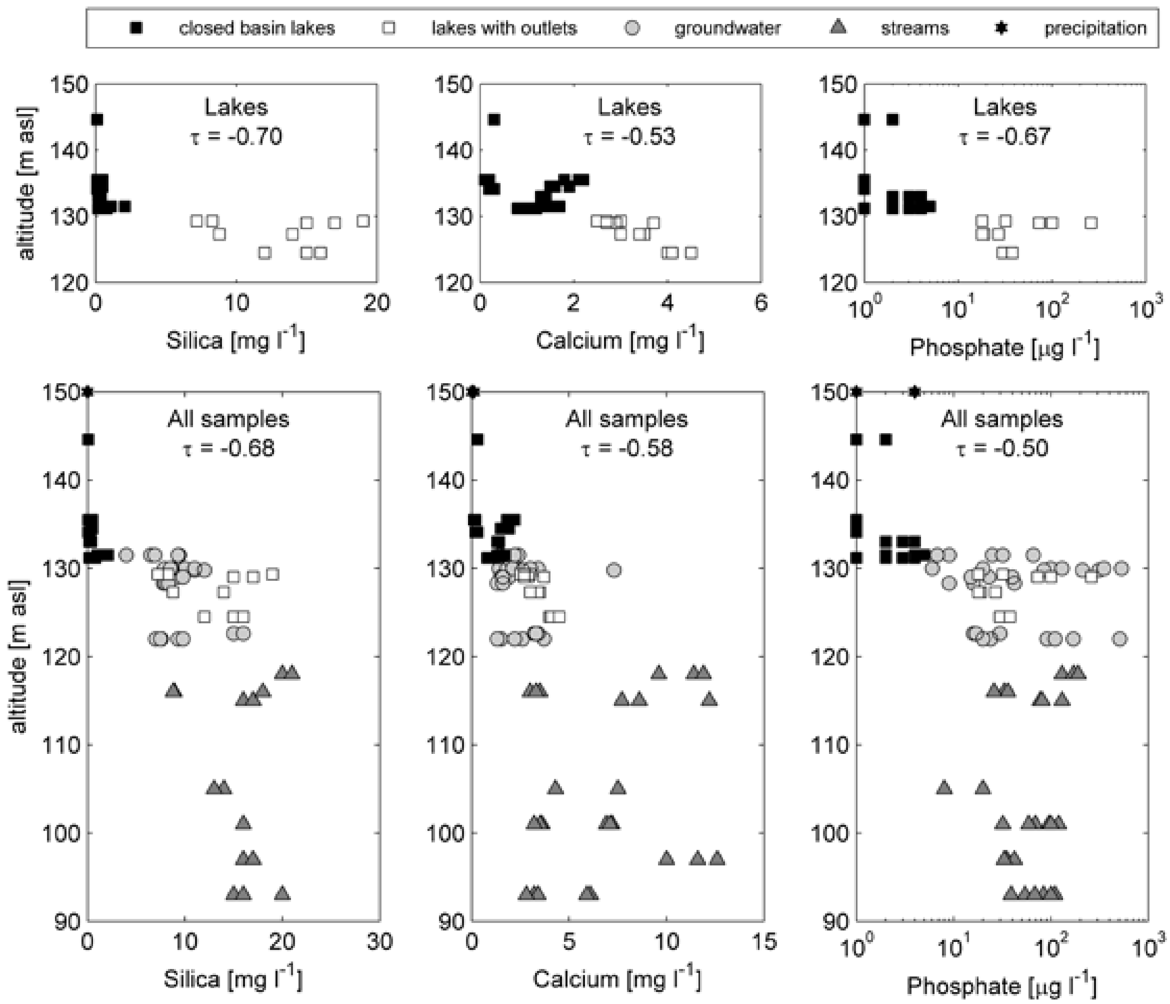


Figure 87. Water quality parameters in Rokua with lake elevation. Right hand side shows the dependence of phosphate in the water in correlation to the lake elevation (from Ala-aho et al. 2013)

Recreational value of second homes

One of the key factors in the recreational value of Rokua is the pristine, clear-water, oligotrophic kettle lakes. To date, 53 second homes have been built on the shores of these lakes and the recreational value of these houses is partially dependent on the shoreline. The water level decline is moving the shoreline away from the houses and revealing former lakebed areas. This will decrease the recreational value of the lake shore as thickets start to grow and the pristine landscape changes.

Attractiveness of the Rokua area

Lakes are also one of the key factors in the attractiveness of Rokua for tourism. Lake level decline might change the landscape and the recreational use of lakes. This again might reduce the amount of visitors to Rokua.

5.2.4. Impacts

The possible land use management alternatives were considered as responses. The set of alternatives was initially developed by the expert group and discussed and revised in a stakeholder meeting. The alternatives developed reflect the main objectives and interests, as well as issues of conflict:

Alternative A: Business-as-usual

Forestry practices continue as usual; reopening of drainage ditches in the groundwater area is not prohibited, but is under case-by-case consideration by the regulators.

Alternative B: Expansion of the groundwater protection area

A 3-5 km2 expansion of the Rokua groundwater protection area into the surrounding peatlands, where groundwater is confined under peat. Forestry is limited or forbidden in these areas. The environmental administration's control over the area is strengthened.

Alternative C: Active restoration (technical solutions) of peatlands

Restoration of critical groundwater exfiltration areas either by damming or filling in drainage ditches. The alternative focuses on adaptive management efforts to locate the most critical areas of groundwater exfiltration instead of protecting larger land areas.

Locations for groundwater area expansion (Alternative B) and restoration targets (Alternative C) were estimated by using the groundwater exfiltration risk prediction method developed for Rokua by Eskelinen (2015). The method estimated the most likely locations of groundwater exfiltration from the slope of the esker, distance from the recharge zone, distance from springs, baseflow of the discharge area watersheds, and peat thickness.

The impact assessment of the selected alternatives was conducted by a group of experts after a stakeholder meeting. The hydrological, ecological, and socio-economic impacts of the proposed alternatives during a 30-year period are presented in Table 19. The impact assessment was based on the studies conducted and the preliminary results of ongoing research in the area. As the assessment was partially based on preliminary results and the time span of the assessment was 30 years, the uncertainty of the impact assessment was considered to be high. For this reason, some of the impacts were studied using less precise, qualitative measures. These qualitative measures indicated whether the alternative had a negative impact (−), no change from the current situation (0), or a positive (+) or highly positive impact (++). For example, active restoration was assessed to have a highly positive impact on the springs surrounding Rokua.

Table 19. Objectives, attributes, and impact matrix of different alternatives (GWP = groundwater protection) (From Karjalainen et al. 2013).

Objective	Attribute(s)	Business-as-usual	GW-expansion	Active restoratior
Normal level of groundwater and dependent lakes	Change in average Rokua water level in 30 years (groundwater and lakes)	−1 m	−1 to0 m	+1 m
Good ecological status in lakes and springs	Chemical state of lakes	0	0/+	+
	Chemical/ecological state of springs	0	0/+	++
Good recreation value of second homes	Recreation value change of second homes in 30 years	−150,000 to −230,000 €	0 to −230,000€	0
Attractive tourist resort	Change in attractiveness of Rokua for tourists in 30 years	-	0	+
Profitable forestry	Forestry income loss in 30 years	0	−50,000 to −250,000 €	−500,000 to −2,500,000 €
Minimal loss of peat production	Income loss in peat production or losses caused by restoration of peat harvesting area	0	0/-	-

Water levels of Rokua

For the impact assessment, the best available at that time information from hydrological studies was used to assess how the water levels would behave in the following 30 years in different alternatives (Table 19). If Alternative A prevails, the long-term decline in water levels will continue and can cause a water level decline of approximately 1 m (from the average value) within 30 years. During dry periods, this would cause lower minimum water levels, which could be more drastic than during the dry periods of the 1980s and the 2000s. In Alternative B, the long-term decline in water levels is stopped, but water levels would not return to the level preceding drainage. In Alternative C, water levels return to the assumed natural state, on average 1 m higher than the current situation. This level is indicated by the kettle lake shore region occupied by the oldest trees. This alternative can be estimated to be less uncertain than Alternative B, as there are active procedures aimed at restoring the groundwater exfiltration patterns to a natural state.

Ecological state of lakes and springs

As the clear oligotrophic kettle lakes are groundwater-dependent, the risk of eutrophication increases due to water level decline. The risk also increases as older groundwater might seep into the lakes and increase the proportional amount of incoming phosphorus. Additionally, lake water volume decreases due to water level decline, increasing the relative amount of phosphorus entering the lakes.

Another ecological issue is that drainage has dried up natural springs that formerly acted as natural groundwater exfiltration locations in the peatlands surrounding Rokua. As they are dry, a poor ecological state currently exists in these spring ecosystems. If drained areas are restored, the springs will most probably return to a more natural state. Spring locations have not been mapped thoroughly and therefore the question of how many springs can be restored increases the uncertainty of this factor. The ecological status of both lake and spring ecosystems is predicted to have a positive impact as a result of implementing Alternatives B and C.

Recreational value of second homes

The link between the recreational value of second homes and lake water level was calculated using the VIRKI model. This model was originally developed to calculate the effects of water level variations on the value of properties on lake and river shorelines (Keto et al. 2005). In the present case, the model was used to calculate how much the recreational value of Rokua would decrease if the shoreline recedes from the level observed in 2008, when lakes no longer showed significant effects due to previous dry years and water levels were close to the estimated average of the past 30 years. In Alternative A, the water level is presumed to decrease by approximately 1 m, and this would cause a shoreline retreat of approximately 5-6 m. This retreat would cause an annual decrease in recreational value of 94-145 € for each of the second homes. In 30 years, this would mean a 150 000-230 000 € decrease in the recreational value. In Alternative B the decline would presumably stop, but as the future level variation is uncertain, the value decrease would be somewhere between 0 and 230 000 €. In Alternative C, the water levels should return to a more natural state and would be at those of 2008 or above.

Attractiveness of the Rokua area

As the lakes are only one part of the landscape in Rokua and as tourism is not only dependent on the lakes, the impact of lake level change can be considered to have less of an effect on tourism than, for example, on the recreational value of second homes.

Economic impacts on forestry income

The impacts of the restoration of drained peatland areas on the forest economy were studied by using exfiltration risk analysis (Eskelinen 2015). Watersheds in high exfiltration risk areas were defined as areas where active restoration procedures in Alternative C would be implemented. In these areas, restoration can be presumed to wet the forest and affect tree growth. As the growth potential of the forest would then be drastically reduced, the income of the forest owner would decrease. Using different input data (different combination sets of available data) in risk scenario maps, the value of income losses in 30 years was calculated to vary from 500 000 to 2 500 000 € (Eskelinen 2015). The change in land value was not taken into account. In Alternative B, where the groundwater protection area is expanded, determining forestry income loss was more problematic. As the expansion would restrict forestry management practices in some of the areas where the groundwater area is expanded, some new areas might become wet. As this is less certain, it was estimated that Alternative B would result in only 10% of the effect on forestry from Alternative C.

Income loss of peat production

Peat production by harvesting in the vicinity of Rokua (Fig. 81, the peat harvesting area west of the esker) was scheduled to end in following years. Furthermore, the hydrological studies showed that approximately 1% of groundwater discharging from Rokua was flowing from the peat harvesting area. This demonstrated the minimal effect of the harvesting area on the whole Rokua esker hydrology. Therefore, different scenarios were presumed to have only a small effect on peat harvesting. In Alternative B, peat harvesting may end earlier, in the event of the groundwater area expanding to the peat harvesting site. In Alternative C, a new method is planned for the restoration of the peat harvesting area to prevent groundwater exfiltration to the harvesting site. This again might be more expensive than current methods and reduce the income from peat production.

5.2.5. Responses

The impacts of the alternative response options A-C were discussed with local stakeholders during the multicriteria analysis process (Karjalainen et al 2013). There was a wide consensus that the ecology and the state of the lakes is important, and that tourism is a crucial part of the local economy. Also, forestry was seen as important for the local economy, but in this the opinions were divided. Based on the results, the C-option as a response was valued highest (Fig. 88).

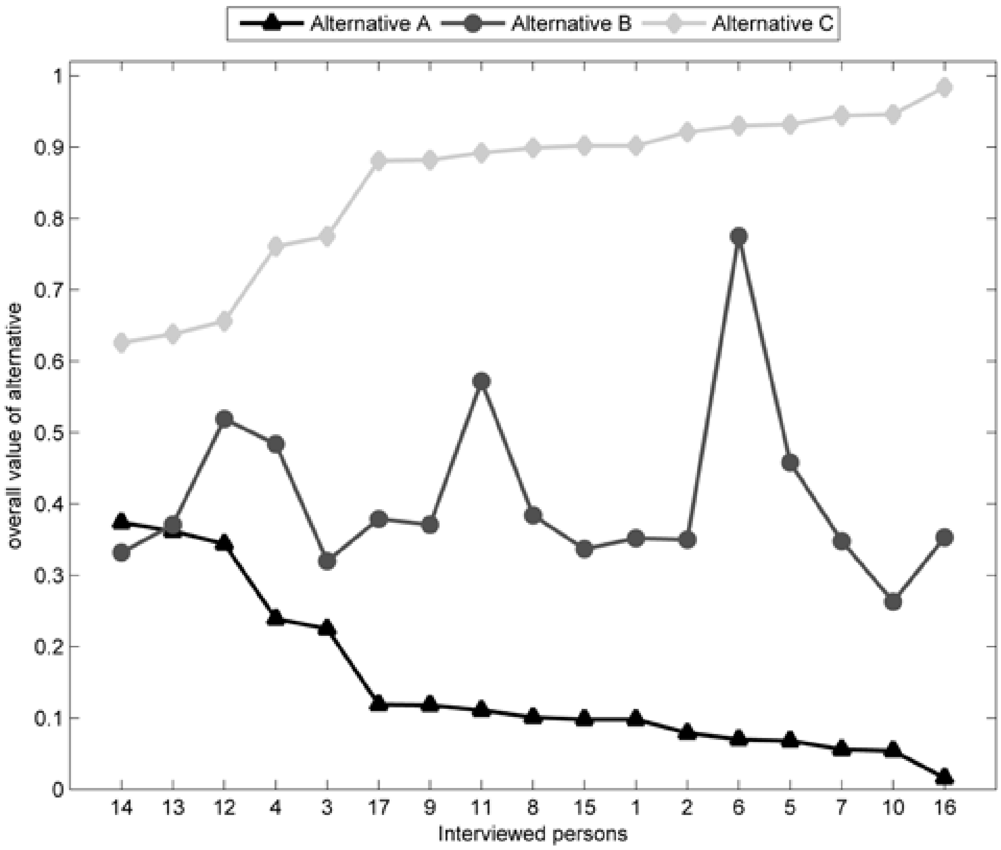


Figure 88. How different interviewed stakeholders value the different alternatives A-C based on their impacts on attributes (e.g., water level, forestry, attractiveness). The higher the overall value, the more valued the alternative (from Karjalainen et al. 2013).

The response in alternative C would mean active restoration with heavy procedures in the ditched peatlands surrounding the Rokua esker. At this point, there were still uncertainties whether this kind of large-scale procedures would be effective, as preliminarily assessed by the experts. Therefore, groundwater modeling results were awaited before discussions on the response were continued. In general, the discussions, meetings and interviews were seen as beneficial by the locals as they learned how the different land use and management options are interlinked to make the most beneficial decisions for the local communities.

Figure 89 represents the overall DPSIR scheme for the Rokua case. More detailed conclusions and recommendations for all sites are presented in chapter 7.

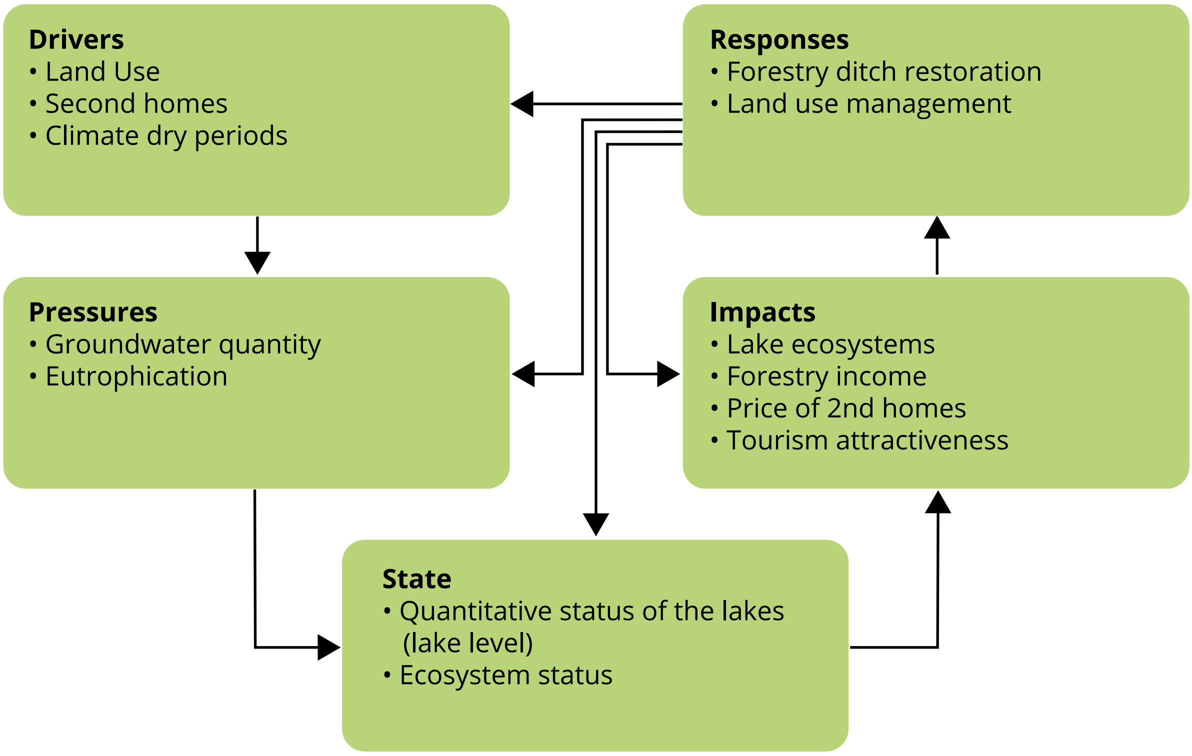


Figure 89. DPSIR framework for the Rokua case. (* refers to potential pressure, + refers to good state, - refers to need for improvement)

5.3 Numerical model for groundwater quantity management and groundwater-surface water interaction: a demonstration

As there was uncertainty regarding how the aquifer system in general functions and how the different management options for the forestry ditches would work, a groundwater flow model was utilized. A MODFLOW groundwater model was built to test different scenarios for management. As a basis of the groundwater model, the Rokua research included detailed geological mapping with geophysical methods and boreholes (Fig. 90). Geophysical methods included i) ground penetrating radar, where electric impulse is released to the ground and the returning impulse is analyzed, and ii) seismic refraction, where seismic wave is released to the ground and wave reflections back to the surface are analyzed. The model was calibrated against an extensive hydrological campaign where groundwater levels and streamflows were monitored continuously with loggers or manually several times a year (Fig. 91).

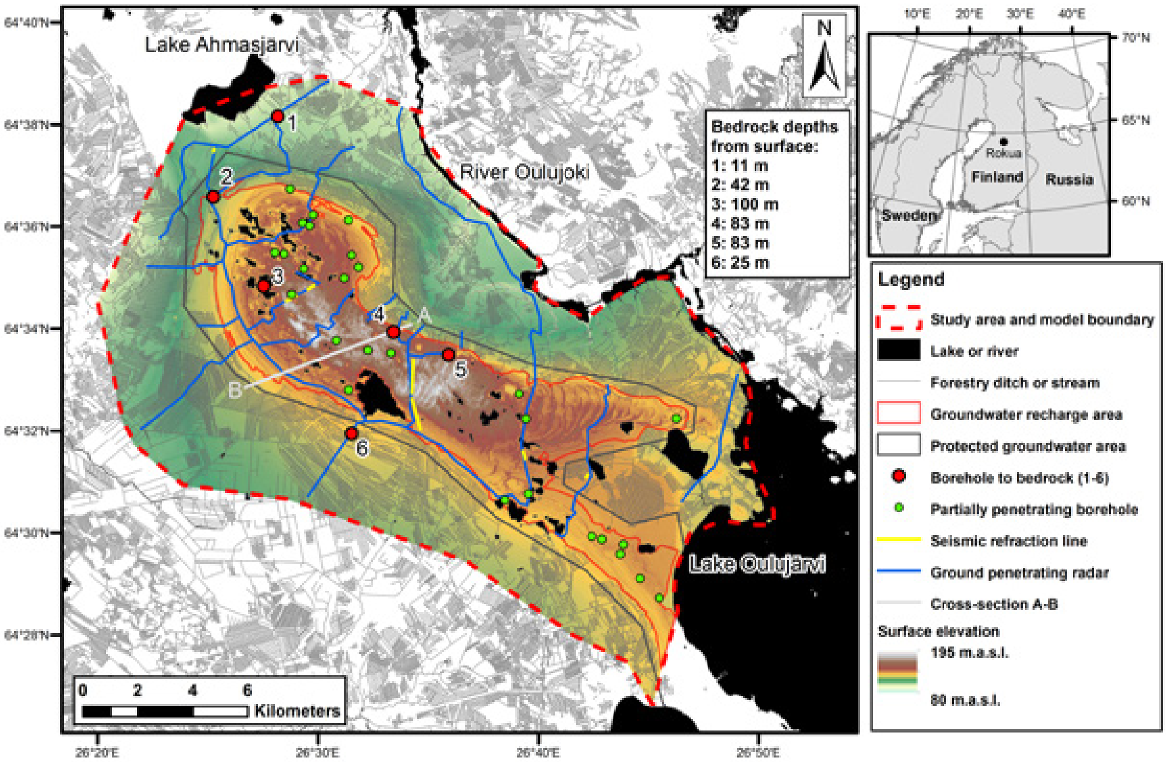


Figure 90. The geological structure studies through geophysical measurement and borehole surveys used as the basis for the groundwater model. Partially penetrating boreholes reach depths of 20–30 m below the ground surface (from Rossi et al. 2014).

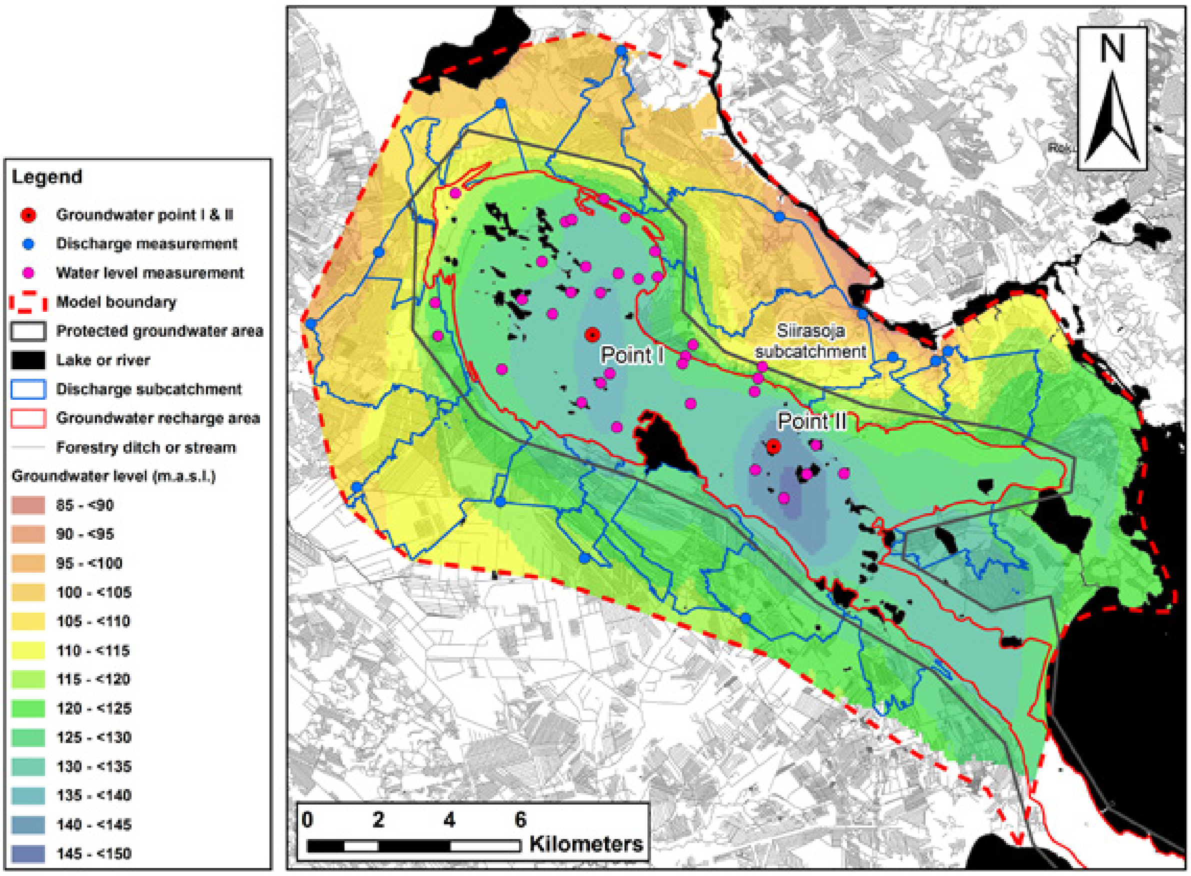


Figure 91. Average groundwater levels in Rokua esker area, water level measurement points, discharge subcatchments surrounding Rokua and discharge measurement points. Non-measurement groundwater points I and II were used for water-level analysis in modeling (From Rossi et al. 2014).

5.3.1. Model conceptualization

The conceptual model is an important part of the process of model building and deciding what to monitor in environmental management. Conceptualization defines i) how the natural surroundings can be defined as a numerical system with certain limits, and ii) what the expected main processes driving the system are. This requires an understanding of both geological structures and hydrological processes driving the groundwater flow. In the SUPER-project, simplified conceptualizations were also made for the Kizhi and Vodlozero cases in application to waste sites. These conceptualizations can help to spot the main places for monitoring that could later be used i) in management, and if needed ii) as a starting point for hydrogeological modeling studies.

For the Rokua case, conceptualization was needed on several levels. One level was concerned with how the ditch-aquifer interaction in the peatland can be defined in the model. To this end, the groundwater-ditch concept was defined based on Figure 92, where water flows through peat to ditches and peat/ditch parameters define the flow dynamics.

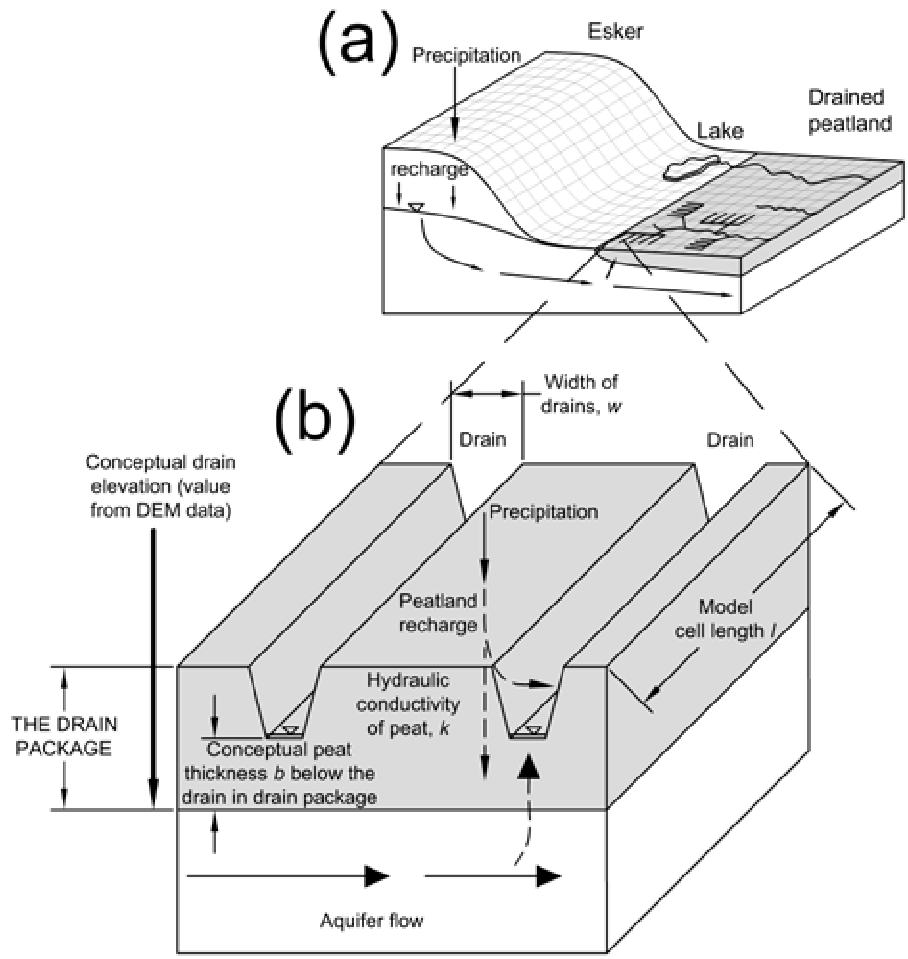


Figure 92. Groundwater flow discharge from the Rokua esker to surrounding peatlands (A), and peatland drain boundary condition concept in the MODFLOW model cell (B) (From Rossi et al 2014).

The second level of conceptualization was about defining the geological system in the model. For this, several options were considered (Fig. 93), but after initial model runs, a simplified peatland/aquifer model was chosen. In the modeling process itself, the hydraulic conductivity for both was calibrated spatially (see details in Rossi et al. 2014).

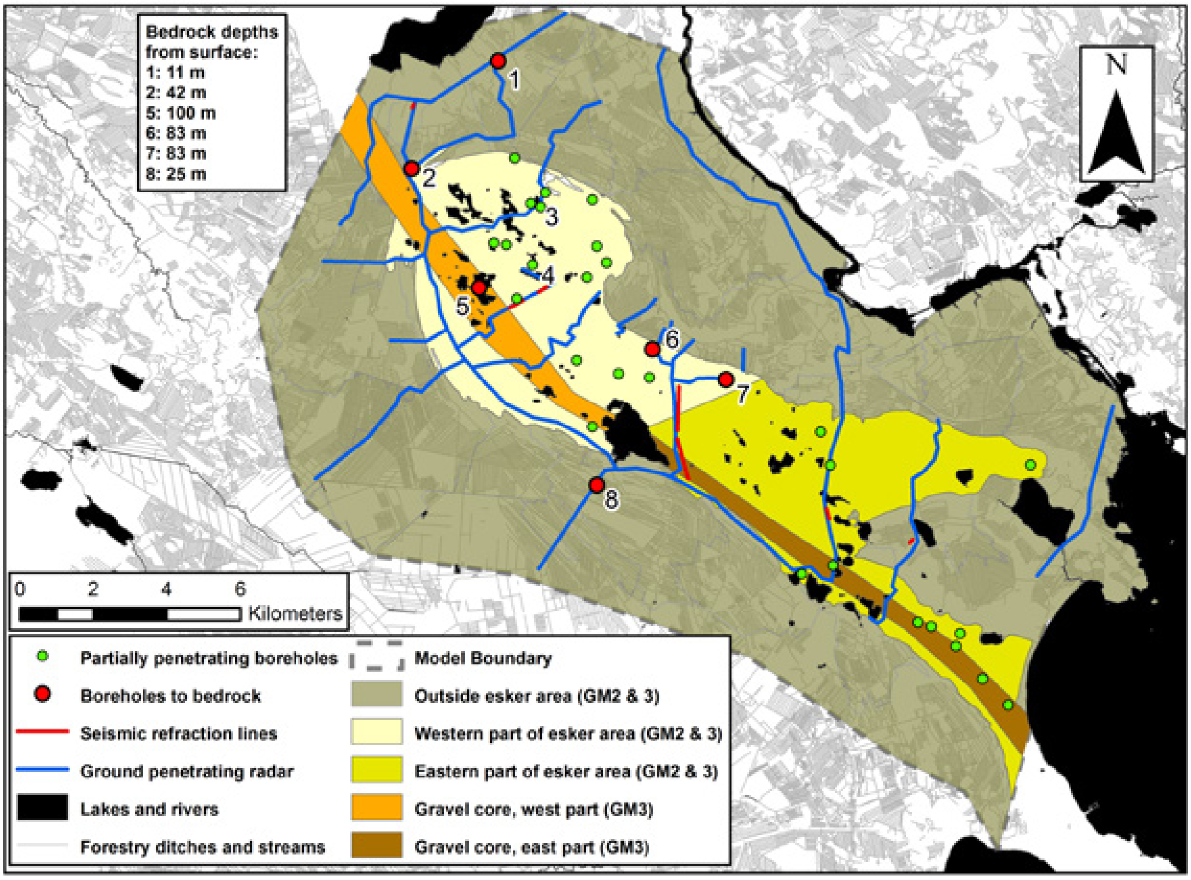


Figure 93. Initial conceptualizations of the geology of Rokua.

The third conceptualization level was the model build-up and different scenario estimations for land-use and climate change. The model area was limited to natural boundaries such as rivers, lakes and shallow soils (Fig. 94). The model was divided into groundwater recharge area (the esker) and discharge area, where peatlands were situated. The peatland drainage system covers almost all the peatlands surrounding the Rokua esker so the first conceptualization (the ditch-aquifer interaction) was implemented for the whole peatland area.

To demonstrate the impact of different land use or climate condition scenarios on the status of groundwater in the esker aquifer, different scenarios were run in the model. The uncertainty of the results was taken into account by running the model with the Null Space Monte Carlo approach, where different parameter combinations (870 per scenario) were used. The effects of the scenarios on esker water levels were studied for groundwater points I and II (Fig. 94), as these points represent the average groundwater state in the esker area.

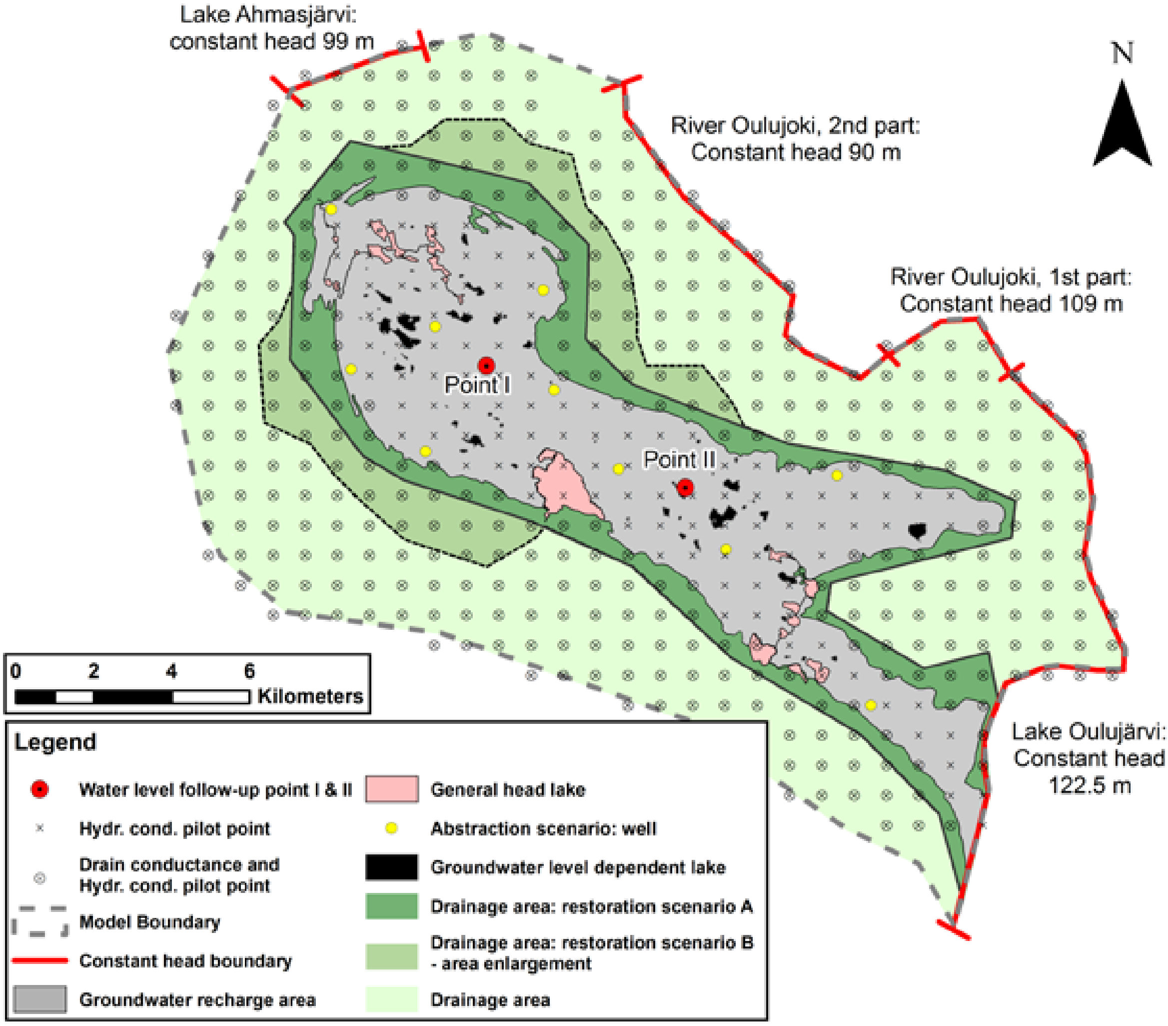


Figure 94. Rokua groundwater model condition conceptualization and land use scenario conditions. Constant water level in the model surroundings were defined for the River Oulujoki with two dams, Lake Ahmasjärvi and Lake Oulujärvi. Lakes with outflow were defined as general heads (constant). Groundwater points I and II were used for water level follow-up in the scenarios (From Rossi et al. 2014).

Drained peatland restoration

Drainage blocking is a common method for restoring the hydrological and ecological conditions of a peatland. Drained peatland restoration has been considered as a potential method to maintain the aquifer water levels at a higher elevation. Here, the effect of such restoration was modeled by: 1) raising drain water levels with dams; and 2) filling the ditches. Both of these methods have been used for peatland restoration. Drains were assumed to reduce the confining effect of the peat layer, thereby enabling more exfiltration from the aquifer to the drainage ditches. Restoration of the drained area, e.g., through filling in the ditches, reduces the hydraulic connection between the aquifer and drainage ditches. Thus, the elevation of the groundwater exfiltration point (elevation of the ditch) in the restored peatland also rises. Six different restoration scenarios were tested (see areas in Figure 94):

- Restoration 1A: Restoration is carried out within the current groundwater protection area. A 0.5 meter rise in drain elevation (as the ditches are dammed) was imposed on the model.

- Restoration 2A: As in scenario 1A, except that drain restoration decreases drain conductance (parameter in peatland-aquifer concept) by a factor of 2 as the drains are filled in (i.e., drain conductance was multiplied by a factor of 0.5) within the restoration area.

- Restoration 3A: As in scenario 1A, except that drain restoration decreases drain conductance by a factor of 10 (i.e., drain conductance was multiplied by a factor of 0.1) within the restoration area. This value is considered to represent a more natural state of the peatlands.

- Restoration 1B: Restoration is carried out in a groundwater protection area expanded at the western edge of the esker, where a sensitivity analysis suggests that changes in drainage conditions will affect aquifer water levels (Fig. 94). Drain elevations were raised by 0.5 m in this area.

- Restoration 2B: As in scenario 1B, except that drain restoration decreases drain conductance by a factor of 2 (i.e., drain conductance was multiplied by a factor of 0.5) in the expanded area.

- Restoration 3B: As in scenario 1B, except that drain restoration decreases drain conductance by a factor of 10 (i.e., drain conductance was multiplied by a factor of 0.1) in the expanded area.

Small-scale restoration through blocking a single ditch within the Rokua discharge area was tested by Kupiainen (2010) (Fig. 95), and a groundwater discharge decrease and groundwater potentiometric level rise adjacent to the restoration area showed a local potential for restoration. That study represented a situation where drain elevation was raised with a dam as in the Restoration 1A scenario. As no local data were available on the effects of filling in the ditches, the factors 0.5 and 0.1 were used as representative end results of the restoration.

Figure 95. Example of ditch damming from a pilot site (Photo by Virve Kupiainen).

Groundwater abstraction

Oulu, the main city in Northern Finland (population 190 000), is situated 70 km from the Rokua esker. There are no current or future plans to extract groundwater for use in Oulu from the vicinity of Rokua, but this scenario was nevertheless tested using the model developed in this study as a further demonstration of its use as a management tool, and to have a comparison point for the effects of peatland drains on aquifer storage. The city currently uses 27 000 m3 of water per day, which is 25% of the daily recharge of the Rokua aquifer (average over 2000-2010). In the abstraction scenario, this amount was assumed to be pumped from 10 abstraction wells around Rokua (Fig. 94). Abstraction scenario was also combined with the Restoration 3A scenario in order to investigate whether the effects of abstraction on water levels could be reduced with concomitant drain restoration.

Past and future dry climate seasons

The driest 10-year period within the available local climate data (1960-2010) was during 1970-1980. The average recharge for this 10-year period was used to examine how the model responded to periods of lower than average recharge compared to climate conditions used for calibration (2000-2010). This dry period scenario was also combined with the Restoration 3A and 3B scenarios. Future recharge was estimated with the same simulation approach as the historical recharge, using the downscaled projected climate change scenario data for years 2010-2100. As for the historical dry period, a 10-year moving average was calculated from the simulated recharge for each of the four climate change scenarios to obtain a recharge estimate for drier than average period for years 2050-2100.

5.3.2. Modeling results

Drained peatland restoration

The simulation results indicate that restoration of drained peatland areas with drain blocking could raise esker aquifer water levels (Fig. 96). For the scenario 1A, where drains are only blocked by dams, and 2A, where drains are filled in, the rise of the groundwater level is less than one meter. The different model runs show small variation between the results. For scenario 3A, representing the situation where filling the drain would restore the peatland to more natural hydraulic conditions, the water level rise could be above one meter. The combination of parameter variability and sensitivity resulted in a spread of the simulation results.

Scenarios including restoration of areas outside the current groundwater protection zone (scenarios 1B, 2B and 3B) did not change the groundwater level dramatically. Based on the results, the restoration would have more impact within the current groundwater protection zone rather than on outside areas.

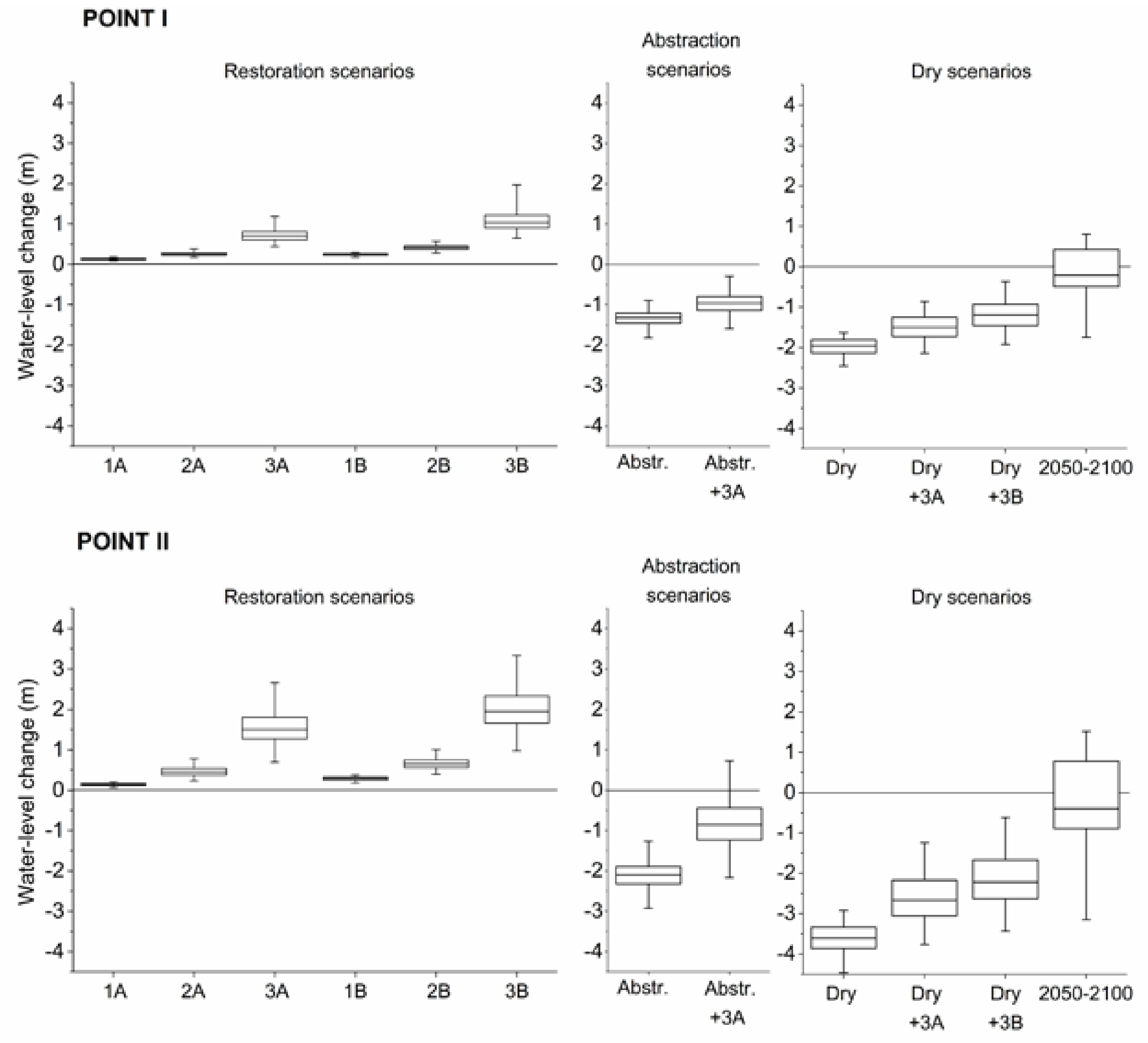


Figure 96. Comparative box plots of the water level changes at points I and II in the drained peatland restoration, groundwater abstraction, and climate scenarios. Scenario outcomes were calculated with the 870 parameter sets. Predictions are shown as a change (in meters) from the 2000-2010 water levels. The box plots represent the median, 50% box, and 1-99% whiskers of the parameter ensemble.

Groundwater abstraction

Hypothetical water abstraction from Rokua (27 000 m3 d-1 to a city of 190 000 inhabitants) would lower the water levels by 1 to 2 meters, according to the median values of the scenario model runs (Fig. 96, abstraction scenarios), but drainage restoration would reduce the fall of water levels (Abstr. +3A). Based on this result, the abstraction would have larger impact on water levels at present conditions compared to the situation where the peatlands in the discharge zone would be in a more natural state.

Past and future dry climate seasons

Based on the groundwater model scenario runs, the water level variations and periodical declines in the Rokua aquifer are highly dependent on climate conditions. Conditions resembling those of a dry period in 1970-1980 resulted in water levels of 2 to 3 meters lower from the 2000-2010 conditions (Fig. 96, dry scenarios). The combination of dry conditions and the drain restoration 3A or 3B scenarios resulted in higher water levels. Scenario runs for the estimated future dry period indicated that future dry periods would be less dramatic than in former decades due to an overall increase in precipitation and thereby recharge. Re-occurring dry periods are important to consider if the combined effect of land-use and climate on minimum water levels is of management interest.

Actions based on modeling

From a management point of view, the main outcome of the modeling concept in the study is the possibility to compare the effects of peatland drainage, and restoration with those of climate (historical and future) or water abstraction. This is important information in order to answer the main management question of whether there is a critical need for expensive drained peatland restorations.

Based on the models and considering the uncertainty analyses, peatland drainage does play a role in the hydrology of the studied esker aquifer, and drainage restoration might affect the aquifer water levels, but the groundwater level seems to be more dependent on climate conditions. In the studied northern aquifer area, the future climate conditions might be more suitable for groundwater recharge. This might mask the impacts of drainage on groundwater levels in the long run.


Photo by J.Kaipainen

6. CASE KOLI AND PETKELJÄRVI NATIONAL PARKS

6.1. Site introduction

Koli and Petkeljärvi national parks are situated within North Karelia Biosphere Reserve in the North Karelia (NK) province. This province is Finland's easternmost region, covering an area of about 21,585 square kilometres with a population of approximately 163,000. NK also shares around 300 km stretch of frontier with Russia. There are 13 municipalities within NK, five of which are towns (Regional Council of North Karelia 2019). With 84 percent forest cover, the region's economy is strongly dependent on its nature and forests; wood, tourism, metal, stone and food are some of the region's leading industries. NK is also home to over 2000 lakes: one of those, Lake Pielinen, being the fourth largest in Finland.

North Karelia Biosphere Reserve was established in 1992 as part of the UNESCO Man and Biosphere Programme. The Biosphere Reserve (BR) territory is approximately 7900 km2 and consists of core areas, buffer zone, and transition area. This BR includes municipalities of Lieksa, Ilomantsi and Joensuu (Tuupovaara district). The BR core areas are the protected areas Koli, Patvinsuo and Petkeljärvi National Parks, the Koivunsuo Strict Nature Reserve, as well as Kesonsuo and Ruunaa Nature Reserves (see Figure 97). Even though it includes conservation and protected areas, the reserve is not limited to them. The area of the biosphere reserve that is not protected is called the area of cooperation; it maintains a human population and economic activities. The overall population living within the biosphere reserve is approx. 21 000 people. This number excludes those who do not live permanently in the biosphere reserve (e.g. second-home owners).

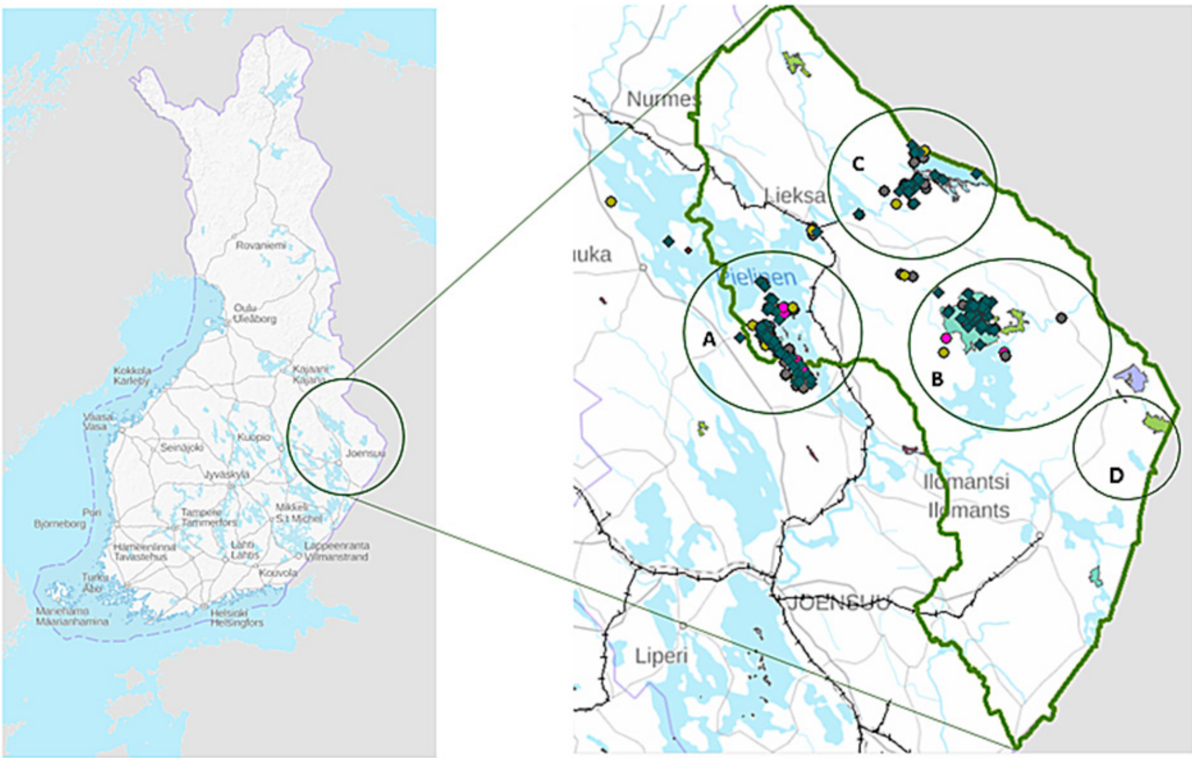


Figure 97. North Karelia Biosphere Reserve outline (in green), and key tourism targets (a. Koli National Park, b. Patvinsuo National Park, c. Ruunaa hiking area, d. Petkeljärvi National Park).

Tourism is the main activity within the Biosphere Reserve's protected areas (i.e. national parks and hiking area). North Karelia province attracts approximately 340,000 visits annually. In 2019, the province recorded 279,949 arrivals. In comparing the total visitor arrivals and total visits to just one target within the Biosphere Reserve (Koli National Park) for the year 2019 (201 800), it is evident that at least 72 percent of visitors arriving to North Karelia province also visit the Biosphere Reserve during their stay (Naumanen 2020). The visitor activities take place mainly across natural environments of Koli, Petkeljärvi and Patvinsuo National Parks, and Ruunaa Hiking Area of the Biosphere Reserve. In addition, public access rights give freedom to visitors to also enjoy the Biosphere Reserve environments outside the National Park and Hiking Area. Current tourism plan includes increasing visitor numbers to the region until 2050 (Naumanen 2020).

On the other hand, being a protected area, the biosphere reserve has unique characteristics, the major one being the sensitivity of its ecosystems to human and climate-change driven pressures (Schaller 2014). The Biosphere Reserve's growing popularity and the current strategy to increase visitor numbers (e.g. tenfold by 2050 for Koli) make it necessary to assess the current and the potential pressures and impacts of tourism (in particular municipal solid waste) under the scenario of a continued upward trend in visitor numbers to the BR's two most visited national parks (i.e. Koli and Petkeljärvi).

The pressures and impacts analysis focuses both on environments inside protected areas, and on surrounding areas outside these parks but within the biosphere reserve. This is because (a) visitor activities also take place outside the parks due to public access rights, and (b) other users' actions (e.g. the communities living or using environments close to the national parks and the hiking area) can also generate waste impacts and pressures that can through natural elements like rain, move into the protected areas. Everyman's Right, also termed "The public access rights", allows anyone living in or visiting North Karelia the freedom to roam the countryside, forage, fish with a line and rod, and enjoy the recreational use of natural areas (Visit Finland 2019). This applies to everyone, including domestic and international visitors. The research concentrates on the BR's two most visited national parks (Koli and Petkeljärvi) as key examples, because tourist traffic is known to positively correlate with the waste generation issue (Fig. 98)

The analysis addresses the following: (a) investigates potential drivers for solid waste in Koli and Petkeljärvi National Parks (NPs) and surrounding environments, (b) discusses possible impacts of the drivers on the regional tourism image to clarify existing problems and challenges (pressures), (c) examines the current state (incl. impacts) of the environments of the Koli and Petkeljärvi NPs and surrounding areas within the North Karelia Biosphere Reserve, after which it investigates the already available actions (responses) for overcoming pressures and enhancing sustainable actions within the national parks studied and their surrounding areas. Lastly, conclusions and recommendation are given.

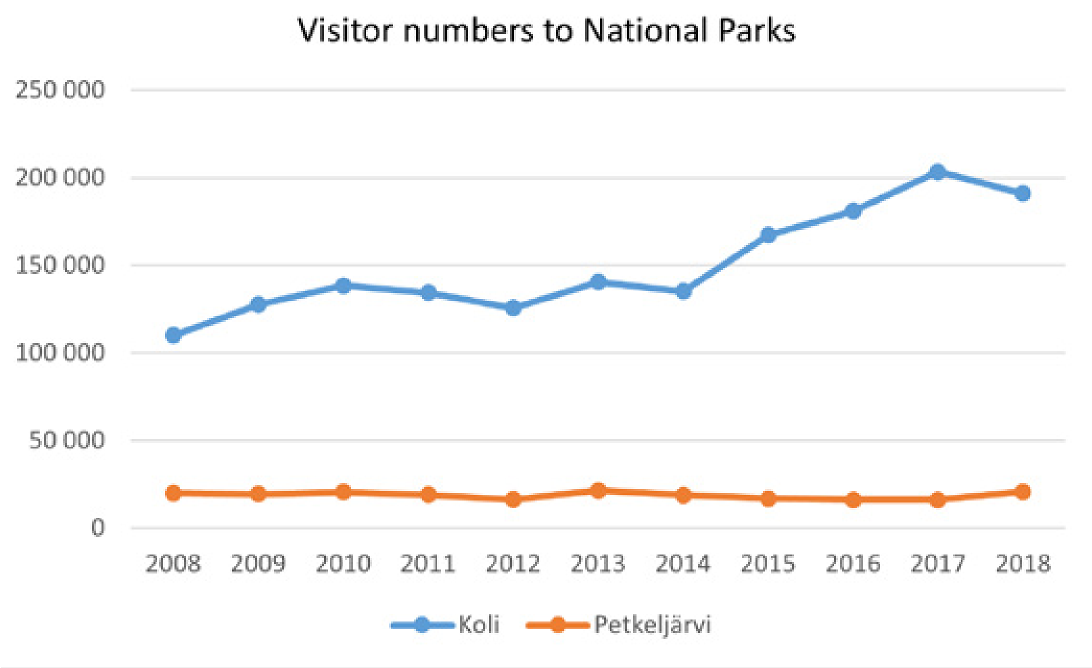


Figure 98. National Parks' visitor numbers in 2008-2018 (Synthesis of Metsähallitus national parks visitor studies in 2008-2018.)

6.1.1. Koli National Park

Koli National Park is located about 70 kilometers north of Joensuu, the capital of the province. The park can be reached by car or by taxi. Other public transport connections to Koli are however problematic. In winter, the ice road over Lake Pielinen to Vuonislahti forms a connection to Lieksa, and in summer, the Suvi Express hydrofoil transports tourists across Pielinen. Car ferry traffic in Pielinen also re-started operating in the summer of 2019.

The park's **80-kilometer-long marked trail** network offers excellent hiking opportunities. Trails suitable for day trips can be found largely in the vicinity of the park. Overnight hikers often head to the southern end of the park, winding a 30-60-kilometer trail in the rugged terrain surrounding Lake Herajärvi. About *6,600 hikers opt for the route every year*. The western part of the Herajärvi trail extends outside the national park and by-passes the city of Joensuu and municipality of Kontiolahti. The park's trail network connects north to the UKK national hiking trail, which continues south through the Kolinpolku trail to Joensuu. Koli NP ski trails are part of Koli's extensive trail network and the park's special features include the skiing slopes within the park. **Wellness, sightseeing, hiking, skiing, and sports** are among other outdoor nature activities, important motives that attract visitors to the destination (Naumanen 2020).

The favourite place for the visitors in the Koli NP is the summit of Ukko-Koli Hill, which is the main site for all landscape admiration activities in the area (Tahvanainen et al. 2009). This scenic point is the highest summit in South Finland, rising 347 meters above sea level and 253 meters above Lake Pielinen (the fourth largest lake in Finland). Since its designation in 1991, visitor numbers to the national park have increased notably, and the visitor impacts are becoming more visible mainly during the peak summer months. In 2019, 201 000 visits were made to the Koli NP (Naumanen 2020).

Statistical analysis shows that the tourist traffic is positively correlated with the waste generation issue, with a sharp increase in the volume and diversity of the solid waste observed during the peak tourist seasons (Chettri 2019). Koli NP is mentioned as one of the most economically significant NPs in the whole country. However, when compared with the rest of the similar classified NPs, it is the smallest in terms of surface area, and hence susceptible to visitor pressures (see Table 20). The plan towards 2050 is to increase tenfold the visitor amount from current numbers (Naumanen 2020).

Table 20. Visitor numbers for the national parks with the highest visitor numbers in 2008-2019 (Synthesis of Metsähallitus National Parks visitor studies in 2008-2019)

No. of visitors (annually)	Pallas-Ylläs (1020km²)	Urho Kekkonen (2 550 km²)	Oulanka (270 km²)	**Koli (30 km²)**
2008	330 000	250 000	-	**110 000**
2009	419 000	289 000	165 500	**127 500**
2010	436 000	287 500	169 000	**138 500**
2011	435 500	277 000	171 500	**134 500**
2012	473 000	300 400	162 400	**125 600**
2013	488 400	292 600	174 600	**140 600**
2014	514 800	288 600	179 600	**135 200**
2015	525 600	291 700	201 200	**167 300**
2016	538 800	295 000	200 600	**181 100**
2017	553 000	334 700	199 000	**203 400**
2018	549 200	340 500	199 500	**190 900**
2019	561 200	367 000	189 300	**201 800**

6.1.2. Petkeljärvi National Park

Petkeljärvi National Park is situated close to the Finnish-Russian border. It features bodies of water and wild ridge scenes. The wild nature of the area is highlighted by the animals that thrive in the park, such as beavers, ravens, and the black-throated diver (the emblem bird of the park). The park's forests have remained untouched by the forest industry, with 150-year-old thick-barked pines as the oldest trees in the park. Species that need dry and warm conditions thrive in the NP. Fen meadows are preserved as a traditional landscape. Soil cover deterioration on ridges in the national park can prove to be a problem; the flora of the dry heath soil is easily damaged when stepped on.

Petkeljärvi Outdoor Centre is located in the middle of the Petkeljärvi NP. It provides visitor information, accommodation, food, sauna, and coffee. There are two circular trails in the national park; the 6.5-kilometer Kuikan Kierros trail leads through varying landscapes up and down ridges, with boardwalks through mires. The ridge formations can be explored by taking the 3.5 km Harjupolku trail. The oldest hiking route in North Karelia, the 31-km-long Taitajan Taival trail, also starts from Lake Petkeljärvi and ends at Mekrijärvi Village (Naumanen 2020).

Apart from hiking, one can also paddle and row in the national park. It is possible to paddle all the way from Petkeljärvi to Lake Koitere and Patvinsuo NP along River Koitajoki, a 200 km long river that meanders back and forth across the borders of Finland and Russia. In 2019, a total of 19,400 visits were made to the Petkeljärvi NP (Naumanen 2020).

6.2. DPSIR for North Karelia Biosphere Reserve

Tourism has been the major focus in a few waste generation rate focused studies (Estay-Ossandon and Mena-Nieto 2018, Mateu-Sbert et al. 2013) and it has been identified as a major factor in other studies (Beigl et al. 2008, Johnson et al. 2017, Oribe-Garcia et al. 2015). Depending on the location, tourism has different effects. Mateu-Sbert et al. (2013) reported that on average a 1% increase in tourist population, causes an overall Municipal Solid Waste (MSW) increase of 0.282%. Estay-Ossandon and Mena-Nieto (2018) report that each additional tourist causes an increase of 1.781 kg/day in the total MSW generation. In some studies, the effect of tourism has been found marginal or secondary to other factors (Lebersorger and Beigl 2011).

In Finland, National Waste Act came into force in 1994. Before that, there was no such problem on the agenda, although some types of waste were somewhat recycled: metal since 1924, paper since 1943, glass since 1978, plastic, cardboard and food waste since 1992, cans and beverage bottles since 1996 (Semnasem 2019). After Finland's accession to the European Union (EU) and the emergence of pan-European legislation, the country lives mainly according to EU rules (Semnasem 2019).

The EU has set waste prevention objectives that oblige member states to deal with the problem. Monitoring MSW generation in member states is a requirement aiming at better knowledge about waste sources, waste quantities, waste generation trends, influencing factors and their impacts (Heilala 2018). At the European level, the term “MSW” is often applied parallel to the basic “Municipal Waste” (EC 2017; EEA 2013). The Finnish Waste Act (646/2011) is more comprehensive in that it classifies MSW as waste generated by households, holiday accommodation, or other housing, as well as the same type of waste generated by administrative, service, and business operations (Sahimaa 2017). In referring to MSW, it must be noted that municipal sewage sludge is not within the scope of this study.

In North Karelia Biosphere Reserve (NKBR) region, the law that applies to waste management is the Waste Act (Finlex, 646/2011, Section 5). According to the Waste Act, waste refers to a substance or object that has been removed, is intended to be disposed of, or is required to be disposed of by the holder (Finlex 2011, Waste Act (Finlex, 646/2011, Section 5). It also clarifies that a substance or object is not waste but a by-product, if it is generated in a production process whose primary purpose is not to produce this substance or object (Waste Act 646/2011, Section 5). The monitoring of the status of protected areas (e.g national parks) is the responsibility of Metsähallitus' nature services. Environments outside the Biosphere Reserve are regulated under defined waste management responsibilities for land and homeowners (residents), second-home owners (e.g. cottages; not used full-time), and for other users (e.g. companies, and visitors exercising public access rights).

6.2.1. Drivers

Driving forces for solid waste in NPs and surrounding areas

Drivers (or driving forces) are natural or human induced factors that cause or can lead to changes in natural environments (Burkhard & Muller 2007). Direct drivers (e.g. human demand for

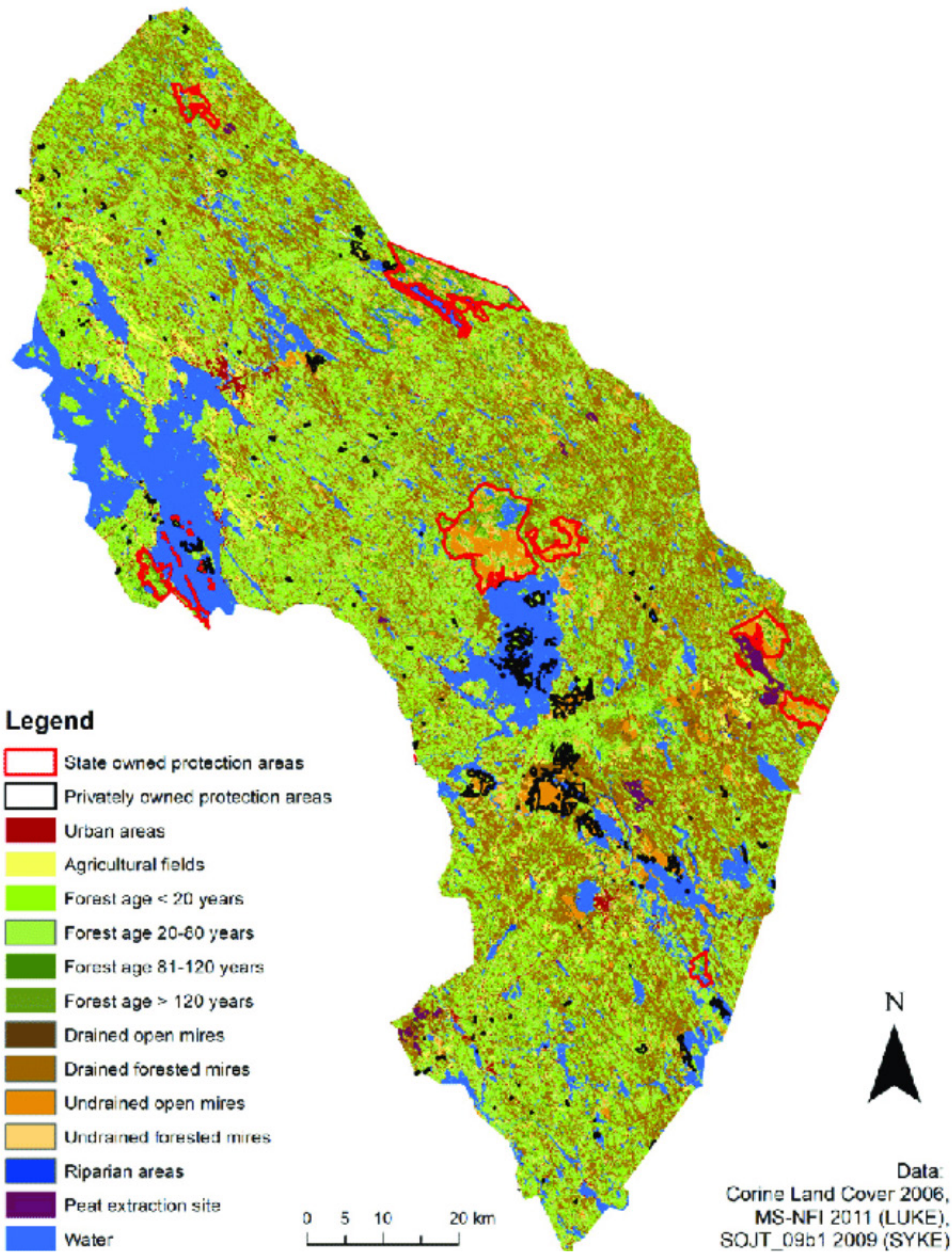


Figure 99. Land-use classes in North Karelia Biosphere Reserve (Wolff et al 2019).

goods and services, good health and social relations, and freedom) have an explicit influence on the environment, while indirect drivers (such as the demographical development, economic and social conditions, the state of the environment, or political situations) act by changing the conditions of one (or more) direct drivers of the system (Burkhard & Muller 2007).

Across the Biosphere Reserve, tourism (e.g. infrastructure developments) and other sectors using same environments for their activities (e.g. forestry, mining, peat production, fig. 99) are drivers for waste (Wolff et al 2019). Residents and second-home owners also use the environments hence are drivers. Tourism service providers (including from outside the region that bring visitors to the Biosphere Reserve), and visitors (due to public access rights) are no exceptions.

Currently, waste management in both Koli and Petkeljärvi NPs includes sorting of different types of waste. However, there are no waste collection bins in the parking areas, along the routes, or at the campfire sites. Visitors are advised pre-travel (via nationalparks.fi website) and upon arrival (via info boards) about responsible hiking principles. Biodegradable waste can be composted in dry toilets and safely combustible (not dangerous waste) can be burnt at the campfires. There are instructions why to take own waste from the hike, where to dispose biowaste and where to bring waste for sorting. The sorted waste is transported, and further processing done at regional designated waste collection and management point. The regional waste management companies are strictly regulated and report to designated local authority about received waste types, amounts and process of handling waste received till landfill (last option).

The waste points both in Koli and Petkeljärvi are strategically located in the main entry and departure points to encourage and maximize waste sorting. For example, the favourite place for the visitors in Koli is the peak of Ukko-Koli Hill, which is the main site of all landscape admiration activities in the area. The visitor centre and waste point are located not far from this scenic point (figure 100).

Outside both national parks but within the Biosphere Reserve, identifying drivers of waste can prove problematic due to the rights of access, and overlapping waste management responsibilities hence a pressure. Companies, residents, and second-home owners have regulations for waste management.

However, for lands outside protected areas but within the Biosphere Reserve (some privately owned), it is challenging to classify waste types and sources e.g. littering and illegal dumping, as the public access rights allow access to anyone living in or visiting North Karelia the freedom to roam the countryside, forage, fish with a line and rod, and enjoy the recreational use of natural areas irrespective of who owns the land. This applies to everyone including domestic and international national park visitors, and companies from outside the province that bring visitors to the biosphere reserve. Even though hiking trails extends outside the national parks, Metsähallitus managed areas are limited to specific areas which makes overlooking waste sources in areas outside their designation a challenge.

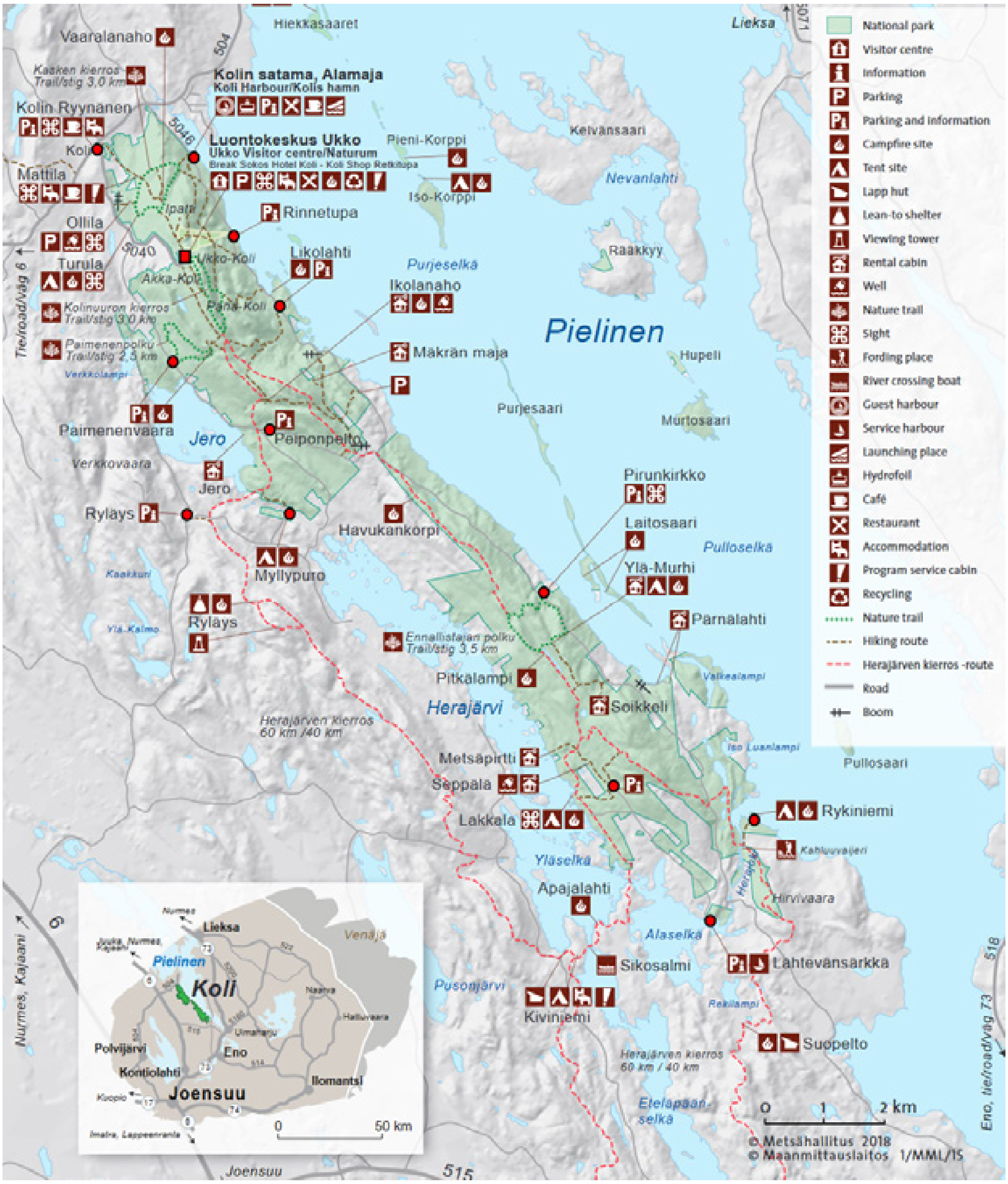


Figure 100. Example of waste management at Koli NP (Red square shows the main waste collection point, while red dots show where areas with information for visitors).

6.2.2. Pressures

Driving forces lead to human activities such as tourism or food production, i.e. result of meeting a need. These human activities can in turn exert pressures (in this case waste) on the environment, as a result of the production or consumption processes, which can be divided into three main types: (i) excessive use of environmental resources, (ii) changes in land use, and (iii) emissions (of chemicals, waste, radiation, noise) to air, water and soil (Kristensen 2014).

Overlapping land-use values by visitors and residents

North Karelia (NK) has over 2000 lakes, about two hundred streams, and a multitude of small waters, ponds, creeks and niches, springs and seeps influenced by ground water (CEDTENK 2014, p.18.) This is particularly apparent in the western part of the province, where the large lakes, as part of Lake-Finland, are marked as important landscapes also for tourism sector. The waterbodies are key assets for nature tourism and are marketed as significant strengths of NK as a nature tourism destination. For example, Lake Pielinen is a key waterway for activities and aesthetic qualities of landscapes across Koli National Park. Their state is therefore important for the aesthetic quality of the landscapes, and in fulfilling the promises marketed to visitors. The lower the human impact on water bodies, the better their ecological state (CEDTENK 2014, p.18).

From Figure 101, it is evident that the mapped values by both visitors and residents are concentrated within national parks, along hiking routes and on waterbodies. In considering the linearity of residents' and visitors uses and values for similar environments (Fig. 101), under the scenario of continued growth in visitor numbers to the area, waste generation inside the national parks and surrounding areas is a potential pressure to maintenance of landscapes and water quality across the key value areas.

Waste impacts on water quality across environments key for tourism

Pielinen's water quality deterioration is currently stated as impacted mainly by regional power plant, agriculture and residents (Ymparisto 2019., CEDTENK 2017). However, in assuming that (a) the values of visitors and local residents to waterbodies stay the same under scenario of continued growth of visitor numbers to Koli and Petkeljärvi NPs, and that (b) on average 1% increase in tourist population, causes an overall Municipal Solid Waste (MSW) increase of 0.282%, the actions of visitors, second home owners and local communities close to Lake Pielinen are potential pressures to the water ecosystems both inside the Koli National Park and surrounding areas. In regard to Petkeljärvi NP, potential pressures are direct impacts to lake Nuorajärvi and Petkeljärvi by visitors in the region, and potential external impacts on Koitajoki River that merges to Lake Nuorajärvi (the river is a cross-border river that flows between borders of Finland and Russia).

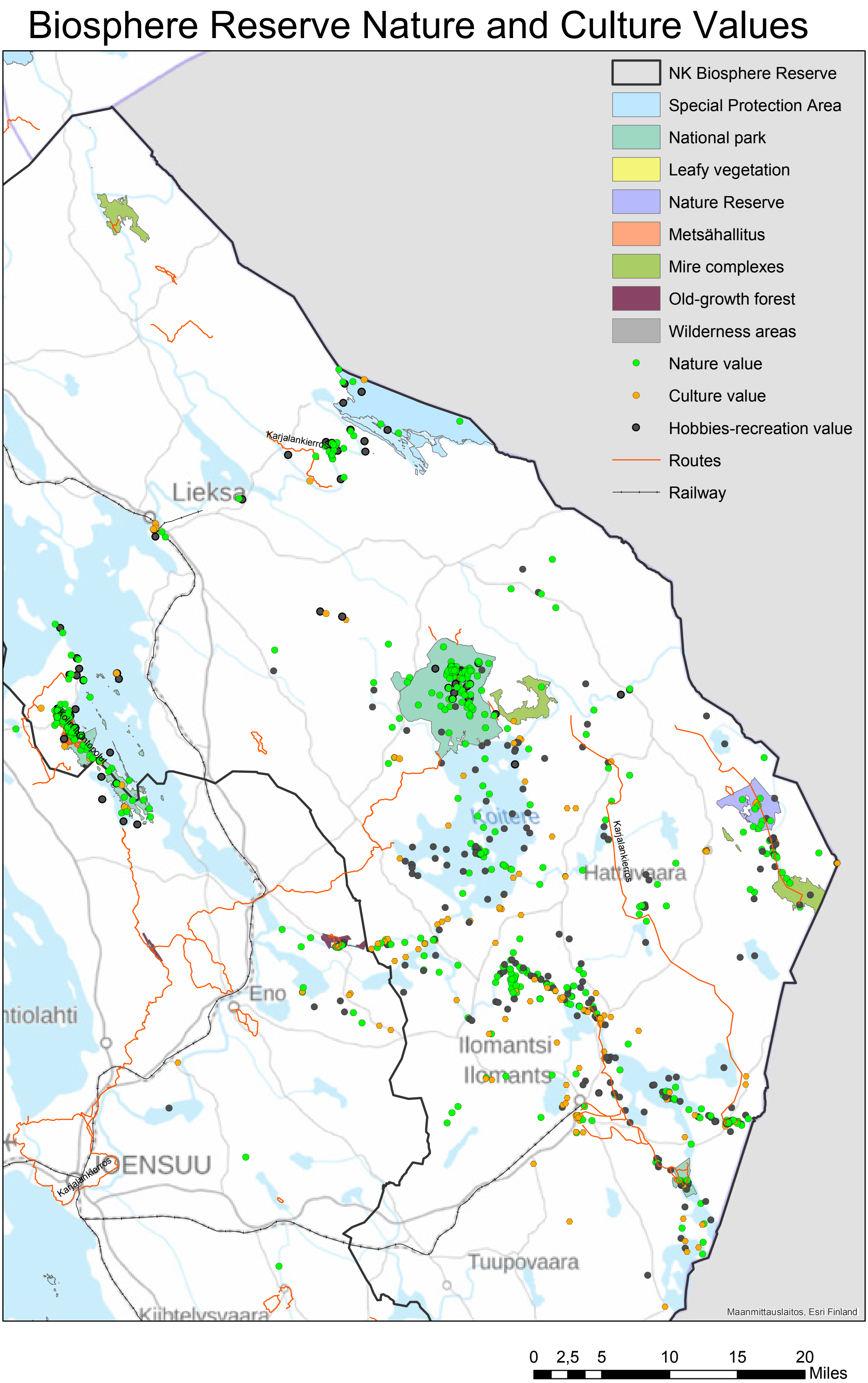


Figure 101. Local vs Visitor land-use values (source: SHAPE NPA/Freshabit life IP ArcGIS map data on land-uses).

Infrastructural and economic developments

Increase in visitor numbers can present the need to update more often the existing infrastructure inside national parks and surrounding areas, or concurrently the need for additional infrastructure or expansions to support increasing numbers of visitors (SHAPE NPA 2019). These tourism industry developments and constructions can inflict environmental harms such as waste pollution, and changes in water systems which concurrently affect the very features that draw the visitors to the region (Borg, Kivi, Partti 2002, p. 45).

SHAPE NPA project research on visitor land-uses and values show that increase in visitor numbers has also presented the need for development of the area to support the growing demand. In the same study, it is evident that three most important values and considerations of tourist groups were (1) destination with scenic beautiful landscapes, (b) unspoilt nature, and (c) overall cleanliness of the destination (SHAPE NPA 2019). Currently, Koli NP attracts approximately 200,000 annual visitors in national park's area of 30km2, and local economic impact of approximately 22M euros. The hope is that by 2050, the area would attract ten times more visitors, meaning 2 million visitors a year (Naumanen 2020). However, in the plan, there is no mention of any changes to size of the Park which currently stands at 30km2.

Constructions and expansions such as tourism infrastructural developments can exert waste pressures on the environments inside National Parks and surrounding areas (Borg, Kivi, Partti 2002, p. 45). Furthermore, if the development of infrastructure is not well thought, problems such as loss of landscape and natural habitats are also possible impacts to be seen (Borg, Kivi, Partti 2002, p. 49.). Therefore, creating a balance between economy (i.e. infrastructural and economic developments within and across environments of Koli and Petkeljärvi NPs) and environmental protection is a potential pressure.

Funding

The financial need for upkeep of most important sites increases with increase in visitor numbers. In addition, active marketing of objects requires that the promises are kept once visitors are at the destinations (in this case in Petkeljärvi and Koli NPs). Deteriorating service equipment is thereby a big brand risk for national nature services and a threat to the development of nature tourism (Metsähallitus 2019a). On the other hand, the state of funding dictates the actions that can be undertaken within the National Parks and surrounding areas. Parks and Wildlife Finland is a part of the state-owned organization Metsähallitus who are tasked with governance of National Parks Finland and Wildlife Service Finland (Metsähallitus 2019b). The services of Parks and Wildlife Finland are largely financed from the national government budget, with part of the funding from works with various partners on projects where the public funding is used to leverage wider funding and benefits (Metsähallitus 2019b). Therefore, the reliability of state of funds and amount of funding is a pressure also for waste management (i.e., ability to employ enough personnel) across the National Parks and surrounding areas (Metsähallitus 2019a).

Climate Change

During the forthcoming decades, the climate in North Karelia Biosphere Reserve (NKBR) is projected to change considerably due to increasing greenhouse gas concentrations (Räisänen & Ylhäisi 2015). Climate models unanimously project mean temperature and annual precipitation to increase (Lehtonen 2017. p.9). Moreover, Climate Change (CC) is stated to have already increased the water temperature of rivers and lakes, and the trend projected to continue. Depending on the climate model and scenario used, the predictions for Finland indicate an increase in precipitation of 5–40% and air temperature increase of 2-7 degrees Celsius by the 2080s (Jylha et. al 2010. p.26).

Under situation of warmer climate scenario, conflicts between maximizing service production and meeting environmental quality objectives e.g., waste management, could be a challenge in NKBR (Silvennoinen, Hokkanen 2018). This is because intensified large-scale disturbances like forest fires, wind thaws/storms and pest outbreaks predicated to occur (Lindner et al 2009). This may lead to changes in runoff as well as in percolation and water quality from the projected intensified erosion and increase in suspended loads (Lindner et al 2009). Likewise, the water quality of lakes and rivers will deteriorate as a result of intensified decomposition of litter and humus caused by extensive canopy openings following disturbances and increased temperatures that lead to leaching of nitrate (Jandl et al. 2008).

Therefore, under the scenario that increase in visitor numbers increases waste generation, CC may impose pressure to waste management methods (e.g., policies) both in the National Park and surrounding areas. Amounts of mixed waste from households (including lack of detailed data on waste sources) is a pressure as these can be difficult waste that then end up in landfill. Most or all the organic waste in landfills decays anaerobically, and most of the carbon is gradually released to the atmosphere, with about half of it as carbon dioxide and half as methane (Ackerman 2000). The latter is the problem: the same amount of carbon has a global warming potential 21 times greater if it is released as methane rather than carbon dioxide.

Illegal dumps are also a potential pressure for NPs and surrounding areas when considering CC projections, because impacts in surrounding areas of the park can concurrently move inside national parks (e.g., by wind, rain, etc.). However, this will depend on how the current Biosphere Reserve Tourism Strategy (Naumanen 2020) will be executed (e.g., infrastructure and awareness to support responsible waste disposal).

6.2.3. State

As a result of pressures, the 'state' of the environment is affected; that is, the quality of the various environmental features (air, water, soil, etc.) in relation to the functions that they fulfil. The state of the environment is thus the combination of the physical, chemical and biological conditions. (Kristensen 2004).

Nature inside National Park areas

One of the most significant threats in protected areas is inappropriate waste management, which relates to the practice of landfilling or combustion of waste. Koli and Petkeljärvi NPs lie within the European Union, and were thereby established in accordance with the provisions of Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds (L 103 EC 25.04.1979, as amended) and Council Directive 92/43 / EEC of 21 May 1992 on the protection of wild fauna and flora (L 206 of 22.07.1992). The national parks constitute a form of nature protection created to maintain biodiversity, resources, creatures and elements of inanimate nature and landscape (Przydatek 2019).

Waste management inside Koli and Petkeljärvi NPs actions are guided by both Waste Act (1072/1993) and Waste Act (646/2011), while activities taking place in the surrounding environments are guided by Waste Act (646/2011) (Finlex 1993). These provisions cover among other, the (a) organization of waste sorting and collection inside National Parks and areas designated to Metsähallitus (the park management authority) (fig. 102), and (b) duty to clean littered area under their designation.

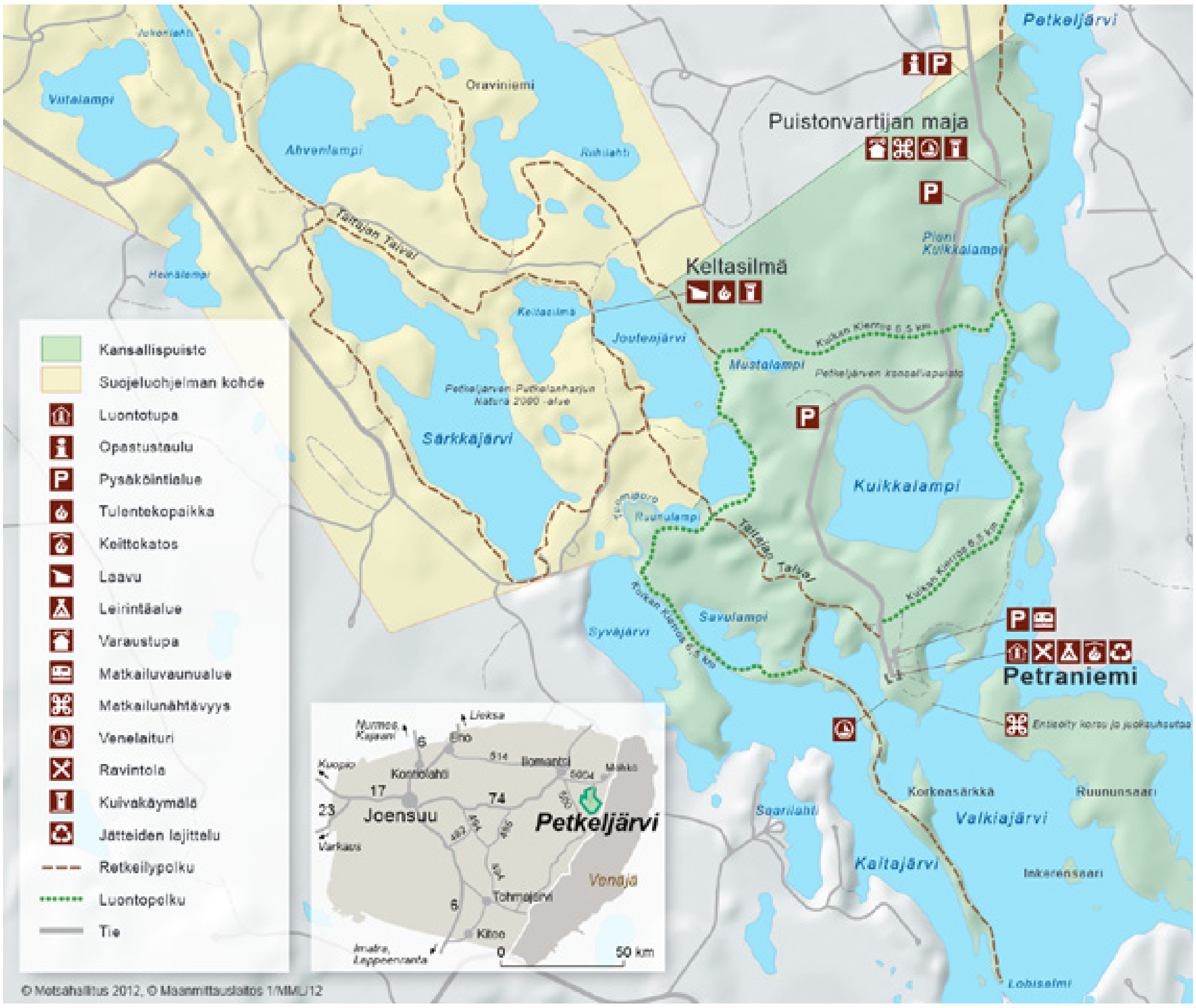


Figure 102. Petkeljarvi National Park recycling point at the heart of the National Park (Source Metsähallitus).

Environmental impacts of nature tourism in the national parks are currently assessed using the LAC (Limits of Acceptable Change) method. The method set limits for acceptable change for the metrics being monitored. A target is also set for each LAC meter selected for monitoring. If the target value has not been reached by the target year, suitable means are sought to achieve or maintain the desired state. The measurement work on sustainable tourism seeks to utilize as much as possible, the information already collected from regions, visitors, and stakeholders (Naumanen 2020).

Visitor data is also collected every five to ten years through continuous visitor count across national parks and the hiking area, and by undertaking of visitor surveys. Even though the visitor profiles of the top nature tourism targets of the Biosphere Reserve vary, the recreational motives have over the years proven rather similar across the biosphere reserve. The main reasons that attract visitors to all these targets are landscapes, experiencing nature and relaxation (Naumanen 2020).

From the SHAPE NPA research on land-use and visitor values, general state of environments according to visitors were collected. The respondents were asked how the values considered by them prior to booking travel, were met while at destination in Lieksa city (where Koli NP is situated). Scenic/beautiful landscapes, unspoilt nature, overall cleanliness of destination, personal safety and security, and diversity of nature attractions were the top five aspects that stood out (Fig. 103).

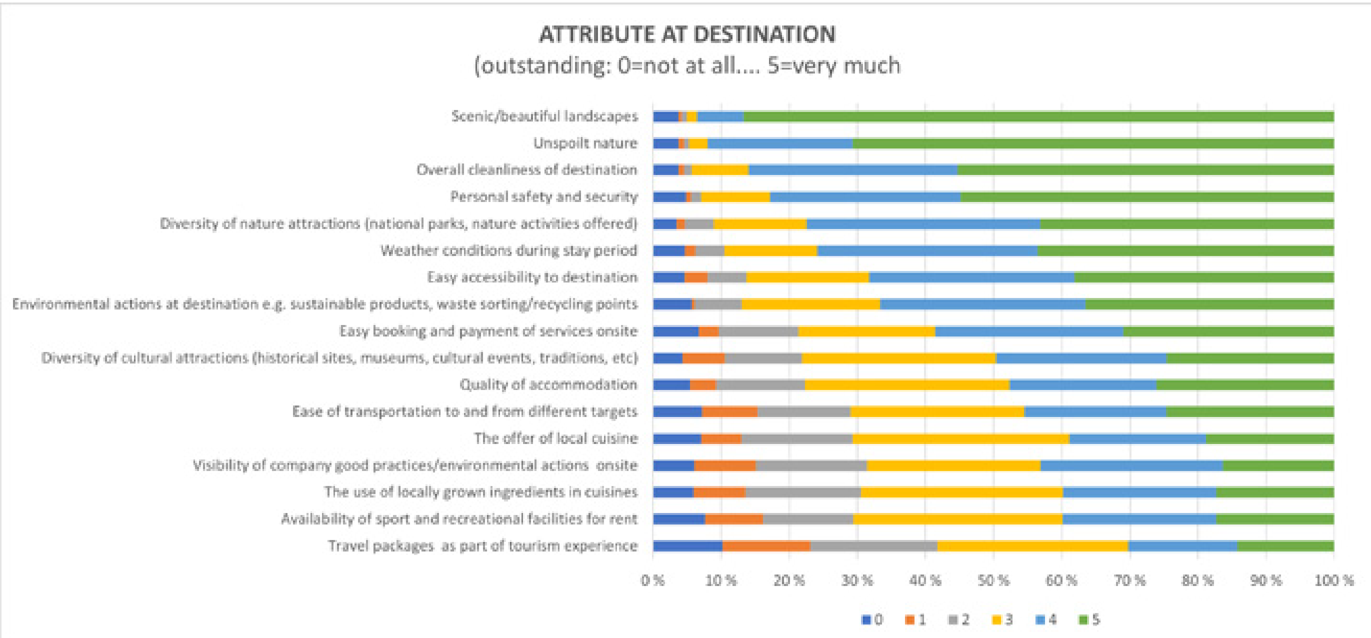


Figure 103. Attributes of North Karelia as a tourist destination (n=663; SHAPE NPA)

Despite the good review, visitors mentioned the info-signs across the National Park were outdated and stop-over areas needing development and frequent clean-up (mainly in peak period). The key issues regarding infrastructure were mainly in connection to Koli NP, with two main ones as information signs "info-signs" and maintenance of the stop-over areas (meaning camping grounds, places of rest, etc within the National Parks). Signs in some areas were considered in bad condition, while current maps as outdated. Some stop-over areas (including the camping area) in Koli were also mentioned as not aesthetically attractive and need improvement.

Under the chapter “pressures”, it has been mentioned that the parks rely on funding and recent funding reductions for the parks may have impacted the frequency by which waste is collected, and ability of securing or adding related facilities for waste management across the sites. Figure 104 shows the key amounts of funding for National Park services by the Ministry of the Environment (the largest source of funding for nature services). The funding is decided by Parliament.

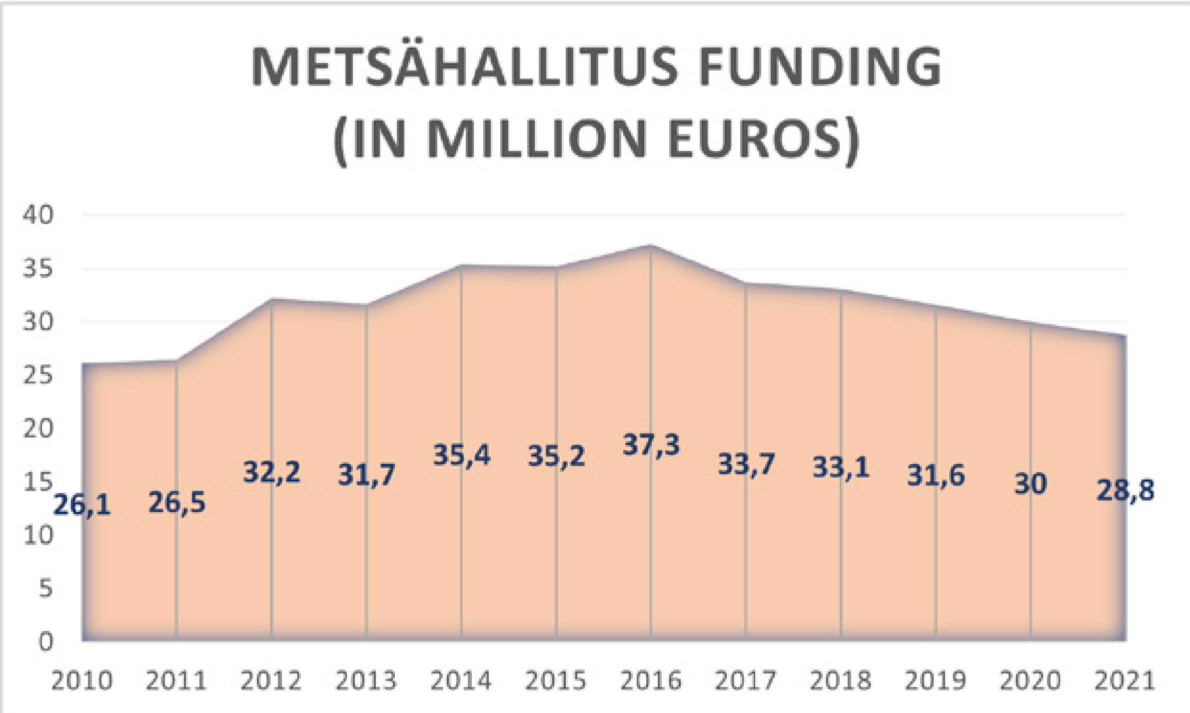


Figure 104. Development of funding for the Ministry of the Environment (Metsähallitus 2019 c.)

Waste management inside NPs and surrounding areas

Waste collection is usually organized and monitored both in NPs and surrounding areas in strict conformity with the Waste Law. In NPs, the waste sorting is strictly regulated, and the organisation of collection is organized by Metsähallitus. In Koli and Petkeljärvi NPs, there are waste sorting facilities, and these are visible already upon entering the National Park (see Figs. 100 and 102).

However, in surrounding areas close to NPs, mixed waste is still rather problematic due to non-motivation of households to waste sorting (see Fig. 105 below). The long distances to sorting sites, and lack of information on how and why to sort waste are stated as key reasons behind the problem (Semnasem 2019). Other reasons for mixed-waste choices is that some waste sorting possibilities are still lacking in smaller towns, and that here is still no permanent solution for the collection of plastic waste e.g. for farms (Silvennoinen et al. 2019). Therefore, there is a need to improve the accessibility of reception sites to enhance waste sorting, which is as described by law, the responsibility of manufacturers, importers, and packers.

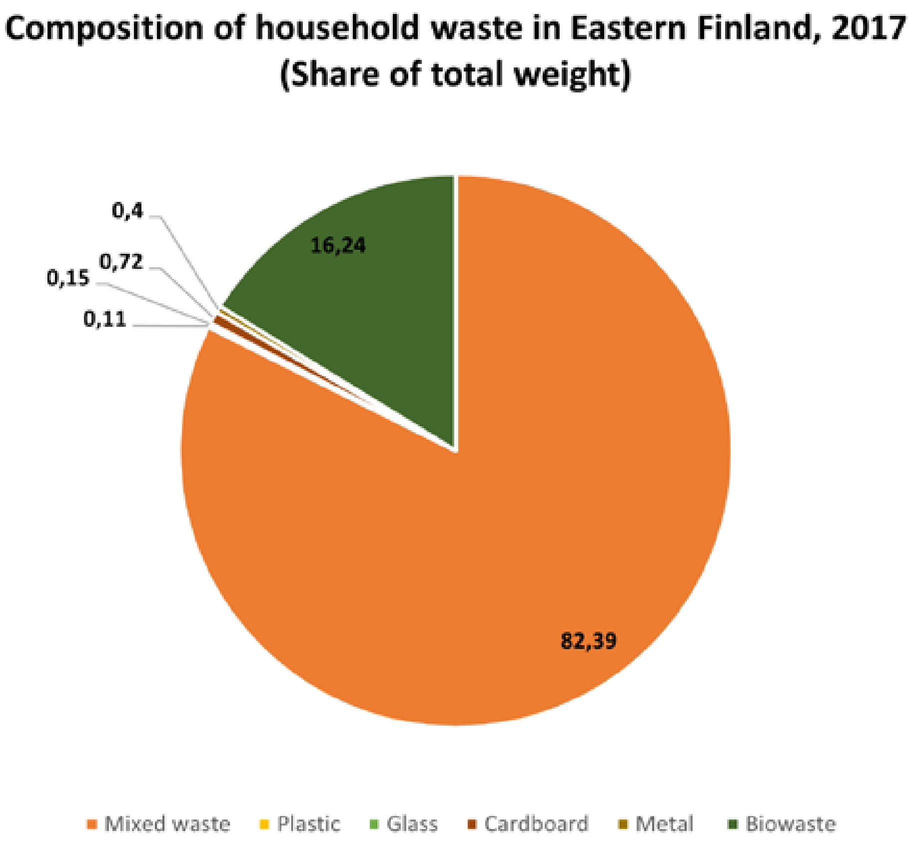


Figure 105: Composition of waste in NK (Jätekukko Oy, in Semnasem 2019)

There is also need for improving awareness through, for example, use of information boards inside NP and surrounding areas. Possible map that can guide the visitors on waste management and locations of waste sorting or bin sites inside national parks, as well as how to handle the waste while inside the NPs mainly for domestic and international visitors (otherwise digging and burning/ burying of mixed waste could be possible impacts to be seen). Waste sorting and sites may be known to residents but same cannot be assumed for other domestic and international visitors. There is need for target awareness on how to act while in the National Park and when in sensitive environments such as the Biosphere Reserve. Metsähallitus has information for visitors, for example, on their websites. Still, there is need of an active role by the service providers organizing trips for visitors within these sensitive environments.

6.2.4. Impacts

Overall, increase in visitor numbers can present the need to update more often the existing infrastructure inside national parks and surrounding areas, or concurrently the need for additional infrastructure or expansions to support increasing numbers of visitors. These tourism industry developments and constructions can in turn inflict environmental harms such as waste pollution, and changes in water systems which concurrently affect the very features that draw the visitors to the region (Borg, Kivi, Partti 2002, p. 45).

Based on the status assessment of all surface waters across North Karelia (NK) completed in September 2013 (see Tab. 21 for levels), the lakes and rivers are mainly in a good or excellent ecological state. The estimates are better than nationwide average. From the analysis, 92 percent of the examined lake area, and 77 percent of the river length are at least in good ecological state (CEDTENK 2014, p.18). For groundwater areas, about 99 percent are in good state i.e., they meet the quality criteria set for domestic water as defined under the Government Decree on Water Resources Management (1040/2006).

Table 21. Criteria for water quality classification for lakes and rivers in North Karelia

Variable	Unit	I	II	III	IV	V
		Excellent	Good	Satisfactory	Passable	Poor
Chlorophyll-a (lakes, rivers)	µg l^{-1}	< 4	<10	<20	20-50	>50
Total phosphorus (lakes, rivers)	µg l-1	< 12	<30	<50	50-100	>100
Transparency	m	> 2.5	1-2.5	<1	-	-
Turbidity	FTU	< 1.5	>1,5	-	-	-
Colour	mg l^{-1} Pt	< 50	50–100 (< 200)[1]	<150	>150	-
Oxygen in surface water	%	80–110	80–110	70–120	40-150	serious problems
Oxygen depletion in hypolimnion	nr in 100 ml	no	no	occasion-ally	frequently	common
Faecal coliforms or streptococci	mg kg^{-1}	<10	<50	<100	<1000	>1000
Hg in carnivorous fish	µg l^{-1}	-	-	-	-	
As, Cr, Pb	µg l^{-1}	-	-	-	<50	>50
Hg	µg l^{-1}	-	-	-	<2	>2
Cd	µg l^{-1}	-	-	-	<5	>5
Total cyanide	µg l^{-1}	-	-	-	<50	>50
Algal blooms		no	occasionally	frequently	common	abundant
Off-flavours in fish		no	no	no	common	common

*1) Humid waters in natural state. Note: Criterion for seas not included in this table.

Koli National Park

Lake Pielinen is an important feature for Koli National Park's landscape quality and tourism. The lake provides environments for water sports, fishing, canoeing, and for other activities and use by those seeking recreation. Therefore, its status and changes require special attention in everyday life. There are other lakes, streams and a multitude of small waters, ponds, creeks and niches, springs and seeps influenced by ground water across NK (CEDTENK 2014, p.18). Joint monitoring and improvement of water quality has been key in assessment and improving of water quality (Fig. 106). Lieksanjoki River that drains into Lake Pielinen, and Lake Pielinen have been observed over a long period of time. The central part of Pielinen has long been involved as a background area in the monitoring of contaminants.

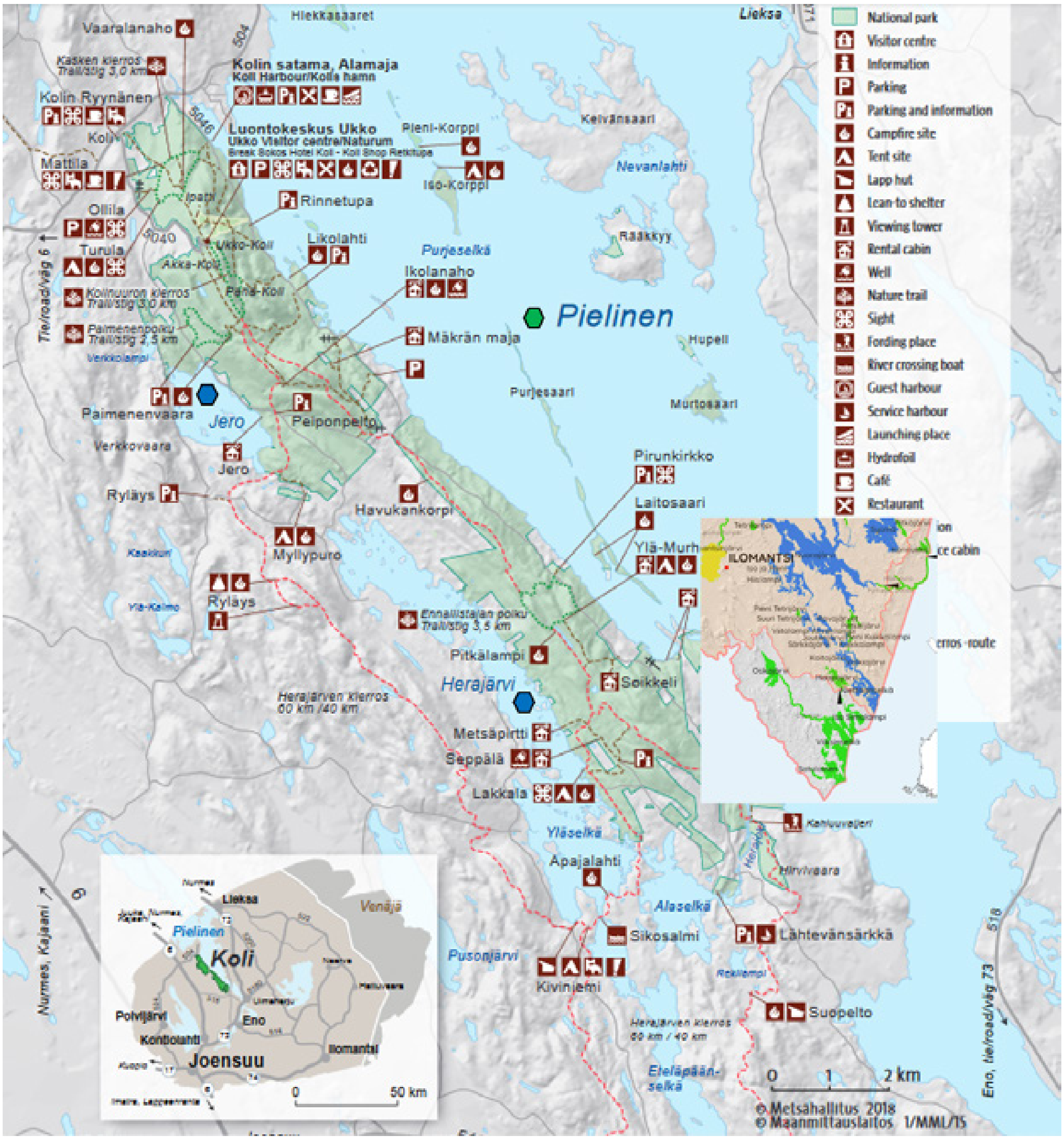


Figure 106. Surface water quality for Koli environments; Blue= excellent, Green=Good (see Tab. 13 for detailed water quality classification)

Due to the peat-dominated waters of Valtimojoki and Saramojoki rivers, the northernmost part of Pielinen is characterized by the humus color of the water (color value 60 mg/I, transparency about 2.7 meters). In the middle part of the lake, the color number is about 50 mg Pt/l, and transparency at 3.3 meters. In the eastern part, the water of Pielinen is darker, the color number is over 70 mg/l and transparency 2.5 meters. As the waters of Pielinen flow towards the southern part of the lake, the humus color of the water is still transparent: the color number is 60 mg/l and visibility depth are slightly less than 3 meters. Nutrient concentrations in Pielinen are currently low, phosphorus is low in backwaters and in the southern part, less than 10 micrograms per liter (Järviwiki 2020., Tab. 13).

There are no problems with oxygen content in Lake Pielinen, although a small natural decrease in oxygen content has been observed when comparing top and bottom layers. The concentrations of total phosphorus and nitrogen are excellent (Ymparisto 2016). A clear downward trend in nitrogen concentrations has been observed since 2006 (Ymparisto 2016). Ground water assessment has also been stated as at least good in all groundwater sites (CEDTENK 2017). The downstream of River Lieksanjoki that drains into Pielinen has been mainly influenced by power plant construction, which has weakened their ecological status (CEDTENK 2014, p.18).

Petkeljärvi National Park

Lake Nuorajärvi and River Koitajoki are examples of important waterbodies that can act as pressure sites for Petkeljärvi National Park (NP) in case of waste pollution. Lake Nuorajärvi and Koitajoki are rated as excellent and good respectively (Mononen et al 2016). The status of the rest are marked on the map (Fig. 107).

Therefore, it can be concluded that solid municipal waste impacts on water quality are rather minimal on the environments within NPs and surrounding areas. Still, potential pressures need not be overlooked e.g. in case of increased influx of visitors to Koli tenfold from current numbers (Naumanen 2020) as key human impacts on Pielinen are stated as from agriculture and residents (CEDTENK 2014, CEDTENK 2017).

Waste impacts on biodiversity inside NPs and surrounding areas

North Karelia Biosphere Reserve (NKBR) includes habitats of endangered species, for example the great crested newt, brown trout, and landlocked salmon populations. An unprecedented growth in NP visitors could possibly impose problems for fragile vegetations with species under Natura 2000 network within NKBR e.g. threat of losing habitats. Presently, about 14% of habitats and 13% of species of European interest have already been assessed to be under pressure because of Climate Change. This proportion is projected to more than double in the near future (EEA 2017 p. 19).

In Petkeljärvi NP, the esker vegetation is considered very fragile since the flora of the dry heath soil easily suffers when it is stepped on. Deterioration of the terrain on the ridges of the National Park could prove to be a problem. The fallen dead pine trees in Petkeljärvi NP are also home to many endangered polypores. The recovery of the damaged forest flora across

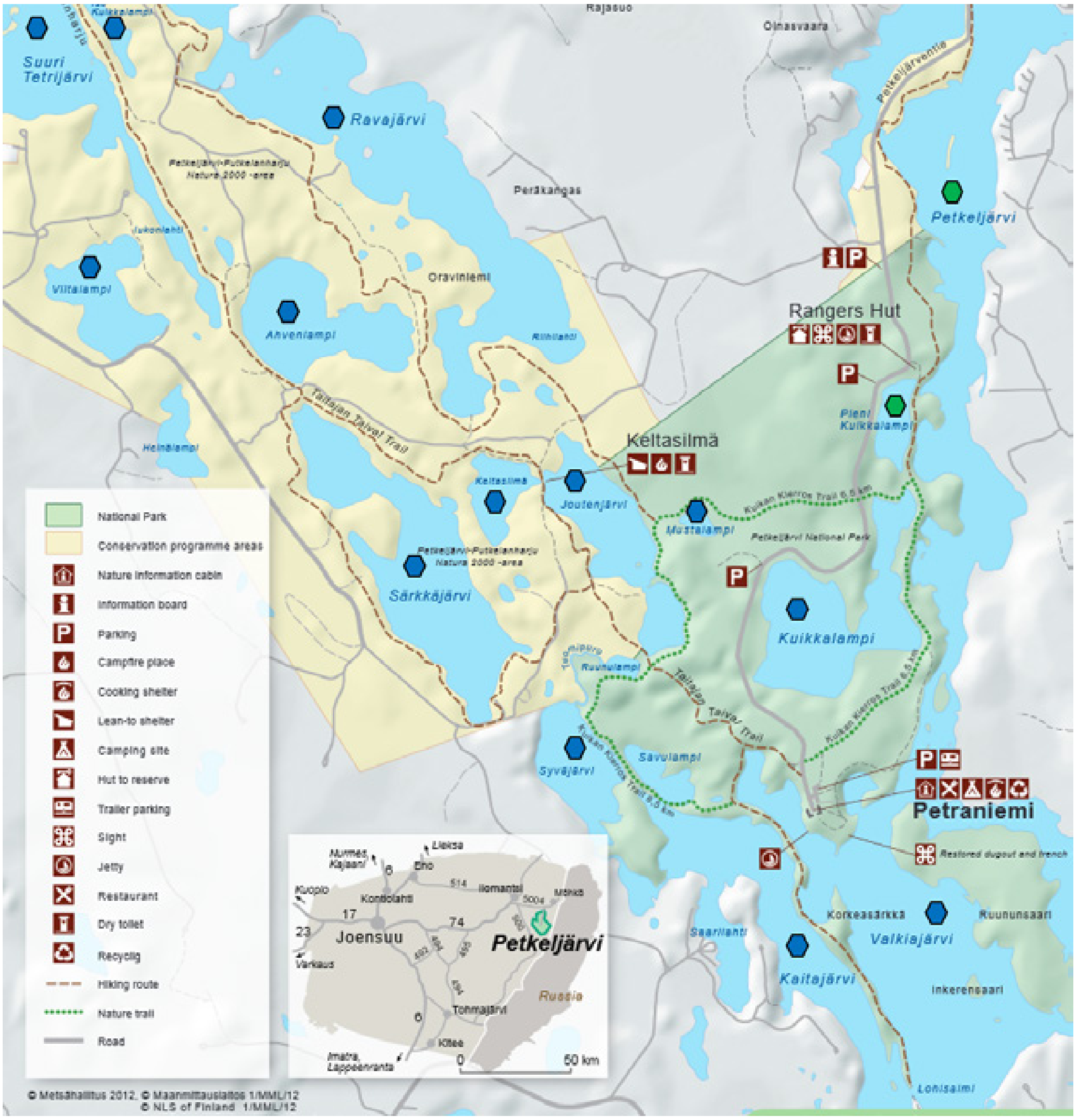


Figure 107. Surface water quality for Petkeljarvi environments; Blue= excellent, Green=Good (see Tab. 13 for detailed water quality classification)

Petkeljärvi is monitored at an old camp site which was in use from 1960–1978. For nature on the ridge to remain as close to the natural state as possible, visitors need to keep to marked trails and existing paths (National Parks 2019). In Koli NP, the threatened bird and plant species are also monitored, and reporting done to the overseeing authority. The plans inside the park must take into consideration the environmental directives drawn for the area (Ymparisto 2019b).

In North Karelia, it is evident that same environments that are valuable for visitors/tourism are also valuable for residents (Figure 108). Therefore, the probability that the value areas mapped may be key waste generation sources is high. These value areas are concentrated within the National Parks (NPs), nature reserves (NRs) and along waterbodies close to the parks. These areas are hence more prone to waste generation e.g. littering.

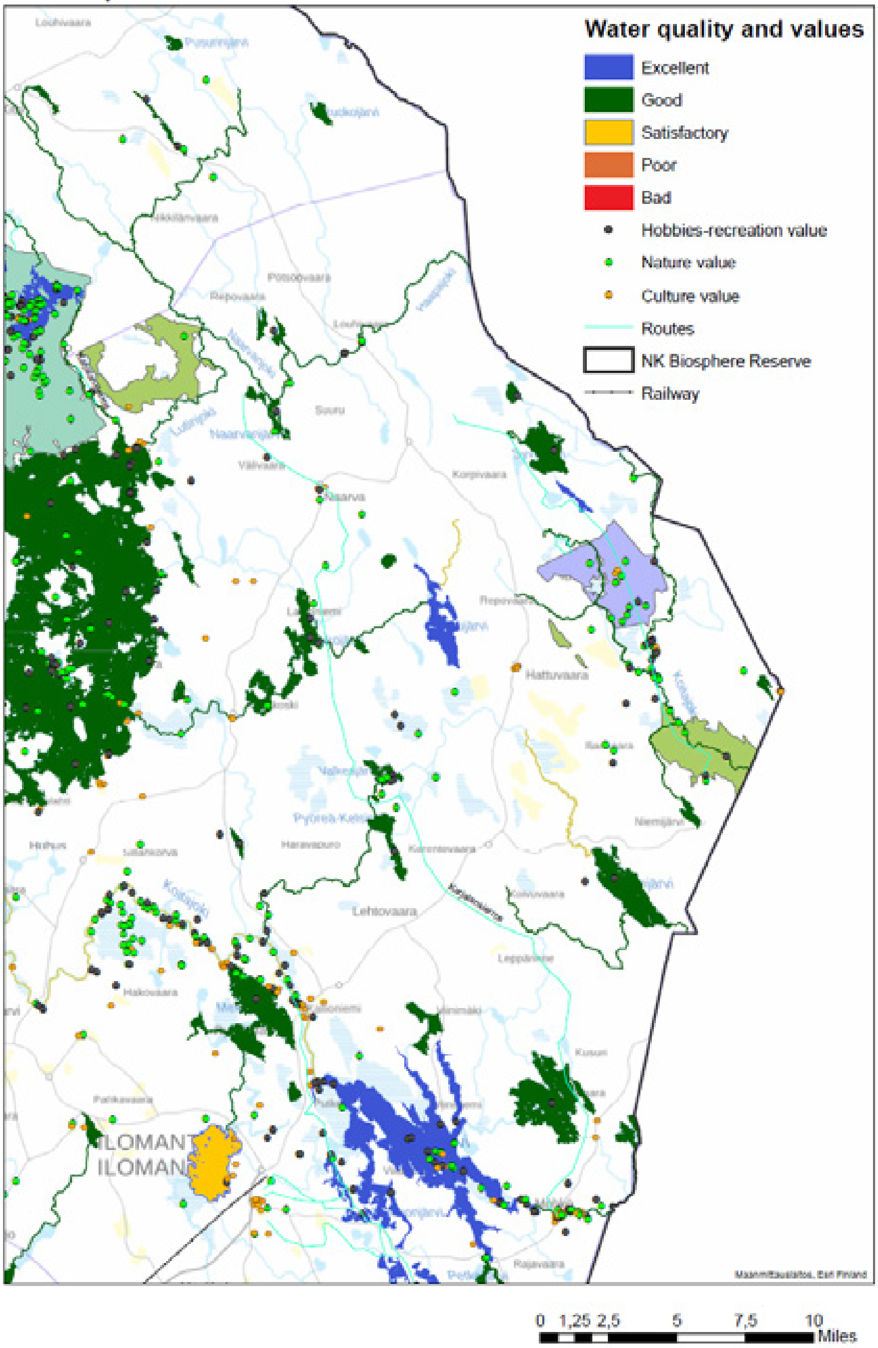


Figure 108. Land-use values as aligned to waterbodies across North Karelia (Blue=Excellent, Red=bad).

6.2.5. Responses

One of the most significant threats in protected areas is inappropriate waste management, which is related with the practice of landfilling or combustion of waste. To decrease the amount of waste generated, the following solutions should be implemented: the development of education to increase the environmental awareness, and planning solutions in accordance with sustainable development (Grzergorz 2019).

Limiting production of single-use containers

In North Karelia, 89% of the population is within the centralised water supply, and 76% on wastewater treatment (Ymparisto 2017). The minimum requirements and recommendations for the quality of drinking water in Finland are defined in the "Finnish Decree Relating to the Quality and Monitoring of Water Intended for Human Consumption on drinking water" issued by the Finnish Ministry of Social Affairs and Health (Finlex 2000). The decree is based on the drinking water directive and concerns all water that is; (1) supplied to be used for human consumption amounting to at least 10 cubic metres a day or for the use of at least 50 people, (2) used for food production undertaking for the manufacture, processing, preservation of substances intended for human consumption, or (3) distributed to be used for human consumption as part of a public or commercial activity like tourism (Mäkinen 2008., Katko et al. 2013).

There is a mandatory regular check and audit monitoring by local health authorities and information delivered every year to the National Public Health Institute of Finland. The measures being to ensure that drinking water, which includes also tap water, is of high quality and hence safe and hygienic to use when compared to the quality requirements and recommendations (Mäkinen 2008, p. 12). For these reasons, visitors in the region are encouraged to drink tap water or refill reusable water bottles (meaning less plastic waste in nature).

For waterways (e.g. lakes and rivers), there is a monitoring system for quality and impacts, and protection measures taken according to case to case situations. Metsähallitus makes public the information on what places one can drink or not drink from. For example, water of Ollila well in Koli is safe to drink without boiling, while Lakkala well, Ikolanaho well, Paimenenvaara well and Ollila draw well are not in use as their water quality is considered poor (National Parks 2020). In Petkeljärvi, visitors are advised to get drinking water from the café-restaurant at the Park, or alternatively boil or filter surface water before drinking as water quality varies from one area to another (National Parks 2020b).

In cases where visitors require bottled water, the locally bought water or soft drink bottles are also strictly regulated through the nation's Waste Act 2011, and pay per return initiative motivates consumers to return to recycling stations the aluminum cans/bottles in shops where the receiving some cents per bottle returned. The bottles are thereafter redistributed back to producers for reuse (see bottle recycling under waste management below).

Bottle recycling

The government plays a key role in waste management by encouraging the use of recyclable containers and discouraging the production of one-way containers. There are two laws in place for this purpose; the first one covers a packaging levy applied on non-refillable one-way containers charged to producers, while the second law exempts refillable and recyclable containers from the first tax law if containers meet the refundable deposit requirements (1037/2004) (Kabugu 2013, p. 23–31). The laws help maximize refilling and recycling of beverages containers over one-time usage (Fig. 109). According to one research, the return rates were 95% for beverage cans, 92% for plastic bottles and 91% for recyclable glass bottles in 2013 (Kabugu 2013, p. 23–31).

Figure 109. Bottle recycling.

The regulation developed by the Ministry of the Environment (MoE) has directives for the operations of parties' maintaining the return system for beverage containers, such as PALPA. These are clarified under the Waste Act of 2011 (Finlex 2011b). Through the Act, the government can still act as a facilitator of the return system by regulating the deposit fees and the other obligations of the parties maintaining the return system. Therefore, if visitors buy bottled beverage, they can recycle bottles in almost all grocery stores and get some cents back for the return while the producers can reuse the bottles. Improvement is still needed as problem with containers (e.g. cans and wine bottles) brought in from outside the country by visitors and residents do not usually meet the refundable deposit requirements hence negatively impacting the efficiency of the return system.

Littering by visitors and residents

The European Union (EU) has set waste prevention objectives which obligate member states to deal with the problem. Monitoring municipal solid waste (MSW) generation in member states is a requirement which aims for better knowledge about waste sources, waste quantities, waste generation trends, influencing factors and their impact.

There is a waste plan prepared for NK province and it defines the targets for waste management; the main goal being to reduce the amount of waste placed in landfill significantly. In addition, energy from combustible material deemed unsuitable for reuse as material is recycled as energy which can in turn be used to replace energy produced by fossil fuels. Depending on the region, majority of bio waste and sludge is treated in biogas plants and used in energy production or refined for use in transportation (Regional Council of North Karelia 2012, p.20).

“Metsähallitus” is designated with managing waste within the parks and hiking areas; this includes Koli and Petkeljärvi NPs. The companies and local residents (including second home-owners residing close to NPs) also bare the responsibility of waste management within their own premises. There is currently no visitor specific waste monitoring except the regulation prohibiting littering. The responsibility of visitors' waste management and sorting at the moment falls mainly upon the tourism service providers, NP and public forest managers (e.g. Metsähallitus when within NPs), and private forest owners (public access rights allows for use of forests but legal obligation to clean waste lies with property owner).

Waste sorting

Tong et. al (2018) suggest that efficient local interactions among various stakeholders are needed in forming the social norm and common space that favor recycling activities at the community level. Waste sorting in North Karelia is generally well-structured (both inside the NPs, and its surrounding communities) with recycling stations for sorting different materials. Common waste stations have bio-waste, clothes, metal, glass, cardboard and paper. There is no sorting fee for returning and sorting the re-usable waste to stations as the packaging fees are usually already included in the product cost.

Close to town centres, the stations are easily accessible and usually close to shops, all with clear guidelines on the containers to ease the recycling process. However, in sparsely populated areas like Koli and Petkeljärvi surrounding communities, the distances to the sorting stations are still a challenge (see chapter on Pressures; waste management inside NPs and surrounding areas). Despite the distances, illegal dumps are not common. Plastic recycling station commenced about summer 2016 in NK and is a rather good addition to waste sorting. For larger home and garden renovation, furniture, electronics and more dangerous waste, there is a larger recycling centre for handling such waste and organized pick up in various regions; jointly owned by municipalities and run by designated waste companies. The actions are overlooked by Centre for Economic Development, Transport and the Environment.

Environmental protection through regulation of waste companies

Unregulated waste disposal is a huge problem across the world since without the right structures and support systems that guide, monitor and regulate actions, waste collection, movement, and handling cannot be verified. The result can be for example illegal dumps, too high fees which then discourage recycling among other. In NK, the companies and persons that undertake the waste collection from consumers (residential areas and companies), or those that receive the waste (waste centres), must apply for, get accepted and be registered as a waste company. The applier must also prove beyond reasonable doubt its intended actions, sphere of activities, and experience.

The waste management company actions are strictly monitored; waste types, sources, amounts and waste management actions from sorting to landfilling (See Finnish law: Environmental and nature protection law 2012; Talentum media Oy, Helsinki 2012, chapter 11, in page 176-178). The prices for waste collection for different types (e.g. bio-waste, mixed waste) are also regulated by law (See Finnish law: Environmental and nature protection law 2012; Talentum media Oy, Helsinki 2012, chapter 9 in page 174-175).

Co-governance

Nature tourism in protected areas hold great economic potential for the region. Well-known conservation and hiking areas are also important for the entire region's image. The Finnish Tourist Board, also using the name "Visit Finland", is a national agency under the Ministry of Employment and the Economy and is designated with actively promoting Finnish tourism. The Board works closely with ministries, travel businesses, transport companies and Finnish regions on cooperation involving research and development (EC 2013, p. 2). There is also a sector manager for tourism who acts as a national tourism expert for all ELY Centres (OECD 2014, p. 165). Other organisations supporting tourism industry in Finland include the Finnish Safety and Chemicals Agency (Tukes) that is concerned with supervision and promotion of consumer safety; "Metsähallitus", designated with managing nature conservation and hiking areas (OECD 2014, p. 165).

At the regional level, various public authorities handle land-use related issues which include waste efficiency and pollution prevention. These are: (1) The Regional State Administrative Agencies which are tasked with legislative and supervisory aspects in the regions, (2) The Centres for Economic Development, Transport and the Environment (ELY) who overlook the regional implementation and development tasks of the state administration, offer advisory, consultancy, financing, and training services for tourism companies' business development, and (3) The Regional Councils as joint municipal authorities, who take care of regional planning and supervise regional interests which include the development of the tourism sector. Furthermore, there are also about 30 regional tourism organisations in Finland that have diverse tasks and ownership structures (EC 2013, p. 2).

The biosphere reserve activities managed by the Ministry of the Environment and the North Karelia Center for Economic Development, Transport and the Environment promotes sustainable development goals. Sustainable nature tourism planning and development in protected and hiking areas is part of the activities of the Biosphere Reserve, done under the coordination of the Biosphere Reserve Steering Committee. Metsähallitus is represented in the steering group of the Biosphere Reserve and takes part in regional projects, where the well-being of the residents is strengthened without compromising on biodiversity.

Metsähallitus' nature services creates conditions for the sustainable recreational use of protected areas by providing a framework and guidelines for visitors, as well as conducive operating conditions for nature tourism companies in the area. Areas and routes maintained by the municipalities, associations and other actors of North Karelia complement the areas managed by Metsähallitus. Extensive cooperation with the authorities and stakeholders as well as joint supervision campaigns have made the supervision more comprehensive and helped strengthen preventive impact (Metsähallitus 2017).

Encouraging networking and cooperation

The Biosphere Reserve has played a significant role in improving awareness of sustainability thinking and networking. The Biosphere Reserve's role is bringing together individuals, community-based organizations, research institutes and corporate organizations in a forum where they can discuss the concept of sustainable development and use this knowledge to encourage and improve the environmental practices within respective fields. The major sectors within NKBR are forestry, tourism, and services. The BR network consists of various private and government institutions, companies and local networks, collectively termed the BR partners. Metsähallitus also has partnerships with companies operating within the protected areas such that they operate within the laid down sustainability principles of the sites.

Policies aiming to influence sustainable development by fostering pro-environmental behaviors may be more effective when considering the cultural participation dimension as a complementary factor (Crociata et. al 2015). The BR has in place national and international collaborations used in instances of research and developments, and networking for example. The idea is that the cooperation partners have own business development plans, and the BR's mission is to help the partners develop those plans in a way that they are economically viable, as well as environmental and socially responsible. This is in form of a joint agreement (BR sustainability partnership agreement) by which the partners hold to specified principles committing to agreed goals and joint efforts towards sustainable development, cooperation, and regional actions, which take into account the specific features of the Biosphere Reserve; meaning also waste minimization and sorting. The BR, using its resources and networks, advices and helps the partners improve actions as needed.

Through the ongoing BR projects, tourism stakeholders from the region and entrepreneurs also get access to funding, e.g. to attend learning journeys and study tours in other tourism destinations and upon return share the knowledge gained within networks or during BR regional workshops and seminars. Project funding are concurrently used in developing the region, for example in updating info-boards which give awareness to visitors on how to act responsibly in the region (e.g. wasteless hiking). These are done in cooperation with BR partners and placed in strategic locations outside national parks (such as stop over areas), and inside national parks (rest points and along the hiking trails).

6.3. Discussion

The growth of nature-based tourism has witnessed an increase in visitor numbers to protected areas, with quality of destination attributes exerting considerable influence over their experience. To allow for sustainable destination management, the rapidly growing visitor demand for nature tourism emphasises the need for more diversified thinking on the visitor growth and potential pressures. Statistical analysis show that tourist inflow positively correlates with the waste generation problem, with a sharp increase in the volume and composition of the solid waste observed during the peak tourist seasons.

From the findings of North Karelia BR, it is evident that the visitor numbers in Petkeljärvi national park (NP) has stayed the same, while Koli NP visitor numbers has doubled since 2008. The growth in Koli NP visitors has similarly resulted in Municipal Solid Waste (MSW) related pressures inside the NP, with visitors suggesting the need for frequent clean-up during peak season, info board updates, and for development of stop-over and camping areas. The impacts on the nature and water ecosystems are presently minimal as waste management inside the NPs are largely under control. Despite that, guiding behaviour of visitors inside the NPs, and regular monitoring of waste points is crucial mainly when considering the plan of increasing visitor numbers to millions come 2050. The latter is difficult to achieve without availability of funds, a problem currently faced by Metsähallitus that is in charge of management of these areas.

Even though the waste is more or else safely disposed and waste management functional across the NPs and within the Biosphere Reserve, mixed waste by households is still a major challenge in the region. MSW management should be focused on minimizing the production of waste and more so reducing the amount of mixed waste. This includes maximizing reuse and recycling of the produced waste also for residents (households). Policies aiming to influence sustainable development by fostering pro-environmental behaviors could be considered as these (such as the bottle return system) has been rather effective. Considerable attention needs to be given to the roles that the residents and visitors can play. Lebersorger et al. state that waste management planning requires reliable data concerning waste generation, influencing factors on waste generation and forecasts of waste quantities based on facts. This is still a problem in North Karelia Biosphere Reserve as the information is rather fragmented within the different waste management companies. The long distances to sorting sites, and lack of information on how and why to sort garbage can also prove hazardous for the areas surrounding national parks, which can in turn move through natural courses inside national parks and hiking areas.

Outside the NPs, results show that visitors and residents land-use values are linearly aligned with these values concentrated along hiking routes and waterbodies. Public access rights also complicate the ability to map waste sources in other zones of the Biosphere Reserve. Residents may to some extent be aware of how to act, and/or know locations of waste points while using the environments. However, resident visitors (meaning domestic tourists not residing in the area) and international visitors may not necessarily possess similar information (e.g. when considering limits of public access rights). The role of the Biosphere Reserve, both as a tool for networking and for awareness is hence important as visitor actions extend also outside the NPs to areas outside Metsähallitus management. The Biosphere Reserve's cross-border and global network could also be utilized in sharing ideas and exchanging experiences on different best practices and solutions other sites are using to manage already existing or potential visitor pressures.

Furthermore, the rise of visitor numbers to Koli NP has also presented the need for additional tourism infrastructure and services to support tourism in the area. This emphasises the need for regional developments to provide appropriate planning, monitoring, evaluation, and management that will contribute towards sustainable tourism consistent with the primary conservation objectives of the protected area studied here.

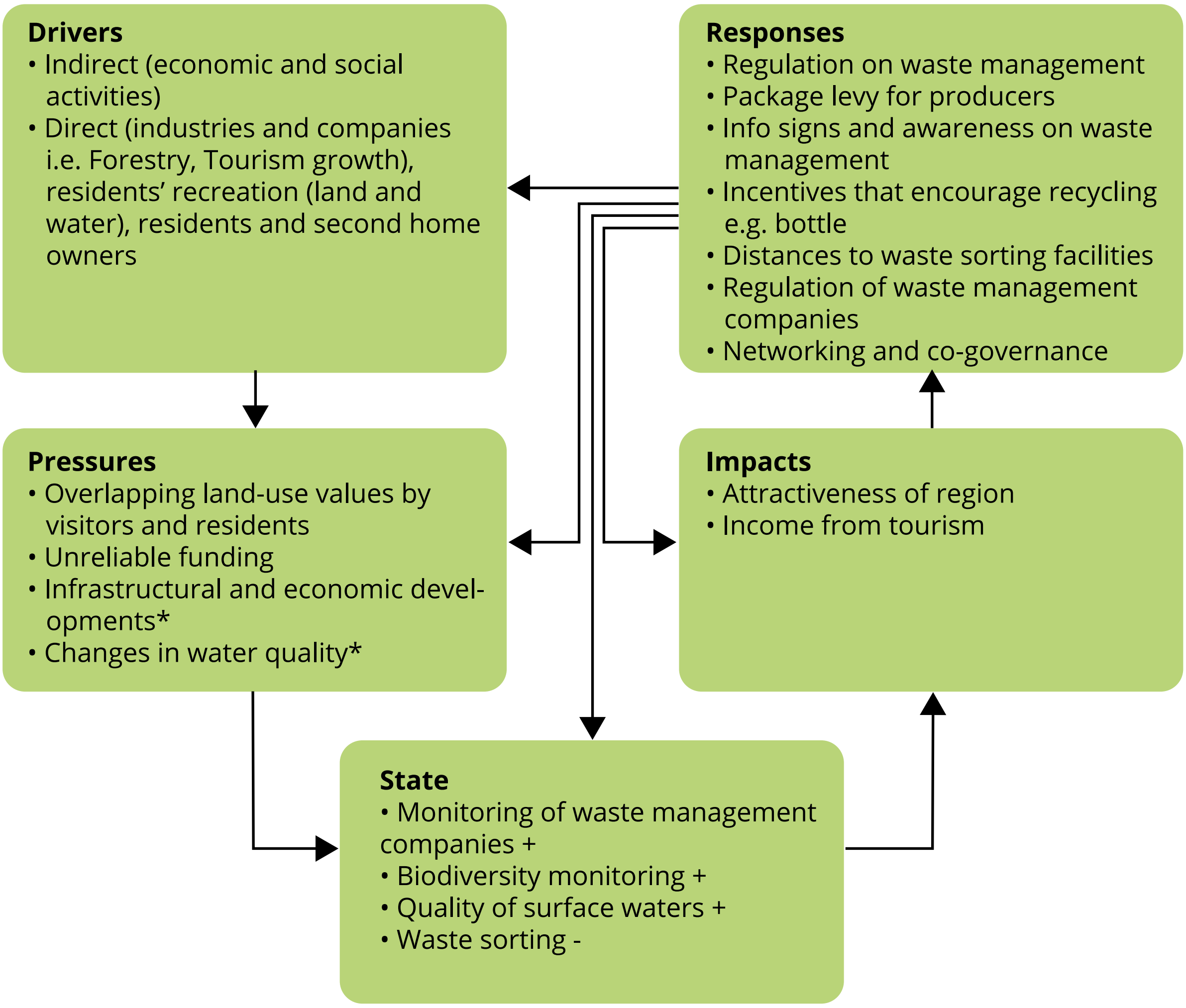


Figure 110. DPSIR for Municipal Solid Waste (MSW) across North Karelia Biosphere Reserve (* refers to potential pressure, + refers to good state, - refer to needing improvement)

Lastly, even though CC is not a pressure in NKBR at the moment, under the scenario that increase in visitor numbers increases waste generation, CC is considered a potential pressure to waste management methods (e.g. policies) both in the National Park (visitor actions while in the NP) and surrounding areas (local community and visitors' actions).

6.4. Conclusions

This study addressed the following: (a) investigated potential drivers for solid waste in Koli and Petkeljärvi NPs and surrounding environments, (b) discussed possible impacts of the drivers on regional tourism image to clarify existing problems and challenges (pressures), (c) examined the current state of environments of Koli and Petkeljärvi NPs and surrounding areas (within the North Karelia Biosphere Reserve) in regard to waste generation, after which it investigated already available actions (responses) for overcoming pressures and enhancing sustainable actions within national parks studied and their surrounding areas. The results of the analyses are synthesised in figure 110.

The results show that the popularity and demand for outdoor recreation has resulted in an increase in number of visitors to NPs within NKBR. However, despite the increase in visitor numbers, there has not been any major environmental Municipal Solid Waste (MSW) impacts across environments studied in this research. The waste management inside the NPs are largely under control, and waste related impacts on the state of environments inside both the national parks and surrounding areas within the NKBR are minimal. However, visitors and residents land-use values are linearly aligned with these values concentrated along hiking routes, waterbodies, and protected areas. The pressure areas present the need for enhancing awareness to both visitors and residents on importance of waste sorting and correct disposal of waste.

Active marketing of objects requires that the promises are kept once visitors are at the destinations. Deteriorating service equipment is a big brand risk for NP tourism, as well as a threat to the development of nature tourism. Moreover, under the scenario of continued growth in visitor numbers and linearity of land-use values by both visitor and residents in the area, considerable attention needs to be given to the roles that residents and visitors can play in reducing MSW impacts and pressures, as well as tools (such as reliable funding) that could help destination managers guide such actions.

7. CONCLUSIONS AND RECOMMENDATIONS

The aim of the SUPER project has been to create such conditions which would improve environmental resilience of the pilot areas both in Russian Federation and Finland despite the different challenges. This report provides detailed information about the environmental side effects of tourism caused by intensive recreational load (i.e., challenges in the waste management, eutrophication of waters, wearing out of the surroundings and vegetation, microplastic pollution, etc.) for each of the pilot areas separately as the status quo and problems are different in every site. The main conclusions and recommendations for each of the four areas are presented briefly in this chapter.

7.1. Russian National parks

The DPSIR (Drivers, Pressures, State, Impacts, Responses) Framework analysis has been conducted for Kizhi and Vodlozero sites. The goal of the DPSIR Framework analysis for these sites was to help local decision makers, inhabitants, and stakeholders understand how different drivers can impact their local economies, and how responses influence the current state of environments and well-being of local population and workers.

Among the main Drivers, or Needs of the Kizhi population and stakeholders, the following were identified: the phenomena of steady growth of tourism and recreational activities (fishing, dacha visits, etc.); based on the growth of quality of life (housing/dachas, transportation, including watercrafts, recreation); together with the growth of individual and business consumption; the growth of small farming and agriculture.

In meeting the main Drivers, the following Pressures, or Human Activities, have been identified: Traffic from intensive one day tourist visits via speedboat (Meteor) from Petrozavodsk and cruise boats with one day tourists traffic from all around Russia (very intensive during the Summer); The 142-194K tourists a year traffic on the main island in 2010-2019 and growing; Growing housing/dachas (incl. construction), automotive, watercrafts, fishing, camping and hiking; The 60 winter and 300 summer inhabitants just in the main island; Waste from individual and business consumption (88 tons transported in 2019, including 2.8 tons of separated waste); Moderate pollution and risk of oil spills, hazardous materials; Small farming and agriculture activities.

The State of the Environment for Kizhi was approximated as: Status of water, groundwater, and drinking water – low-pollution category; Status of soil's REE, heavy metals/HMs, nitrogen, biological pollution (i.e. elevated Phosphorus, risk of eutrophication) – higher counts in some of the sites; Microplastic – higher counts in some of the sites (highest at Kizhi main pier) –

highest measured in the Lake Onega); Status of Kizhi skerries waters) – periodical high levels of Maximum Permissible Concentration/MPC of petroleum products and HMs Bioaccumulation; Ecosystems – adventitious/invasive plant species in some of the sites.

The above-mentioned State(s) can have Impact(s) on the quality of ecosystems and human welfare in Kizhi, i.e.: Attractiveness of region; Income from tourism; Ecological trends and education of the local inhabitants; and Social wellbeing such as Park's staff, dacha residents and local inhabitants.

The following Responses, i.e. comprehensive actions by the society and policy makers, could be recommended: Creation of the Waste and water management improvement plan (supply, utilization, logistics and road conditions); Removal of the old waste sites, closing of the active illegal dumps in the surrounding villages; Enhanced sorting of the domestic and industrial waste, as well as control and monitoring of the of waste waters discharge, dissolvement and treatment; Continued environmental research and monitoring, including REE, heavy metals, nutrients and microplastic in water and soil, as well as biological research; Continued improvement of the environmental tourism infrastructure; Continuation of environmental seminars to the staff and villages; Continuation of environmental volunteers' work on cleaning and removal of illegal waste in the villages; Continuation of work on prevention of pollution and readiness to contain possible environmental risks as oil spills, exposure of hazardous materials, household and forest fires.

Among the main Drivers, or Needs of the Vodlozersky NP population and stakeholders, were identified: the need and phenomena of a controllable growth of tourism and recreation activities in the protected area; (hiking, rafting, fishing, dacha, etc.); based on the growth of quality of life (housing/dachas, transportation, including watercrafts, recreation); together with a controllable growth of individual and business consumption; as well as growth of small farming and agriculture.

In meeting the main Drivers, the following Pressures, or Human Activities, have been identified: Dirt-road with considerable traffic is in 'average' to 'poor' condition in the last 15 km and some impacts of wearing out in several spots of the first 45 km of the dirt-road to Kuganavolok village; Moderate and well controlled watercraft traffic (both transport, recreational and small fishery/ aquaculture production; Moderate and well controlled tourist traffic (6K visits per year); Moderately and well controlled growing of housing/dachas (incl. construction), automotive, watercrafts, fishing, camping, rafting and hiking; The 400 winter and 2000 summer inhabitants in the main village of Kuganavolok and in the Park area; Waste from individual and business consumption (600 cubic meters of mixed waste transported per year, including 0.5 tons of separated waste); Low pollution and risk of oil spills, hazardous materials; Small farming and agriculture activities.

The State of the Environment for Vodlozersky NP was identified as: Status of water, groundwater, and drinking water – low-pollution category; Status of soil's REE, heavy metals/HMs, nitrogen, biological pollution (i.e. elevated phosphorus, risk of eutrophication) – moderate to higher counts in some of the sites; Microplastic –increased counts in some of the sites in internal comparison; Ecosystems - adventitious/invasive plant species in some of the sites.

The above State(s) can have Impact(s) on the quality of ecosystems and human welfare in the Vodlozersky NP, i.e.: Attractiveness of region; Income from tourism; Ecological trends and education of the local inhabitants; and Social wellbeing of Park's residents and a local inhabitants.

The following Responses, i.e. comprehensive actions by the society and policy makers, could be recommended: Creation of the Waste and water management improvement plan (supply, utilization, logistics and road conditions); Removal of and soil remediation of the active illegal dump, surrounding Kuganavolok village; Improved sorting of the domestic and industrial waste, as well as control and monitoring of the of waste waters discharge, dissolvement and treatment; Continued environmental research and monitoring, including REE, heavy metals, nutrients and microplastic in water and soil, as well as biological research; Continued improvement of the environmental tourism infrastructure. Continuation of the environmental seminars to the staff and villages; Continuation of environmental volunteers' work on cleaning and removal of illegal waste in the villages; Continuation of work on prevention of pollution and readiness to contain possible oil spills, exposure of hazardous materials, household and forest fire.

As revealed by soil surveys, soils in the unauthorized municipal solid waste dumps in the study areas belong to the low-pollution category according to the regulation "On the procedure of quantifying damage from land pollution with chemical substances". The following approach can be recommended – to eliminate the dumps, whereas further remediation actions can be proposed after a more thorough additional sanitary-parasitological analysis of the territory. That said, even small-size unauthorized waste dumps are a potential threat to the environment, as well as to humans. More attention should therefore be given to environmental education of local people and tourists, building up awareness among authorities, and establishing the infrastructure for environmentally sustainable management of the sites.

Overall, a well-arranged infrastructure has helped avoid major recreation-induced changes in soil properties and other natural elements. To reduce the detrimental environmental impact of recreation, namely soil damage, the following improvements can be recommended for recreational areas:

1. Build decking in sites for tents to avoid soil compaction and trampling down of the ground cover in campsites.
2. Mark out the paths most popular among tourists, as this will notably reduce the number of alternative paths and thus mitigate overall digression.
3. Put up more information boards in campsites with instructions regarding visitor behavior and nature conservation (waste handling, fire safety, tree protection against damage, etc.).
4. Build temporary access barriers around larger forest patches (1.0×1.0, 3.0×3.0 m, etc.) within campsites, e.g., using colorful caution tapes, to prevent further trampling damage and irreversible disturbance of the forest community. In actively visited campsites, such patches should be fenced out for 1-2 years to give the living ground cover enough time to recover.
5. Eliminate as soon as possible all identified micro-dumps, since they often act as starting points for the dispersal of alien (invasive) vascular plant species, many of which have an aggressive survival strategy.
6. When large source areas of invasive species (such as Himalayan balsam, Canadian pondweed, Sosnowsky's hogweed) are detected in the region, the recommendation is to eradi-

cate them as soon as possible, before massive dispersal has occurred.
7. Regular botanical monitoring of habitats such as dumps, and other ruderal habitats is needed to be able to adequately predict how the situation with invasive species will develop and understand the strategies of their potential future behavior in the republic.

Microplastics (MPs) cannot be removed from the environment with known methods. In order to reduce water bodies' contamination with MPs the following procedures can be recommended:

1. Environmental education to reduce the input of plastic wastes to the environment from locals and tourists.
2. Reducing secondary MPs formation in the environment (degradation of large plastic litter) by means of remediation of illegal dumps and regular shore clean-up actions to remove plastic litter from the environment.
3. Application of the best available water treatment techniques able to remove particulate matter from effluents to reduce the input of primary MPs to the water environment or at least, maintaining the performance of local waterworks at the designed standard. Reducing the use of MP-containing cosmetics, facial cleansers, toothpaste, etc. Reducing direct untreated domestic wastewater discharges to water bodies.

The most pressing waste-related problems in both protected areas seem to be illegal dumping of waste and insufficient waste management systems. In addition, challenges are caused by the waste load due to rather heavy tourism. Moreover, infrastructures of the areas are not on the adequate level to maintain sufficient and sustainable waste management system.

When considering the well-functioning and more sustainable waste management in parks, the issue of major concern is infrastructure and logistics improvement in the areas. For instance, Kizhi could benefit from better shipping arrangements for the waste transportation – investments in water transport could help to improve waste management not only on the island, but also in the protective zone. Vodlozersky National Park could also benefit from arranging transportation across Lake Vodlozero.

To find out the best solution for waste transportation and management in the areas, the detailed and careful studies should be done, and amount of waste and waste fractions need to be solved for the proper planning and sizing of the more sustainable waste management system. In the future, there is a need for projects which would monitor, control and reduce the current amount of waste generated by tourism in Russian areas and provide additional recommendations for the waste management improvement.

This report, as well two-year joint project work, leads the way and recommends a comprehensive engagement of best international practices and modern solutions for collecting, sorting, transporting, recycling and discharging the waste in the national parks, including other specific recommendations to each park. The authors of this report are confident that information exchange and continuous joint monitoring of the ecological situation, including the waste and water management, across the border is highly needed in order to mitigate the existing risk of environmental degradation in the national parks, as well as to improve environmental resilience and well-being of people living, working and visiting these marvels of the nature.

7.2. Finnish National parks

The Rokua case site example showed how DPSIR approach (edited from the conducted Multicriteria decision analysis) can clarify the connections between different aspects of a groundwater area and how it is managed. The connections between lake ecosystems, groundwater and land use can be shown in an orderly fashion that can contribute to discussions between experts, stakeholders, locals and regional authorities.

Modelling is a powerful tool to analyze different management scenarios for groundwaters and dependent ecosystems such as lakes. The key part of the modelling process is the conceptualization of case site and the studied hydrogeological dynamics. This helps to plan where to monitor the studied system for most valuable data. It is a key step to build a functioning model where the key dynamics of the system are represented in needed detail.

For the Rokua case, which will possibly have less severe dry periods in the future, extensive drainage restoration by completely filling significant amount of ditches of the whole protection zone could be seen currently as a too oversized, uncertain and expensive measure compared to the benefits. Even though there was acceptability of the measures, the effects from the lowest water levels were with economic impacts to tourism were temporary during the dry periods. A smaller, sub-catchment scale pilot test of ditch filling would improve our knowledge on the effectiveness of ditch filling restoration method. Further, the groundwater modeling approach used in Rokua would be interesting to conduct for a smaller aquifer, of a recharge area less than 5 km2. The impacts of peatland ditches for a smaller aquifer might differ with scale.

The North Karelia Biosphere Reserve results show that despite the increasing rise of popularity and demand for outdoor recreation and increased number of visitors to NPs within NKBR, there has not been any major environmental impacts regarding MSW across environments. Waste management inside the NPs are largely under control, and waste related impacts on the state of environments both inside the national parks and surrounding areas within the Biosphere Reserve are minimal. However, visitors and residents land-use values are linearly aligned with these values concentrated along hiking routes, waterbodies, and protected areas. Active marketing of the region as clean nature also requires that the promises are kept once visitors are at the destinations. These pressure areas present the need for enhancing awareness to both visitors and residents on importance of waste sorting and correct disposal of waste.

Moreover, under the scenario of continued growth in visitor numbers, ongoing tourism plans, and linearity of land-use values by both visitor and residents in the area, considerable attention needs to be given to the roles that residents and visitors can play, as well as tools (such as reliable funding) that could help destination managers guide such actions.

Results reveal the need of cross-border collaboration as a way of exchanging information and ideas, experiences and best practices regarding MSW management across protected area.

Photo by Pekka Rossi

КРАТКОЕ СОДЕРЖАНИЕ

Этот отчет является неотъемлемой частью проекта «Устойчивость под давлением: способность окружающей среды объектов природного и культурного наследия противостоять высокой рекреационной нагрузке» (KA5033-SUPER) Программы ППС Карелия, финансируемой Европейским Союзом, Россией и Финляндией. Работы по проекту проводились в период с октября 2018 г. по январь 2021 г. с целью создания условий для повышения экологической устойчивости уникальных объектов природного и культурного наследия, находящихся на таежных территориях Карелии и Финляндии: 1) Государственного музея-заповедника «Кижи» и его охранной зоны, где расположено более 20 деревень (объект наследия ЮНЕСКО); 2) национального парка «Водлозерский», включая деревню Куганаволок (Биосферный заповедник ЮНЕСКО); 3) Биосферного заповедника «Северная Карелия» (БЗСК) около российской границы в Финляндии (Биосферный заповедник ЮНЕСКО); 4) Геопарка «Рокуа», расположенного в 100 км от г. Оулу в регионе Оулу и Каяани (геопарк ЮНЕСКО).

Основная идея проекта SUPER заключалась в решении вопросов слабой или неопределенной экологической устойчивости выбранных целевых территорий. Их посещает множество туристов, и им сложно справляться с побочными эффектами туризма и других антропогенных воздействий (среди проблем: отходы, нарушение природной среды и растительности, загрязнение, эвтрофикация водоемов и т. д.).

В данном отчете представлено комплексное исследование территорий на примере четырех национальных парков и заповедников ЮНЕСКО в России и Финляндии, проведенное группой международных исследователей-экологов при участии специалистов из семи организаций, работающих в приграничном регионе: 1) Ассоциация «Центр по проблемам Севера, Арктики и приграничного сотрудничества» («Север-Центр», Ведущий партнер); 2) Государственный историко-архитектурный и этнографический музей-заповедник «Кижи»; 3) Карельский научный центр Российской академии наук (КарНЦ РАН); 4) Национальный парк «Водлозерский»; 5) Отдел водных ресурсов, энергетики и охраны окружающей среды Университета Оулу (UOulu); 6) Лесная служба Финляндии Metsähallitus, Национальные парки Финляндии; 7) Центр экономического развития, транспорта и окружающей среды Северной Карелии. Для создания отчета использовались несколько методов исследования, включая полевые работы, анализ проб, моделирование и обработка собранных данных методом «Структура DPSIR» (подробнее в главе 2).

Модель DPSIR (движущие силы, нагрузки, состояние, воздействие, реагирование) представляет собой структуру для описания причинно-следственных связей при взаимодействии между обществом и окружающей средой, принятую Европейским агентством по окружающей среде, в которой: Движущие силы - это индивидуальные, социальные, экономические, производственные и государственные потребности роста и развития; Нагрузки - это деятельность человека по удовлетворению этих потребностей (Движущих сил); Состояние - это состояние окружающей среды (физические, химические и биологические условия) вследствие Нагрузок; Воздействие - это качество экосистемы и благополучие населения, определяемые Состоянием; Реагирование - это комплексные действия общества и власти в ответ на нежелательные Воздействия. Цель DPSIR-анализа - помочь местным руководителям, населению и заинтересованным сторонам понять, как различные движущие силы могут, например, влиять на местную экономику, и как меры реагирования влияют на текущее состояние окружающей среды. Он также помогает руководителям определить проблемные сферы и разработать соответствующие планы по решению проблем.

Для российских объектов – парка «Водлозерский» и музея-заповедника «Кижи», структура DPSIR актуализировалась в ходе полевых работ и исследований, проводимых специалистами из Университета Оулу (UOulu) и Карельского научного центра Российской академии наук (КарНЦ РАН) при поддержке сотрудников национального парка и музея-заповедника. Исследователи из UOulu сосредоточились на общем концептуальном гидрогеологическом анализе свалок. Исследователи из КарНЦ РАН изучали почвы, гидрологию, загрязнение микропластиком и биологию растений (растительный покров) этих участков. В Кижском музее-заповеднике и Водлозерском парке исследовались территории свалок, а в Водлозере предметом экологического и почвенного анализа стали также подвергающиеся вытаптыванию туристические стоянки.

В частности, проведены исследования почв на стихийных свалках у деревень в районе Кижских шхер, а также на крупнейшей несанкционированной свалке у деревни Куганаволок в Водлозерском национальном парке. С каждого обследованного участка отбирались пробы почв и определялось содержание тяжелых металлов, как один из важнейших показателей негативного воздействия свалки на почву. Кроме того, контролировался температурный режим, проводились санитарно-бактериологические исследования и определялась кислотность почв.

Исследования показали, что почвы на территории свалок по сравнению с фоновыми почвами контроля характеризуются повышенными значениями pH, то есть происходит снижение кислотности. Загрязнение почв свалок зависит от состава мусора. Небольшие свалки, главным компонентом которых являлись стеклянные и пластиковые бутылки, представляют меньшую опасность, так как не являются источниками загрязнения тяжелыми металлами и изменения санитарно-гигиенических показателей. В то же время, на свалках, где было найдено большое количество консервных банок, гвоздей, пружин и прочего мусора, содержащего черный и цветной металл, обнаружено повышенное содержание ряда элементов – цинка, меди и мышьяка. Наиболее крупная свалка на территории Кижских шхер (в д. Сенная Губа) является серьезным источником загрязнения почв тяжелыми металлами. Здесь обнаружено высокое содержание меди, кадмия, цинка, сурьмы, олова и других тяжелых металлов.

Поверхностный слой почв на территории крупной нефункционирующей свалки возле деревни Куганаволок в Водлозерском парке характеризуется высоким содержанием цинка и свинца по отношению к российским нормативам. Выявлено также превышение предельно допустимых концентраций олова и сурьмы. Санитарно-бактериологические исследования показали, что число энтерококков в почве в 1000 раз выше нормы, а индекс БГКП (бактерии группы кишечной палочки) находится на границе допустимых значений.

Также, на территории Водлозерского парка в местах наиболее популярных туристских стоянок исследовали влияние рекреации на физические и водные свойства почв. Выявлено, что происходит изменение этих показателей в зависимости от интенсивности вытаптывания – уменьшается содержание свободной влаги в почве, происходит незначительное уплотнение ее верхних слоев, что оказывает негативное влияние на снабжение корней деревьев влагой и питательными веществами.

Температурный режим почв свалок значительно отличается от контроля. Это, в первую очередь, связано с изменением характера напочвенного покрова, отсутствие которого способствует прогреванию почвы на свалках. Наибольшие повышения температуры
характерны для верхнего слоя почв, а в нижележащих горизонтах выявленная тенденция сохраняется, но изменения менее значительные.

В рамках проекта SUPER были проведены исследования растительного покрова туристических стоянок и свалок в национальном парке «Водлозерский» и архипелаге Кижи.

Оценка состояния живого напочвенного покрова (ЖНП) туристических стоянок (НП «Водлозерский») показала, что их флора по видовому разнообразию резко отличается от естественных ненарушенных лесных выделов и богаче в 5,4–7,6 раз. Наряду с сохранением разнообразия большинства типичных лесных видов, флора стоянок постоянно обогащается за счет внедрения широко распространенных в регионе луговых и сорных элементов.

На каждой стоянке есть зоны с сильной, средней и слабой степенью вытаптывания. Площадь и характер нарушений зависят от наличия, расположения и количества объектов инфраструктуры (костровище, беседки, хозпостройки и др.) внутри площадок, а также транспортной доступности стоянок.

В зонах сильного вытаптывания растительные сообщества трансформированы однотипно: лесная подстилка разрушена, почвы выбиты до минерального горизонта, корни деревьев оголены, травяно-кустарничковый и мохово-лишайниковый ярусы представлены единично встречающимися видами, устойчивыми к антропогенным нагрузкам. Нарушения такой степени носят локальный характер и не распространяются за пределы стоянок, т.к. области вытаптывания регламентированы грамотной расстановкой элементов быта. Участки с сильным (тотальным) вытаптыванием живого напочвенного покрова занимают около 30-35% от площади стоянок.

В зоне средней степени вытаптывания живой напочвенный покров фрагментарен, куртины растительности сохраняют черты фитоценоза, в пределах которого расположена стоянка. Главными доминантами остаются лесные виды (черника, брусника, луговик извилистый и др.). Данная зона занимает от 50 до 70% и отличается от двух других повышенным уровнем видового разнообразия за счет появления сорных и луговых видов. Напочвенный покров в таких зонах может существенно отличаться на разных стоянках в зависимости от условий места произрастания и возможностей заноса диаспор чужеродных конкретному лесному сообществу видов.

Зоны слабого вытаптывания на стоянках занимают 10-25% от всей площади и расположены, как правило, по периметру участков. Живой напочвенный покров нарушен только в пределах троп; площадь вытоптанной поверхности 10-15%. При сохранении существующих режима и интенсивности использования, площадь нарушенных участков в пределах туристических стоянок существенно увеличиваться не будет. Дальнейшие изменения, вероятно, будут связаны с заносом аборигенных луговых и адвентивных видов.

Флора свалок Водлозерского НП и Кижского архипелага отличается существенно бо́льшим (в 2-8 раз) разнообразием по сравнению с флорой окружающих их ненарушенных лесных сообществ. Закономерно выше число видов на самых крупных свалках (Куганаволок, Сенная Губа), тогда как на микросвалках, удаленных от населенных пунктов, число видов в 2-3 раза ниже.

На всех свалках в составе флоры преобладают аборигенные виды, при этом доля чужеродных (заносных) видов может быть в 3-6 раз ниже, что зависит от размеров свалки, состава и количества мусора. Растительные сообщества свалок сформированы, преимущественно, бореальными (таежными) луговыми и лесными видами. Значительную группу (около ¼ всех видов) составляют пионерные виды (рудеральные, сорные). Постоянными спутниками свалок являются «беглецы из культуры» – декоративные и пищевые виды растений, популярные у населения на приусадебных участках (укроп пахучий, картофель клубненосный, лук репчатый и др.). На свалках отмечены четыре инвазивных для Карелии вида: бузина обыкновенная, кипрей железистостебельный, недотрога железконосная, яблоня домашняя.

Изучено содержание микропластика в донных осадках водных объектов особо охраняемых природных территорий - национального парка «Водлозерский» (оз. Водлозеро) и музея-заповедника «Кижи» (Кижские шхеры Онежского озера). Всего отобрано и обработано 9 проб донных отложений. Во всех пробах был обнаружен микропластик. В Кижских шхерах его среднее содержание составило 3413 ± 1965 шт./кг сухого веса осадка, что несколько выше, чем ранее было определено для Петрозаводской губы и открытой части Онежского озера. Максимальное содержание микропластика обнаружено рядом с главным пассажирским причалом музея-заповедника «Кижи». Среднее содержание микропластика в донных осадках оз. Водлозеро составило 1506 ± 845 шт./кг. Повышенное содержание микропластика в донных осадках особо охраняемых природных территорий, видимо, связано с его поступлением со сточными водами и разрушением крупных пластиковых объектов в береговой зоне и на неорганизованных свалках, с последующим поступлением вторичного микропластика в водные объекты с поверхностным стоком.

Таким образом, наиболее актуальными проблемами, связанными с отходами, на обеих территориях ("Водлозерский" и "Кижи"), являются незаконное складирование отходов и недостаточно эффективная система обращения с отходами. Кроме того, проблемы с отходами возникают из-за значительного потока туристов, растущего числа дачных хозяйств, любительского рыболовства (а также, отчасти, промышленного рыболовства в Водлозере), а также недостаточной и, что важно, устаревшей системы обращения с отходами. При этом, уровень развития инфраструктуры территорий не всегда может обеспечить достаточную и устойчивую систему обращения с отходами.

На примере территории Рокуа в Финляндии показано применение подхода DPSIR (модифицированного на основе проведенного мультикритериального анализа решений) для выявления связей между различными аспектами охраняемого участка подземных вод с сезонными понижениями уровня и подходами к управлению этим участком. Этот метод создает упорядоченную картину связей между озерными экосистемами, грунтовыми водами и землепользованием, что помогает при обсуждении проблем экспертами, заинтересованными сторонами, местными жителями и региональными властями.

Моделирование - это мощный инструмент для анализа различных сценариев управления. Ключевой частью процесса моделирования является разработка концепции конкретного участка и изученной гидрогеологической динамики. Концептуализация в рамках модели подземных вод в Рокуа изучалась в качестве инструмента для совершенствования управления территорией. Это помогло спланировать мониторинг изучаемой системы для получения наиболее информативных данных и сделать систему более наглядной для дальнейшего обсуждения. Это ключевой шаг для построения рабочей модели, в которой основные динамические показатели системы представлены на нужном уровне детализации.

В случае с Рокуа, были изучены различные сценарии землепользования, как основа для принятия управленческих решений. Широкомасштабное восстановление осушенной территории путем засыпки значительной части дренажных каналов по всей охраняемой зоне в настоящее время может рассматриваться как чрезмерная мера с неясным эффектом и затратами, превышающими выгоды. Несмотря на то, что эти меры считались приемлемыми, экономические последствия максимального понижения уровня воды для сферы туризма являются преходящими и имеют место только в засушливые периоды. Пробные работы по засыпке канав на части водосборной территории могли бы способствовать пониманию того, насколько эффективным будет этот метод. Кроме того, подход по моделированию подземных вод, используемый в Рокуа, было бы интересно применить для водоносного горизонта меньшего размера, с площадью подпитки менее 5 км. В малых водоносных зонах воздействие болотных осушительных канав может отличаться в зависимости от масштаба.

DPSIR-анализ на объекте БЗСК в Финляндии был сосредоточен на обращении с твердыми бытовыми отходами (ТБО). Анализ показал, что, несмотря на рост популярности и спроса на отдых на природе и рост числа посетителей национальных парков в пределах БЗСК, не было выявлено каких-либо серьезных воздействий на окружающую среду, связанных с ТБО. Обращение с отходами в данных национальных парках в значительной степени держится под контролем, а их воздействие на состояние окружающей среды как внутри национальных парков, так и на прилегающих территориях в пределах биосферного заповедника минимально. Однако, основная ценность территории с точки зрения ее использования посетителями и населением сосредоточена линейно вдоль пеших маршрутов, водоемов и охраняемых территорий. Активное продвижение региона как уголка чистой природы также требует выполнения этого обещания перед теми, кто сюда приезжает. Для этих испытывающих нагрузки участков требуется просвещение как посетителей, так и жителей по вопросам важности сортировки мусора и правильной утилизации отходов.

Более того, учитывая принятый сценарий развития БЗСК, предусматривающий непрерывный рост числа посетителей, текущие планы по развитию сферы туризма и линейное расположение ценностей землепользования для посетителей и населения этой территории, необходимо уделять значительное внимание той роли, которую могут играть жители и туристы, а также инструментам (например, надежное финансирование), которые могут помочь руководителям туристских объектов в принятии нужных мер.

С точки зрения улучшения функционирования и повышения экологичности обращения с отходами на охраняемых природных территориях основной проблемой является совершенствование инфраструктуры и логистики. Например, для музея-заповедника «Кижи» будет полезно наладить вывоз отходов - вложения в водный транспорт могут улучшить ситуацию с отходами не только на самом острове, но и в защитной зоне музея-заповедника. НП «Водлозерский» также может выиграть от организации перевозок через оз. Водлозеро. Чтобы найти наилучшее решение для транспортировки и обращения с отходами на данных территориях, необходимо провести подробные и тщательные исследования, а также оценить количество отходов и их фракций для надлежащего планирования и определения оптимального масштаба более устойчивой системы обращения с отходами.

Результаты комплексного DPSIR-анализа, проведенного на выбранных объектах, свидетельствуют о необходимости постоянного приграничного сотрудничества, как способа обмена информацией и идеями, опытом и передовыми практиками в области обращения с отходами и управления водными ресурсами на охраняемых природных территориях.

ВЫВОДЫ И РЕКОМЕНДАЦИИ ДЛЯ РОССИЙСКИХ ПИЛОТНЫХ ТЕРРИТОРИЙ

Целью проекта SUPER было создание условий для повышения экологической устойчивости пилотных территорий, расположенных в Российской Федерации и в Финляндии, несмотря на существующие проблемы. В отчете представлена подробная информация о побочных экологических эффектах туризма вследствие интенсивной рекреационной нагрузки (в частности, отходы, эвтрофикация водоемов, нарушение ландшафтов и растительности, загрязнение микропластиком и т. д.) отдельно для каждой из пилотных территорий, так как их текущее состояние и проблемы отличаются. Основные выводы и рекомендации по каждой из четырех территорий кратко представлены в этой главе.

Для объектов Кижи и Водлозеро проведен анализ по схеме DPSIR (движущие силы, нагрузки, состояние, воздействие, реагирование). Цель DPSIR-анализа этих объектов - помочь местным руководителям, населению и заинтересованным сторонам понять, как различные движущие силы могут влиять на местную экономику, и как меры реагирования влияют на текущее состояние окружающей среды и благополучие местного населения и сотрудников.

В качестве **основных Движущих сил** или Потребностей населения и заинтересованных сторон на архипелаге **Кижи** были определены следующие: явления, связанные с устойчивым ростом туристско-рекреационной деятельности (рыбалка, дачники и т. д.); в результате повышения качества жизни (жилье/дачи, транспорт, в том числе плавсредства, отдых); вместе с ростом личного и хозяйственного потребления; рост мелкого фермерства и сельского хозяйства.

С учетом основных Движущих сил, были выявлены следующие антропогенные **Нагрузки**: интенсивный транспортный поток из-за однодневных туристических поездок на "Метеорах" из Петрозаводска и однодневных посещений круизных судов со всей России (особо интенсивный в летний период); В 2010-2019 гг. главный остров посещали 142-194 тыс. туристов ежегодно и это число продолжает расти; Растущее количество жилья/дач (в т.ч. строящихся), автомобилей и плавсредств, рыбаков, числа походов; Население только главного острова составляет 60 человек зимой и 300 летом; Отходы личного и хозяйственного потребления (в 2019 году вывезено 88 тонн, в том числе 2,8 тонн отсортированных отходов); Умеренное загрязнение нефтепродуктами и опасными веществами и соответствующие риски; Мелкое фермерство и сельское хозяйство.

Состояние окружающей среды объекта Кижи приблизительно оценивалось следующим образом: Состояние поверхностной, грунтовой и питьевой воды - низкий уровень загрязнения; Состояние загрязнения почвы редкоземельными элементами, тяжелыми металлами/ТМ, азотом, биогенного загрязнения (т.е. повышенный уровень фосфора, риск эвтрофикации) - повышенные уровни на некоторых участках; Микропластик - повышенный уровень на некоторых участках (выше всего у главного причала о. Кижи - самый высокий показатель по Онежскому озеру); Состояние вод Кижских шхер - периодические превышения ПДК по нефтепродуктам и биоаккумуляции ТМ; Экосистемы - местами наличие заносных/инвазивных видов растений.

Вышеупомянутое Состояние может оказывать **Воздействие(я)** на качество экосистем и благополучие людей на Кижах, а именно на: Привлекательность региона; Доходы от туризма; Экологические тенденции и просвещение населения; и Социальное благополучие сотрудников музея-заповедника, дачников и местных жителей.

Могут быть рекомендованы следующие меры **Реагирования**, то есть комплексные действия со стороны общества и управленцев: Создание плана по совершенствованию управления отходами и водными ресурсами (снабжение, использование, логистика и дорожные условия); Ликвидация старых свалок, закрытие действующих незаконных свалок в окрестных деревнях; Наращивание сортировки бытовых и промышленных отходов, а также контроль и мониторинг сброса, растворения и очистки сточных вод; Продолжение экологических исследований и мониторинга, в частности по редкоземельным элементам, тяжелым металлам, биогенным веществам и микропластику в воде и почве, а также биологические исследования; Постоянное улучшение инфраструктуры экологического туризма; Продолжение экологических семинаров для сотрудников и населения; Продолжение работы экологических волонтеров по расчистке и удалению незаконных свалок отходов в деревнях; Продолжение работы по предотвращению загрязнения и готовности к локализации возможных экологических рисков при разливе нефтепродуктов, воздействии опасных веществ, бытовых и лесных пожарах.

В качестве **основных Движущих сил** или Потребностей населения и заинтересованных сторон в **НП «Водлозерский»** были определены следующие: потребности и явления, связанные с контролируемым ростом туристско-рекреационной деятельности на особо охраняемой природной территории (ООПТ) (походы, отдых на воде, рыбалка, дачники и т. д.); в результате повышения качества жизни (жилье/дачи, транспорт, в том числе плавсредства, отдых); вместе с контролируемым ростом личного и хозяйственного потребления; а также ростом мелкого фермерства и сельского хозяйства.

С учетом основных Движущих сил, были выявлены следующие антропогенные **Нагрузки:** Последние 15 км грунтовой дороги с активным движением находятся в «удовлетворительном» или «плохом» состоянии, а на первых 45 км грунтовой дороги до деревни Куганаволог наблюдаются признаки износа; Умеренный и хорошо контролируемый водный трафик (вкл. транспорт, любительское и мелкомасштабное рыболовство, аквакультуру); Умеренный и хорошо контролируемый туристский поток (6 тысяч посещений ежегодно); Умеренный и хорошо контролируемый рост количества жилья/дач (в т.ч. строящихся), автомобилей и плавсредств, рыбаков, числа походов; Население основной деревни Куганаволок и территории национального парка составляет 400 человек зимой и 2000 летом; Отходы личного и хозяйственного потребления (ежегодно вывозится 600 м3 отходов, в том числе 0,5 тонн отсортированных отходов); Низкий уровень загрязнения нефтепродуктами и опасными веществами и соответствующих рисков; Мелкое фермерство и сельское хозяйство.

Состояние окружающей среды НП «Водлозерский» оценивалось следующим образом: Состояние поверхностной, грунтовой и питьевой воды - низкий уровень загрязнения; Состояние загрязнения почвы редкоземельными элементами, тяжелыми металлами/ТМ, азотом, биогенного загрязнения (т.е. повышенный уровень фосфора, риск эвтрофикации) – умеренные или повышенные уровни на некоторых участках; Микропластик - повышенный уровень на некоторых участках по сравнению с фоном; Экосистемы - местами наличие заносных/инвазивных видов растений.

Вышеупомянутое Состояние может оказывать **Воздействие(я)** на качество экосистем и благополучие людей в НП «Водлозерский», а именно на: Привлекательность региона; Доходы от туризма; Экологические тенденции и просвещение населения; и Социальное благополучие сотрудников парка и местных жителей.

Могут быть рекомендованы следующие меры **Реагирования**, то есть комплексные действия со стороны общества и управленцев: Создание плана по совершенствованию управления отходами и водными ресурсами (снабжение, использование, логистика и дорожные условия); Ликвидация и рекультивация нефункционирующей незаконной свалки у деревни Куганаволок; Наращивание сортировки бытовых и промышленных отходов, а также контроль и мониторинг сброса, растворения и очистки сточных вод; Продолжение экологических исследований и мониторинга, в частности по редкоземельным элементам, тяжелым металлам, биогенным веществам и микропластику в воде и почве, а также биологические исследования; Постоянное улучшение инфраструктуры экологического туризма; Продолжение экологических семинаров для сотрудников и населения; Продолжение работы экологических волонтеров по расчистке и удалению незаконных свалок отходов в деревнях; Продолжение работы по предотвращению загрязнения и готовности к локализации возможных разливов нефтепродуктов, воздействия опасных веществ, бытовых и лесных пожаров.

Как было выявлено в процессе проведенных почвенных исследований, почвы несанкционированных свалок ТБО, расположенных на изучаемых территориях, согласно положению «О порядке определения размеров ущерба от загрязнения земель химическими веществами», относятся к категории с низким уровнем загрязнения. Предлагаются следующие рекомендации – ликвидация свалок, а мероприятия по рекультивации лучше предложить после дополнительного более тщательного санитарно-паразитологического анализа территории. В тоже время, выявлено, что даже небольшие по размеру несанкционированные свалки могут нести опасность для окружающей среды, в том числе для человека. В связи с этим, следует больше внимания уделить экологическому просвещению местного населения и туристов, привлечению внимания властей и содействовать формированию инфраструктуры, способствующей рациональному природопользованию на территориях изучаемых объектов.

В целом, благодаря налаженной инфраструктуре, рекреационная нагрузка не оказывает значительного воздействия на свойства почв и других природных объектов. Для снижения негативного воздействия рекреации на окружающую среду, в частности на почвы, даны следующие рекомендации по усовершенствованию рекреационных зон:

1. Оборудовать места для палаток, то есть установить деревянные настилы, что

поможет избежать уплотнения почв и вытаптывания напочвенного покрова на стоянках.
2. Маркировать наиболее популярные у туристов тропы, что приводит к существенному сокращению количества альтернативных троп и, как следствие, к снижению суммарной дигрессии.
3. Установить на стоянках дополнительные информационные щиты с правилами поведения на территории и информацией об охране природы (утилизация мусора, противопожарная безопасность, защита деревьев от повреждений и т.д.).
4. Временно оградить наиболее крупные сохранившиеся в пределах туристических площадок лесные куртины (1,0×1,0, 3,0×3,0 м и др.), например, яркими лентами, чтобы предотвратить их дальнейшее вытаптывание и необратимую трансформацию лесного сообщества. При активном использовании стоянок, такие куртины следует ограждать на 1-2 года, чтобы живой напочвенный покров успевал восстановиться.
5. Своевременно ликвидировать выявляемые несанкционированные микросвалки, т.к. они часто являются отправными точками для расселения чужеродных (инвазивных) видов сосудистых растений, многие из которых проявляют агрессивную стратегию выживания.
6. При выявлении в регионе крупных очагов инвазивных видов (например, недотрога железконосная, элодея канадская, борщевик Сосновского), рекомендуется удалять их как можно раньше, до массового расселения.
7. Для грамотного прогнозирования ситуации, связанной с инвазивными видами, и понимания стратегии возможного их «поведения» на территории республики в будущем, требуется регулярный ботанический контроль таких местообитаний, как свалки и прочие рудеральные местообитания.

Микропластик (МП) не может быть удален из окружающей среды известными методами. Для снижения загрязнения водоемов микропластиком можно рекомендовать следующие меры:

1. Экологическое просвещение для сокращения попадания пластиковых отходов от местных жителей и туристов в окружающую среду.
2. Сокращение образования вторичного МП в окружающей среде (при разложении крупного пластикового мусора) за счет рекультивации незаконных свалок и регулярных мероприятий по очистке берегов от пластикового мусора.
3. Внедрение наилучших доступных технологий очистки воды, способных удалять твердые частицы из сточных вод и, таким образом, сокращать поступление первичного МП в водную среду или, по крайней мере, поддержание производительности местных очистных сооружений на проектном уровне. Сокращение использования косметических средств, содержащих МП, таких как очищающие средства для лица, зубная паста и т. д. Снижение прямых сбросов неочищенных бытовых сточных вод в водоемы.

Наиболее актуальными проблемами, связанными с отходами, на обеих территориях ("Водлозерский" и "Кижи"), представляются незаконное складирование отходов и недостаточно эффективная система обращения с отходами. Кроме того, проблемы возникают из-за отходов, генерируемым значительным потоком туристов. При этом, уровень развития инфраструктуры территорий не всегда может обеспечить достаточную и устойчивую систему обращения с отходами.

С точки зрения улучшения функционирования и повышения экологичности обращения с отходами на охраняемых природных территориях основной проблемой является совершенствование инфраструктуры и логистики. Например, для музея-заповедника «Кижи» будет полезно наладить вывоз отходов - вложения в водный транспорт могут улучшить ситуацию с отходами не только на самом острове, но и в защитной зоне музея-заповедника. НП «Водлозерский» также может выиграть от организации перевозок через оз. Водлозеро.

Чтобы найти наилучшее решение для транспортировки и обращения с отходами на данных территориях, необходимо провести подробные и тщательные исследования, а также оценить количество отходов и их фракций для надлежащего планирования и определения оптимального масштаба более устойчивой системы обращения с отходами. В дальнейшем существует потребность в проектах, которые будут отслеживать, контролировать и сокращать количество отходов, образующихся в результате туризма на российских объектах, а также выработают дополнительные рекомендации по улучшению управления отходами.

Этот отчет, а также двухлетняя совместная работа по проекту, прокладывают путь и дают рекомендации по комплексному использованию передового международного опыта и современных решений для сбора, сортировки, транспортировки, переработки и утилизации отходов на ООПТ, включая конкретные рекомендации для каждого исследованного объекта. Авторы отчета уверены, что трансграничный обмен информацией и постоянный совместный мониторинг экологической ситуации, включая управление отходами и водными ресурсами, чрезвычайно важны для снижения существующего риска деградации окружающей среды на ООПТ, а также для повышения устойчивости окружающей среды и благополучия людей, здесь живущих и работающих, а также посетителей этих чудес природы.

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APPENDICES

Appendix 1. Russian regulations for chemicals in soils

Table 1. Current MPC regulations for chemicals in soils of Russia

Element, chemical substance	MPC value, mg/kg soil
Total	
Vanadium	150
Manganese	1500
Manganese + Vanadium	1000+100
Arsenic	2.0
Tin	4.5
Mercury	2.1
Lead	32
Antimony	4.5
Chromium (+3)	90
Water soluble	
Fluorine	10
Labile **	
Lead	6
Nickel	4
Chromium	6
Copper	3
Zinc	23
Cobalt	5
Manganese: for chernozem soils for sod-podzolic soils for pH 4.0 pH 5.1-6.0 pH > 6.0	700 300 400 500

Table 2. Tentative permissible concentrations (TPC) of chemical substances in soil

(Hygienic norms GN 1.2.3685-21)

Substance	Soil group	TPC (mg/kg) with regard to the background (clarke unit)
Cadmium	a) sandy and loamy-sandy	0.5
	b) acid (loamy and clayey), pH KCl < 5.5	1
	c) near-neutral and neutral (loamy and clayey), pH KCl > 5.5	2
Copper	a) sandy and loamy-sandy	33
	b) acid (loamy and clayey), pH KCl < 5.5	66
	c) near-neutral and neutral (loamy and clayey), pH KCl > 5.5	132
Arsenic	a) sandy and loamy-sandy	2
	b) acid (loamy and clayey), pH KCl < 5.5	5
	c) near-neutral and neutral (loamy and clayey), pH KCl > 5.5	10
Nickel	a) sandy and loamy-sandy	20
	b) acid (loamy and clayey), pH KCl < 5.5	40
	c) near-neutral and neutral (loamy and clayey), pH KCl > 5.5	80
Lead	a) sandy and loamy-sandy	32
	b) acid (loamy and clayey), pH KCl < 5.5	65
	c) near-neutral and neutral (loamy and clayey), pH KCl > 5.5	130
Zinc	a) sandy and loamy-sandy	55
	b) acid (loamy and clayey), pH KCl < 5.5	110
	c) near-neutral and neutral (loamy and clayey), pH KCl > 5.5	220

Table 3. Indices of land chemical contamination level (taken from the “Procedure of quantifying damage from land pollution with chemical substances”)

Element	level 1 permissible	Content (mg/kg) corresponding to contamination level			
		level 2 low	level 3 medium	level 4 high	level 5 very high
Cd	<MPC	MPC to 3	3-5	5 - 20	>20
Pb		" MPC "125	"125 "250	"250 " 600	>600
Hg		" MPC " 3	" 3 " 5	" 5 " 10	>10
As		" MPC " 20	" 20 " 30	" 30 " 50	>50
Zn		" MPC "500	"500 "1500	"1500"3000	>3000
Cu		" MPC "200	"200 "300	"300 " 500	>500
Co		" MPC " 50	" 50 "150	"150 " 300	>300
Ni		" MPC "150	"150 "300	"300 " 500	>500
Mo		" MPC " 40	" 40 "100	"100 " 200	>200
Sn		" MPC " 20	" 20 " 50	" 50 " 300	>300
Ba		" MPC "200	"200 "400	"400 "2000	>2000
Cr		" MPC "250	"250 "500	"500 " 800	>800
V		" MPC "225	"225 "300	"300 " 350	>350

Appendix 2. Plant species found in the plant survey

Table 1. List of vascular plant species found in the surveyed dumps and campsites

Taxa	Dumps		Campsites
	Kizhi Museum and Reserve	NP Vodlozersky	
Achillea millefolium L.	+	+	+
Aconitum septentrionale Kölle	+		
Adoxa moschatellina L.	+		
Aegopodium podagraria L.	+		
Agrostis capillaris L.	+	+	+
Alchemilla acutiloba Opiz	+	+	+
Alchemilla micans Buser			+
Allium cepa L.		+	
Allium sativum L.	+	+	
Alnus glutinosa (L.) Gaertn.	+		
Alnus incana (L.) Moench	+	+	+
Alsine media (L.) Vill.	+	+	+
Androsace filiformis Retz.		+	
Anethum graveolens L.	+		
Angelica sylvestris L.	+		
Anthoxanthum odoratum L.	+	+	+
Anthriscus sylvestris (L.) Hoffm.	+	+	+
Arctium tomentosum Mill.	+	+	
Arenaria serpyllifolia L.	+		
Artemisia camprestris L.	+		
Artemisia vulgaris L.	+	+	+
Athyrium filix-femina (L.) Roth	+	+	+
Atriplex patula L.		+	
Avenella flexuosa (L.) Drej.	+		+
Barbarea arcuata (Opiz ex J. et C. Presl) Reichenb.	+		

Betula pendula Roth			+
Betula pubescens Ehrh.	+	+	+
Bidens tripartita L.		+	
Botrychium lunaria (L.) Sw.	+		
Bromopsis inermis (Leyss.) Holub	+		
Bunias orientalis L.	+		
Calamagrostis arundinacea (L.) Roth	+		+
Calamagrostis canescens (Web.) Roth			+
Calamagrostis epigeios (L.) Roth	+	+	+
Calamagrostis neglecta (Ehrh.) Gaertn., Mey. et Scherb.			+
Calamagrostis phragmitoides C. Hartm.	+	+	+
Caltha palustris L.	+		
Calystegia sepium (L.) R. Br.		+	
Campanula glomerata L.	+		
Campanula patula L.		+	+
Campanula rotundifolia L.	+		
Capsella bursa-pastoris (L.) Medik.	+	+	+
Cardamine dentata Schult.	+		
Cardaminopsis arenosa (L.) Hayek			+
Carduus crispus L.		+	
Carex aquatilis Wahlenb.	+		
Carex brunnescens (Pers.) Poir.			+
Carex cinerea Poll.		+	+
Carex echinata Murr.			+
Carex digitata L.			+
Carex globularis L.			+
Carex leporina L.		+	+
Carex nigra (L.) Reichard		+	+
Carex pallescens L.			+
Carex paupercula Michx.		+	
Carex vesicaria L.		+	

Carum carvi L.	+	+	+
Centaurea jacea L.	+	+	
Centaurea phrygia L.	+	+	+
Centaurea scabiosa L.	+		
Cerastium holosteoides Fries	+	+	+
Chaerophyllum aromaticum L.	+		
Chamaenerion angustifolium (L.) Scop.	+	+	+
Chelidonium majus L.		+	
Chenopodium album L.	+	+	
Chenopodium glaucum L.		+	
Chenopodium polyspermum L.	+		
Cicuta virosa L.	+		
Cirsium palustre (L.) Scop.	+	+	
Cirsium setosum (Willd.) Bess.	+	+	
Cirsium vulgare (Savi) Ten.		+	
Clinopodium vulgare L.	+		
Coccyganthe flos-cuculi (L.) Fourr.			+
Comarum palustre L.	+		
Convallaria majalis L.	+	+	+
Cosmos bipinnatus Cav.		+	
Dactylis glomerata L.	+	+	+
Dactylorhiza fuchsii (Druce) Soó			+
Dactylorhiza maculata (L.) Soo	+	+	+
Daphne mezereum L.	+		
Deschampsia cespitosa (L.) Beauv.	+	+	+
Dianthus deltoides L.	+		
Dryopteris carthusiana (Vill.) H. P. Fuchs	+	+	+
Dryopteris filix-mas (L.) Schott	+		
Elytrigia repens (L.) Nevski	+	+	+
Epilobium adenocaulon Hausskn.		+	
Epilobium montanum L.		+	

Epilobium palustre L.		+	
Equisetum arvense L.	+	+	+
Equisetum fluviatile L.	+	+	
Equisetum pratense Ehrh.	+	+	
Equisetum sylvaticum L.	+		+
Erigeron acris L.		+	+
Eriophorum vaginatum L.		+	
Erodium cicutarium (L.) L'Her.	+		
Euphrasia brevipila Burn. & Gremli		+	+
Fagopyrum tataricum (L.) Gaertn.	+		
Fallopia convolvulus (L.) A. Love		+	
Festuca ovina L.			+
Festuca rubra L.			+
Filipendula ulmaria (L.) Maxim.	+		
Fragaria moschata (Duch.) Weston		+	
Fragaria vesca L.	+	+	+
Frangula alnus Mill.	+		+
Fumaria officinalis L.	+		
Galeopsis bifida Boenn.	+	+	
Galeopsis speciosa Mill.		+	
Galium album Mill.	+	+	+
Galium boreale L.	+		+
Galium palustre L.	+		
Galium uliginosum L.			+
Geranium sylvaticum L.	+	+	
Geum rivale L.	+		
Geum urbanum L.	+		
Glechoma hederacea L.	+		
Glyceria fluitans (L.) R. Br.		+	
Goodyera repens (L.) R. Br.			
Totalularia reclinata (L.) Mill.	+		

Gymnocarpium dryopteris (L.) Newm.			+
Heracleum sibiricum L.	+		
Hieracium umbellatum L.	+	+	+
Hieracium vulgatum Fries		+	+
Hypericum maculatum Crantz	+		+
Impatiens glandulifera Royle		+	
Iris pseudacorus L.	+		
Juncus alpinoarticulatus Chaix		+	
Juncus bufonius L.		+	
Juncus filiformis L.		+	+
Juniperus communis L.			+
Knautia arvensis (L.) Coult.	+		+
Lathyrus sylvestris L.	+		
Lathyrus pratensis L.	+	+	+
Leontodon autumnalis L.	+	+	+
Lepidotheca suaveolens (Pursh) Nutt.	+	+	+
Leucanthemum ircutianum (Pursh) Nutt.	+	+	+
Limosella aquatica L.		+	
Linaria vulgaris Mill.	+		
Linnaea borealis L.		+	+
Luzula pallescens (Wahl.) Bess.		+	+
Luzula pilosa (L.) Willd.		+	+
Lycopodium annotinum L.	+		+
Lycopus europaeus L.	+		
Lysimachia vulgaris L.	+		+
Maianthemum bifolium (L.) F. W. Schmidt	+		+
Malus domestica Borkh.	+	+	
Melampyrum nemorosum L.	+		
Melampyrum pratense L.	+	+	+
Melandrium album (Mill.) Garcke	+		
Melica nutans L.		+	

Mentha arvensis L.	+		+
Milium effusum L.	+		
Myosotis arvensis (L.) Hill	+	+	+
Myosoton aquaticum (L.) Moench	+		
Naumburgia thyrsiflora (L.) Reichenb.			+
Oberna behen (L.) Ikonn.	+		
Omalotheca sylvatica (L.) Sch. Bip. & F.Schultz	+		+
Orthilia secunda (L.) House		+	
Oxalis acetosella L.	+		+
Padus avium Mill.	+	+	
Paris quadrifolia L.	+		
Parnassia palustris L.		+	
Persicaria amphibia (L.) S. F. Gray		+	
Persicaria hydropiper (L.) Spach		+	
Persicaria lapathifolia (L.) S. F. Gray	+	+	
Phalaroides arundinacea (L.) Rauschert	+		
Phleum pratense L.	+	+	+
Phragmites australis (Cav.) Trin. ex Steud.	+		+
Picea abies (L.) Karst.			+
Picea obovata Ledeb.		+	
Pilosella officinarum F. Schultz & Sch. Bip.	+	+	+
Pilosella pubescens Norrl.	+		
Pimpinella saxifraga L.	+		+
Pinus sylvestris L.	+	+	+
Plantago lanceolata L.	+		
Plantago major L.	+	+	+
Platanthera bifolia (L.) Rich.		+	
Poa annua L.	+	+	+
Poa compressa L.		+	+
Poa palustris L.	+	+	+

Poa pratensis L.	+	+	+
Polemonium caeruleum L.			+
Polygonum aviculare L.	+	+	+
Populus tremula L.		+	+
Potentilla anserina L.	+	+	
Potentilla argentea L.	+		
Potentilla erecta (L.) Raeusch.		+	+
Potentilla norvegica L.	+	+	
Prunella vulgaris L.		+	
Pseudolysimachion longifolium (L.) Opiz		+	
Ptarmica vulgaris Blakw. ex DC.		+	+
Pyrola media Sw.	+		+
Pyrola minor L.			+
Pyrola rotundifolia L.		+	
Ranunculus acris L.	+	+	+
Ranunculus fallax (Wimm. & Grab.) Schur aggr.	+		
Ranunculus polyanthemos L.	+		
Ranunculus repens L.	+	+	+
Rhinanthus minor L.		+	+
Ribes nigrum L.	+	+	+
Ribes spicatum Robson	+		
Rorippa palustris (L.) Bess.		+	
Rosa acicularis Lindl.			+
Rosa majalis Herrm.			
Rubus idaeus L.	+	+	+
Rubus saxatilis L.			+
Rumex acetosa L.	+	+	+
Rumex acetosella L.	+	+	+
Rumex thyrsiflorus Fingerh.		+	+
Sagina procumbens L.	+	+	+

Salix aurita L.	+		+
Salix caprea L.	+	+	+
Salix myrsinifolia Salisb.	+	+	+
Salix pentandra L.		+	
Salix phylicifolia L.		+	+
Sambucus racemosa L.	+		
Schedonorus pratensis Huds.	+	+	
Scirpus sylvaticus L.		+	
Scleranthus annuus L.	+		
Scrophularia nodosa L.	+		
Scutellaria galericulata L.	+		+
Senecio vulgaris L.	+		
Solanum tuberosum L.	+	+	
Solidago virgaurea L.			+
Sonchus arvensis L.	+		
Sorbus aucuparia L.	+	+	+
Spergula sativa Boenn.	+		
Spergularia rubra (L.) J. et C. Presl		+	
Stachys palustris L.	+		
Stellaria fennica (Murb.) Perf.		+	
Stellaria graminea L.	+	+	+
Tanacetum vulgare L.	+	+	+
Taraxacum officinale Wigg.	+	+	+
Thalictrum flavum L.	+		
Thyselium palustre (L.) Rafin.	+		
Trichophorum caespitosum (L.) C.Hartm.		+	
Trientalis europaea L.	+		+
Trifolium hybridum L.	+	+	
Trifolium medium L.			+
Trifolium pratense L.	+	+	+
Trifolium repens (L.) C. Presl.		+	+

Tripleurospermum inodorum (L.) Sch. Bip.	+	+	
Trollius europaeus L.	+		
Turritis glabra L.	+		
Tussilago farfara L.	+	+	+
Typha angustifolia L.		+	
Ulmus laevis Pall.	+		
Urtica dioica L.	+	+	+
Vaccinium myrtillus L.	+	+	+
Vaccinium uliginosum L.		+	+
Vaccinium vitis-idaea L.		+	+
Veratrum lobelianum Bernh.			+
Verbascum nigrum	+		
Veronica chamaedrys L.	+	+	+
Veronica officinalis L.			+
Viburnum opulus L.	+		
Vicia cracca L.	+	+	+
Vicia sepium L.	+	+	+
Viola arvensis Murr.	+	+	
Viola epipsila Ledeb.			+
Viola palustris L.			+
Viola riviniana Reichenb.	+		