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Soil Diversity of the Island of Gogland in the Gulf of Finland: History of Land Development and Current Status

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Abstract: One of the most effective nature conservation measures is the creation of territories where human impact is limited, this is called specially protected natural areas. A significant contribution to increasing the area of the Russian Federation covered by protected areas was made by the creation of the State Nature Reserve in the Leningrad Region, known as the "East of the Gulf of Finland". Initially, the reserve was supposed to include the island of Gogland (but it is now not part of the protected area). The locked status of the island, its remoteness from the coast, and the harsh features of the Gulf of Finland have contributed to the transformation of Gogland into a kind of open-air "museum". The biological diversity of the island is closely connected with edaphic diversity, as soil is a natural habitat for a huge variety of living organisms. Therefore, the purpose of this work was to assess the edaphic potential of the island of Gogland, a territory that has existed for a long time with an extremely weak anthropogenic impact, in order to assess the ecosystem services of the island as one of the approaches to taking effective measures for nature protection. Data on chemical soil characteristics are discussed, as well as current soil pollution processes of these remote areas by trace elements. Edaphic studies carried out showed that the soil cover of the island of Gogland is characterized by sufficient diversity, the presence of soils at initial stages of development, soils with a fully developed differentiated profile with a pronounced eluvial process—eluvozems and various podzols, as well as the rarest, organogenic soils—bog, and bog-gley soils. The pH_{H2O} of the studied soils on Gogland is characterized by a strongly acidic to weakly acidic reaction. The total pollution indicator of the studied soils is characterized by low values (Zc < 16), whereas the geoaccumulation index (Igeo) showed moderate/heavy pollution by only one element: Pb.

Keywords: Gogland; soil contamination; fallow soils; ecosystem services; edaphic diversity

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1. Introduction

Soil, as a natural habitat for a huge variety of living organisms, is a source of biological diversity in terrestrial ecosystems [1,2]. There is a close relationship and interdependence between soils and the communities of living organisms inhabiting them: each soil type is characterized by particular species of plant, bacteria, and animal communities [3–5]. The soil serves a number of important ecosystem functions, such as fulfilling the property of fertility and ensuring the dynamics, diversity, and functioning of terrestrial ecosystems as a whole [6,7]. It follows as a logical consequence that the problem of biodiversity conservation cannot be solved without preserving soil diversity [8–10]. The most important aspect of edaphic diversity protection is having an allotted area of upland watershed reference soils that are the most typical, zonal soils, relatively unaffected by human activities. A feasibility of this task in the European part of the Russian Federation is limited by a high degree of economic development of watershed lands, which necessitates the study of soil cover at specially protected natural areas (SPNA) [11,12]. In particular, for example, the Leningrad region is heterogeneous both in physical and geographical terms and in the history of its development. There are many abandoned lands in the region, which can serve as a model for studying the degradation and amelioration of soil and ecosystems over time [13,14].

The study of edaphic diversity, along with floristic, geobotanical, and faunal studies, is an essential part of comprehensive environmental surveys, justifying the project of giving the territory a special conservation status [15,16]. Unfortunately, the existing SPNA network in Russian Federation does not have sufficient representativeness and does not reflect the edaphic and biological diversity of the territory [17,18]. The creation of territories, where human impact is limited, is one of the most effective conservation measures [19,20]. A significant contribution to increasing the area of the Russian Federation covered by protected areas was made by the creation of the Ingermanland State Nature Reserve in the Leningrad Region, which is currently called the "East of the Gulf of Finland". It is located on islands belonging to the Vyborg and Kingisepp districts of the Leningrad Region, in the waters of the Gulf of Finland [21]. Initially, the reserve was supposed to include the island of Gogland (which, ultimately, was not part of the protected area), located in the Gulf of Finland, which has been almost abandoned since the Second World War, meaning it is now possible to assess how good or bad it is in terms of ecosystem services and nature conservation of the moderate climate zone of Eurasia [22]. The island of the Gulf of Finland has been a closed border zone for the past 70 years and this has created ideal conditions for the development of natural complexes and conservation of a unique nature with little influence by mankind. The locked status of the island, its remoteness from the coast, and the harsh features of the Gulf of Finland have contributed to the transformation of Gogland into a kind of open-air "museum". According to research data, there are currently about 1000 different plant species on island, including critically endangered species. The islands of the Gulf of Finland as a whole are unique natural formations that originate from ancient geogenic processes and recent glacial and post-glacial processes, including processes of lake transgressions [23].

The territories of the Gulf of Finland islands are characterized by soil areas that are isolated from each other, so each island is characterized by a specific combination of soils and a set of soil taxonomic units. However, in the case of soil cover research, some of the islands still remain "blank spots", including the island of Gogland. This is not only due to being practically inaccessible to researchers for more than 70 years. There was a time when there were fishing villages on the islands, and fishermen were also doing agricultural work. At present, ancient soil layers of fallow soils are covered with sandy sediments. Thus, external islands of the Gulf of Finland, including the island of Gogland, are unique models of abandoned agroecosystems that are promising for soil research. The soils of Gogland are almost never studied. Work published by Schastnaya referenced the topic but only as a short note [24]. The specificity of the soil cover is completely determined in this case by the specific features of the relief and soil parent rocks.

Thus, the purpose of this work was to assess the edaphic potential of Gogland, a territory that has existed for a long time with an extremely weak anthropogenic impact, in order to assess the ecosystem services of the island as one of the approaches to taking effective measures for nature protection.

The following objectives were set to achieve this goal: (1) studying the history of the Gogland development and their physical and geographical position; (2) evaluating soil topography patterns of unique natural formations of Gogland and giving detailed information about the main elements of soil cover; (3) assessing the main soil characteristics and the current environmental soil state of the island.

2. Materials and Methods

The island of Gogland (fin. Suursaari) is the largest and the highest of external islands of the Gulf of Finland. These islands include Gogland, Roadsher, Bolshoi and Maly Tyuters, Moshchny, Nerva, Maly, Seskar, Sommers, the Virgin Islands, and smaller nearby islands [23]. Gogland is located in the central part of the Gulf of Finland, 180 km west of St. Petersburg (Figure 1). It is part of the Kingisepp district of the Leningrad Region, as a village of Suur-Saari. Its area is about 21 km^2. The island has an elongated shape from southeast to northwest with a total length in the same direction of about 11 km. Its width reaches 2.5 km. The highest point is Mount Lounatkorkia, which has a height of 176 m. There are also three more hills on the island with a height from 106 to 142 m. Thereby, Gogland is visible, in good weather, at a distance of 70–75 km. There are two lighthouses on the island—in the north and south [21,23,25]. The basis of the island is granite, which forms many hills and valleys of different sizes, where small freshwater lakes of glacial origin are found. A huge role in the island's natural habitus formation was played by geological processes that took place from the Archean–Proterozoic times until the present. There are numerous marine terraces of different levels and products of their activity, as well as rocky outcrops of solidified igneous formations from a long time ago. The coastline is indented with hundreds of bays of all shapes and sizes. Two bays are often used for yachts and boats [26–30]. The first one is Surkyla (Suuryulyan-Lahti), suitable for ships with a draft of up to 4 m; the second is Limonnikov Bay, which is located on the western side of Gogland, with a depth of 17 m that is used for boat parking. Gogland's nature is rich and varied. There are about 700 species of vascular plants. Almost 80% of the island's territory is covered with coniferous and small-leaved forests. Communities of *Vaccinium myrtillus*, *Rubus idaeus*, *Ribes alpinum*, and *Juniperus* bushes are common at the bottom of the cliffs. The population of the island, according to the latest census, is 47 persons. There are two ruined Finnish villages [31–33].

Figure 1. Study object—the location of the island of Gogland in the Gulf of Finland.

The following methods were used in order to achieve the study goal: field surveys of the island and laboratory studies.

The morphological soil topographic patterns of Gogland were studied during a complex expedition that took place within the framework of the "My Region" cultural and educational program from May to October 2019. The program was initiated and supported by Nord Stream 2 AG, the developer of the Nord Stream-2 offshore gas pipeline, in accordance with the company's environmental and social initiatives strategy. Environmental studies were carried out using standard methods for describing soils (soil pits, morphological description, and laboratory analyses aimed at studying soils' properties chemically, physically, and biologically) [34,35]. Soil diagnostics were carried out according to the "Classification and diagnostics of soils of Russia" [36] and the World Reference Base for

Soil Resources, FAO 2015 [37]. Logistic issues were resolved with the help of the Leningrad Regional Branch of the Russian Geographical Society.

The determination of main soil characteristics was carried out using standard analysis procedures [34,35]. The pH values were determined in water and salt suspensions (soil-to-solution ratio 1:2.5). The values of exchange and hydrolytic acidity were determined in solutions of KCl and CH_3COONa, respectively (the ratio of soil and solution was 1:2.5). The soil basal respiration was also assessed by the substrate-stimulated respiration method, but in soil that was not enriched with the substrate. The carbon content was determined using the Tyurin method. The content of selected heavy metals in individual extracts was determined in mg kg^{-1} by the AAS method using flame detection. The quantitative index of soil pollution by heavy metals (geoaccumulation index (Igeo) with regard to background level of heavy metals content) was calculated in accordance with Muller [38]. Zc is an indicator of trace elements status that takes into account the different toxicity of heavy metals and was calculated, according to the Methodical Guidelines of Russian Federation 2.1.7.730-99, "Sanitary audit of soil quality in populated areas".

The data's normal distribution was verified, and an analysis of variance (ANOVA) and post hoc test (Fisher's least significant difference) were performed. Differences were considered significant at $p < 0.05$. Statistical data processing and analysis were carried out using standard methods in software packages MS Excel 2016 and Statistica 64 (version 10).

3. Results and Discussion

3.1. The History of Gogland Land Development and Reclamation

The earliest archaeological evidence of human presence on external islands of the Gulf of Finland was a hand axe on Gogland that dates back to the Late Stone Age. Axes of this type date back to the end of the 3rd millennium BC [39]. Representatives of the "hand-axe culture" actively migrated at this time from the southern coast of the Gulf of Finland to the northern part through the chain of islands (Bolshoy and Maly Tyuters, Gogland, eastern Finnish archipelago [40]). At the same time, the first ancient people who were engaged in the fishing and hunting of seals most likely began to develop these territories at the beginning of the Stone Age.

Ancient fishermen and hunters were present on the island during the Bronze Age and in the early Iron Age. Stone labyrinths, burial grounds, and building remains from this period (Gogland, Southern Virgin Island, Krutoyar, etc.) most likely belong to the ancient Sami, who were later ousted by representatives of the Finnish-speaking tribes. However, the climatic conditions of that period did not allow for a permanent population to be established with an agricultural culture on the islands.

Historically, the island of Gogland and the other external islands of the Gulf of Finland have been of great strategic importance because of their geographical location on the fairway line when approaching the mouth of the Neva River, where the capital of the Russian Empire, the city of St. Petersburg, was founded in 1703 [41,42]. They became the object of the struggle between Russia and Sweden in the 17th–18th centuries, although they were then inhabited mainly by Finnish fishermen. The islands have long been used as a site for lighthouses.

Some of the islands, particularly Gogland, became part of the Russian Federation under Peter the Great. The next campaign of the Swedes in the Baltic—the Northern War—resulted in defeat and the Nishtadt Peace. In 1721, the islands were transferred to the Tsardom of Russia (together with Estland, part of Karelia, Livonia (Estonia and Latvia), and Ingermanland (now part of the Leningrad region)). However, the Swedes began another Russian–Swedish war, which ended in 1743 with the Abo Peace in favor of Russia, and Russia took away the most important island of the archipelago at that moment—Gogland. After that the Swedes unsuccessfully tried to take revenge in 1788 through to the 1790s, and the Gogland battle took place. Finally, the Friedrichsgam Peace made the situation more final following the six-century Russian–Swedish dispute regarding the islands in the Baltic Sea in 1809. The Swedes were stripped of Finland, which became part of the Russian Empire.

Finland received the opportunity to claim the islands in 1917 when it became independent. The population on Gogland, as well as the other external islands of the Gulf of Finland, was Finnish, and in 1920, the Bolsheviks passed on the islands. The islands returned to their former owner after the Soviet–Finnish Winter War as part of the peace treaty in 1940. The strategic position of external islands was strengthened at the outbreak of the Second World War, and they turned out to be fundamentally important for all sides. The role of Gogland and other external islands of the Gulf of Finland in the defense of Leningrad City, in the victory of the Soviet Union as a whole, is generally known only to military historians. For example, few people know that recent enemies—the USSR and Finland—repelled the attacks of the Germans on Gogland together in 1944 [41–44]. Soviet troops occupied all the islands in the fall of 1944, and, finally, they were again assigned to Russia in 1947 under the terms of the next "peace" agreement (Paris), and they still remain Russian islands to this day.

3.2. Soil Formation Factors at the Island of Gogland

Apart from time, which is one of the soil formation factors and described in detail in the previous section, there are several factors that will be discussed below.

The climate of this region can be characterized as transitional from continental to maritime with moderately warm summers, rather long moderately cold winters, and unstable weather conditions. The average annual air temperature is 3.7–5.2 °C. The warmest month is July, with an average monthly air temperature of 16.9–17.6 °C, and the coldest month is February, with an average of −6.2 to −8.5 °C. Due to the prevalence of marine air masses, air humidity in the eastern part of the gulf is high throughout the year. The average annual relative humidity is 79–82%, and the average annual precipitation generally varies from 500 to 650 mm.

The geological structure of Gogland is characterized by two structural geological layers that are overlain by thin Quaternary sediments cover [26,27]. Deposits of the lower structural geological layer are widespread at the western shore of the island. Its structure includes granite gneisses, leptites, leptite and micaceous gneisses, and metabasites of the Ladoga group, intensively disturbed and migmatized to varying degrees [28]. Deposits of the upper structural geological layer, bedded on the intensively disturbed and deeply eroded rocks of the crystalline basement, occupy at least 60% of the island's area, mainly its entire eastern part, interspersed with a central massif of gabbroids, forming a sub-platform sedimentary–volcanogenic "cover" of submeridional strike with a pitch to east at angles of about 10°, rarely up to 40° [29].

Quaternary sediment thickness at the island is small; they are represented by recent Upper Quaternary marine and eluvial–deluvial deposits. Marine sediments are represented by boulders and pebbles, and less often gravel and sands (near Suurkylänlahti bay). Eluvial–deluvial deposits occur on various rocks of the pre-Quaternary age, representing the products of its weathering; a coarse detrital material prevails in particle-size distribution—grus, crushed stone, chunks, and pseudo-boulders [22]. There are also coastal beach ridges with dense vegetation in the central part of the island. Moreover, colluvial deposits, consisting of boulders and debris of local rocks, are observed throughout the island at slopes and near the bottom of the hills. Lacustrine-bog deposits with a thickness of up to 4 m are associated with lakes and small lakeside bogs [30].

The group of external islands of the Gulf of Finland, including Gogland, as well as the entire Gulf of Finland, is confined to the regional tectonic zone separating the Baltic Shield and the Russian Platform, where increased seismicity is assumed: both at the final stages of deglaciation and in the period after the glacial load [45].

Geological structure determines the characteristics of the modern relief in many respects. Gogland's relief belongs to the structural-denudation type, partially modified by ice gouging. The relief of the island is characterized by large differences in altitude and a changeable landscape. Its surface is formed by many rock massifs separated by numerous valleys [25]. The skyline of the island is formed by four hills, the southern is Lounatkorkia—it reaches a height of 175 m. Three other peaks—from the south to the north—are named: Haukkavuori—142 m, Mäkiinpäällys—126 m, and Pohjoiskorkia—106 m. Colluvial deposits, represented by angular, non-rounded large-diameter fragments, are accumulated at the bottom of slopes.

The island's relief is also characterized by a wide distribution of selga, domineering over the surrounding landscape of about 20–30 m. Its slopes are smoother, deluvium accumulates, and sandy loamy moraine deposits have been preserved at the lower part of the slope. Eluvium often does not accumulate at the top of the selga; tops are occupied by weakly developed soils or are simply bare. A characteristic feature of selga is the significant steepness of their slopes and the absence or weakness of exaration terraces. Spaces between selga are occupied by moraines that compose transeluvial landscapes with waterlogging, as well as other accumulative positions of the relief associated with the areas of lake and river distribution (occupying no more than 20% of the island's area).

Marine terraces composed by bouldered sandy loams are also a widespread form of relief. There are beach ridges along the coast that consist of rounded granite boulders of glacial origin. Sandy shores and layered deposits are rare.

According to their socio-economic function, landscapes within Gogland can be divided into forestry (most of the island area), agricultural (abandoned fields of old Finnish settlements, hay meadows), and protected landscapes (if the island is given the status of a specially protected natural area). In terms of ruggedness degree, dissected landscapes dominate in Gogland. According to the type of geochemical regime, eluvial landscapes, when runoff dominates over accumulation, prevail. According to anthropogenic change degree, island landscapes are classified as weakly altered and impacts are expressed in local scale. It is represented in military infrastructure locations and in former Finnish settlements that traces of intense anthropogenic activity in the past are well visible, including fallow soils.

3.3. Pedo-Environmental Characteristics of Gogland

Edaphic studies carried out show that the soil cover of Gogland is distinguished by some originality and diversity, although it belongs to the Vyborg-Sortavalsky district of thin gravelly soils. Soil mapping was carried out on Gogland as part of the survey (Figure 2).

The strong relief dissection, the predominance of dense crystalline rocks of various compositions and ages, and the variety of hydrological conditions determined the specificity of island soil cover. It is characterized by sufficient diversity; the presence of soils at initial stages of development; soils with a fully developed differentiated profile with a pronounced eluvial process, such as eluvozems (Cambisols—WRB); and various podzols (Podzols—WRB), as well as the rarest, organogenic soils—bog, and bog-gley soils (Histosols—WRB).

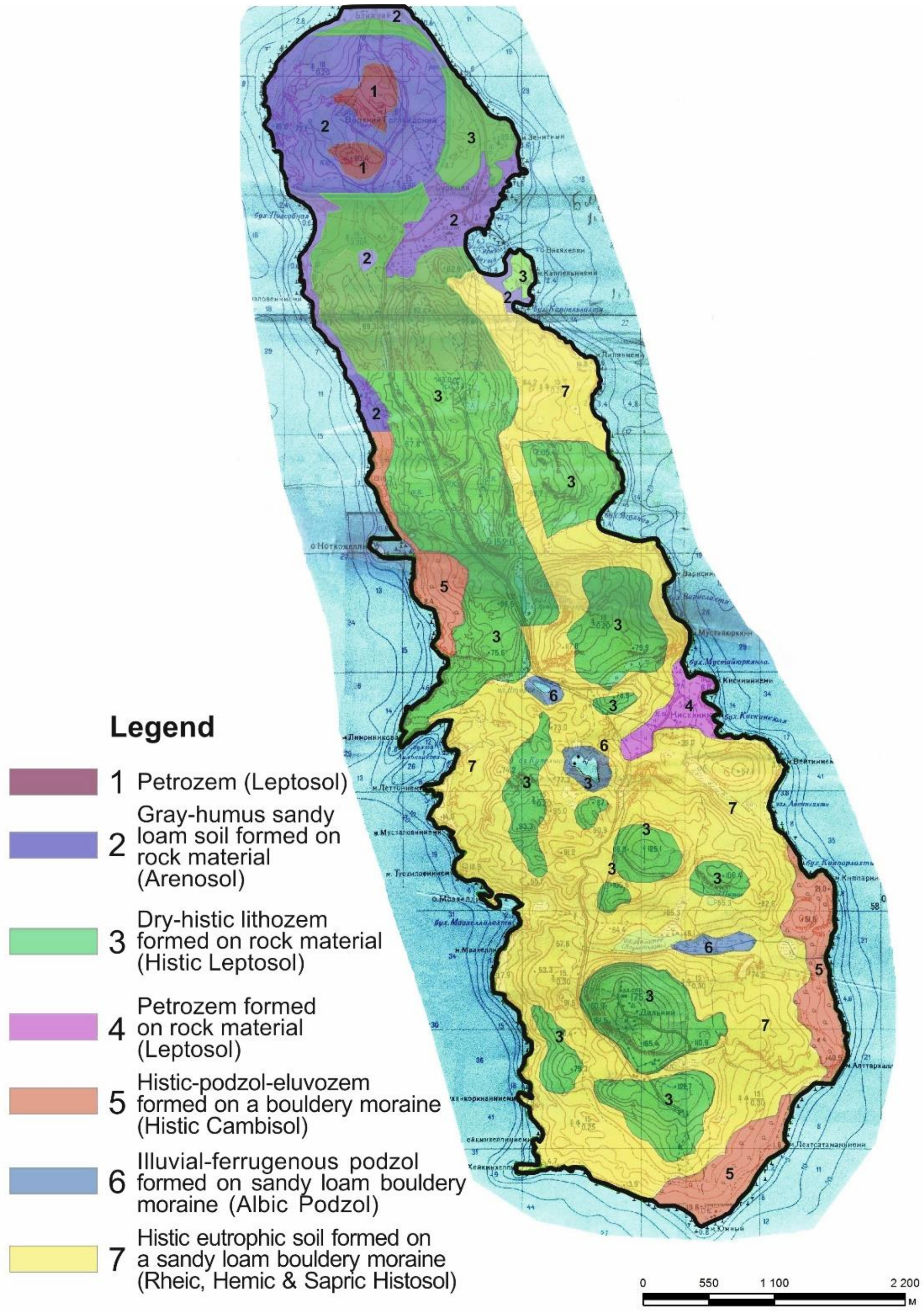


Figure 2. Soil cover map of Gogland (the author is Abakumov E.V., St. Petersburg State University). Soil names are given, according to [36]; soil names in the brackets, according to [37].

Shallow soils—Lithosol and Petrozem [36] (Leptosols—WRB) (Figure 3)—are characteristic of the tops of selga-type landscapes (Leptosols (Humic)), rocky outcrops, large fragments of colluvium, and rubble eluvium of granite rocks. Soils profiles are shallow (from several centimeters to several tens of centimeters). They do not have a middle fine earth horizon (B horizon). Gray-humus soils (Arenosols—WRB), with a more developed profile (Figure 4), and dry-histic lithozem (Histic Leptosols—WRB), with weakly decomposed organic matter accumulations (Figure 5), can be found on the slopes of selga-type landscapes.

Figure 3. The photo of Petrozem (AY horizon) formed on rock material (Leptosol (Humic)—WRB).

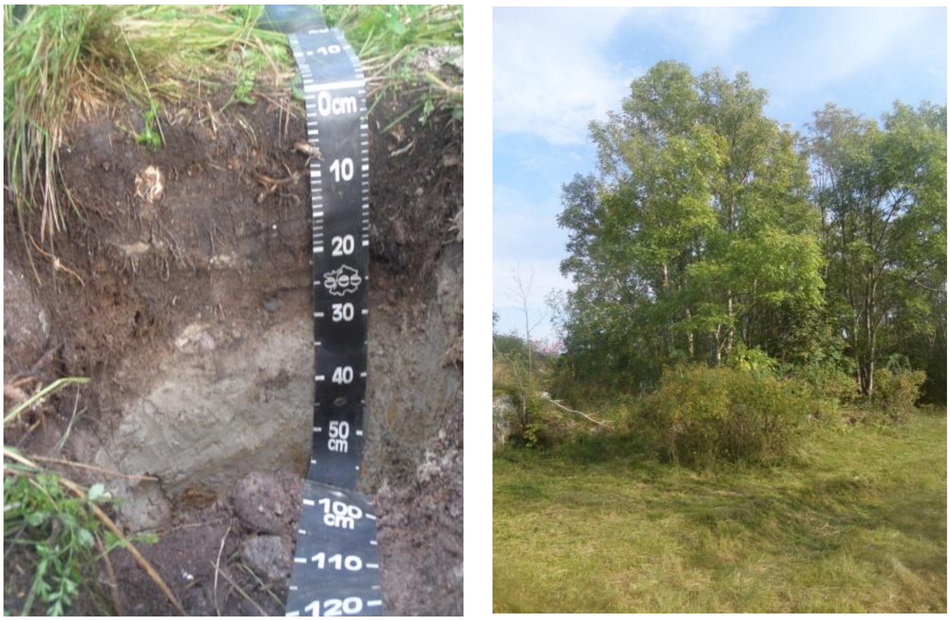
Figure 4. The photo of Sandy loam gray-humus soil formed on rock material (Arenosol—WRB).

Figure 5. The photo of Dry-histic lithozem formed on rock material (Histic Leptosol—WRB).

Histic-podzol-eluvozems (Histic Cambisols—WRB) appear in transit positions, and an illuvial horizon is absent there, but the eluvial horizon is present. Such soils are common in the central part of the island at mild, weakly drained slopes.

Podzols (Albic Podzols—WRB) are quite typical for inter-selga-type landscape areas at altitudes of 60–70 m above sea level, and they can be peaty (Histic Podzols—WRB) and gley (Gleyic Podzols—WRB), depending on local conditions. Histic (eutrophic) soils (Rheic, Hemic & Sapric Histosol—WRB) are widespread at lake's shores and relief depressions. The thickness of the organic strata here is an average of about 50 cm.

There are few anthropogenically transformed soils on the island (only 5% from the whole area), and they are common on the former arable lands and hayfields in the Kiskenkylä Bay in the south and Surkulä in the north of the island. There are now sparse ash forests on sod-podburs (Entic Podzols—WRB) (there are no traces of the arable horizon, but weathering processes are expressed in the middle part of the profile, combined with an illuvial–ferruginous process) (Figure 6). There are also soils with an old-arable horizon in some places.



(**a**) (**b**)

Figure 6. Agro-soddy-podbur gley post-agrogenic formed on boulders moraine (Entic Stagnic Gleyic Podzol—WRB): (**a**) soil profile; (**b**) vegetation and landscape of boulders moraine.

In general, shallow soils on massive crystalline rocks dominate on Gogland. Soils with eluvial process (eluvozems (Cambisols—WRB) and various podzols) are the second most common, followed by bog and bog-gley soils (Histosols—WRB). The pH_{H2O} of the studied soils on Gogland is characterized by a strongly acidic to weakly acidic reaction, which increases towards the lower horizon (Figure 7). The pH_{H2O} in upper soil horizons did not show high variability, it ranges from 4.6 to 5.6. The decreasing of pH_{H2O} in subsurface layers was observed in almost all studied soils: the peat horizon (TJ) had pH_{H2O} 4.2 on average and the podzolic horizon (E) had 4.5, and down the soil profile there is a slight increase in pH_{H2O} (5.4–5.6).

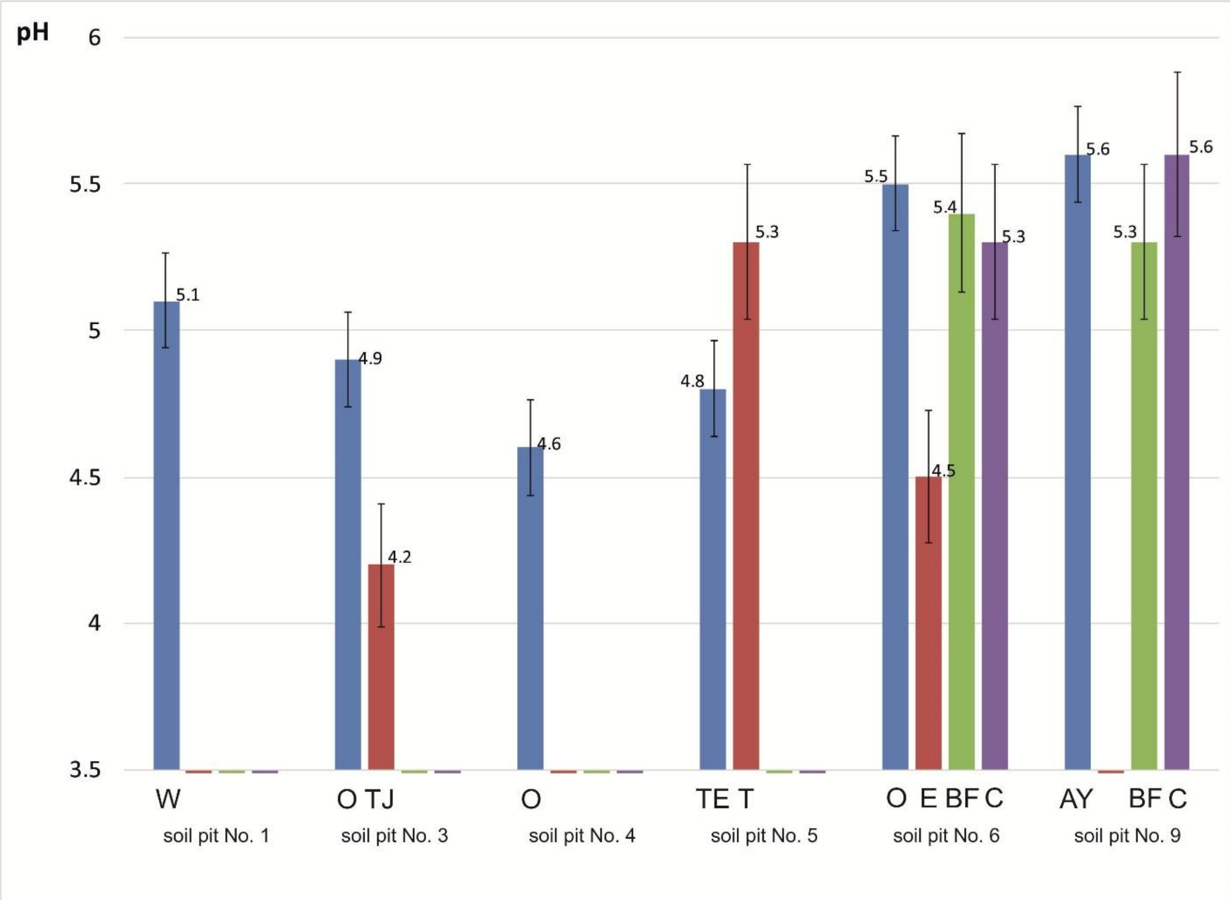


Figure 7. The pH in fallow soils on Gogland: soil pit No. 1—humus petrozem formed on rock material (Leptosol (Humic)—WRB); soil pit No. 3—dry-histic lithozem formed on rock material (Histic Leptosol—WRB); soil pit No. 4—petrozem formed on rock material (Leptosol—WRB); soil pit No. 5—sandy loam histic-podzol-eluvozem formed on a bouldery moraine (Histic Cambisol—WRB); soil pit No. 6—illuvial–ferruginous podzol formed on a sandy loam bouldery moraine (Albic Podzol—WRB); soil pit No. 9—gley soddy podbur on stratified marine sandy-loamy sediments (Entic Stagnic Tidalic Gleyic Podzol—WRB). Soil horizons: W—incipient humic horizon; O—litter; TJ—dry peat horizon; TE—eutrophic horizon; T—peat horizon; AY—gray humic horizon; E—podzolic horizon; BF—illuvial-rusty horizon; C—soil-forming rock.

The carbon content in upper soil horizons showed relatively high variability (11.5–44.4%). Topsoil horizons of the studied soils (O or AY) had the maximum C content throughout the whole soil profile of 33.6% on average for the O horizon and 4–5% in the AY horizon (Figure 8). The decreasing of organic matter in lower soil horizons was observed in all soils: the podzolic horizon (E) had 0.8–2.1% on average, and down the soil profile there was an accumulative horizon (BF), so there is a little accumulation of organic matter (2.6%). Finally, the parent material had the lowest C content (0.9%).

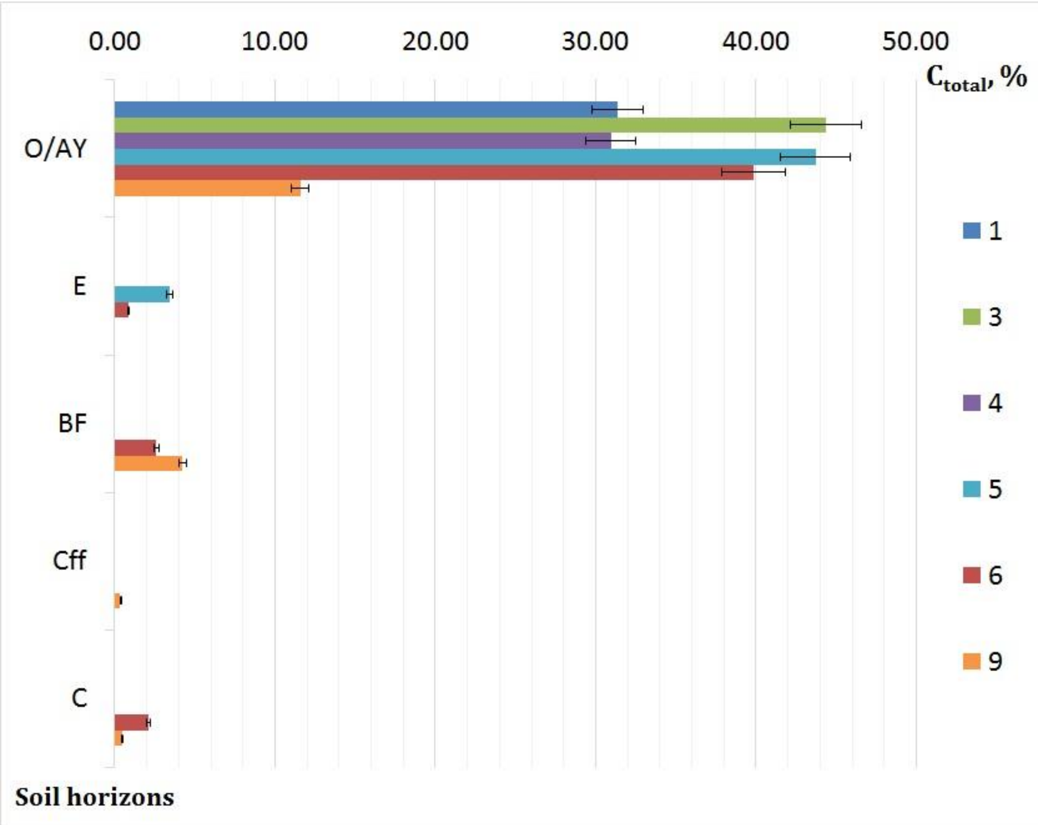


Figure 8. C_{total} content (%) in fallow soils on Gogland (No. of soil pits, according to Figure 7).

The results of soil organic matter elemental analysis (Figure 9) indicate the following information. Comparative analysis of the soil's organic-matter elemental composition using atomic ratio diagrams made it possible to distinguish a group of petrozems (Nudilithic Leptosols—WRB), which differ from more developed lithosols (Leptosols—WRB) by a lower content of carbon and hydrogen. Alfehumus soils also form a separate group of organic matter characterized by an increase in the proportion of aliphatic chains (in terms of the H:C ratio).

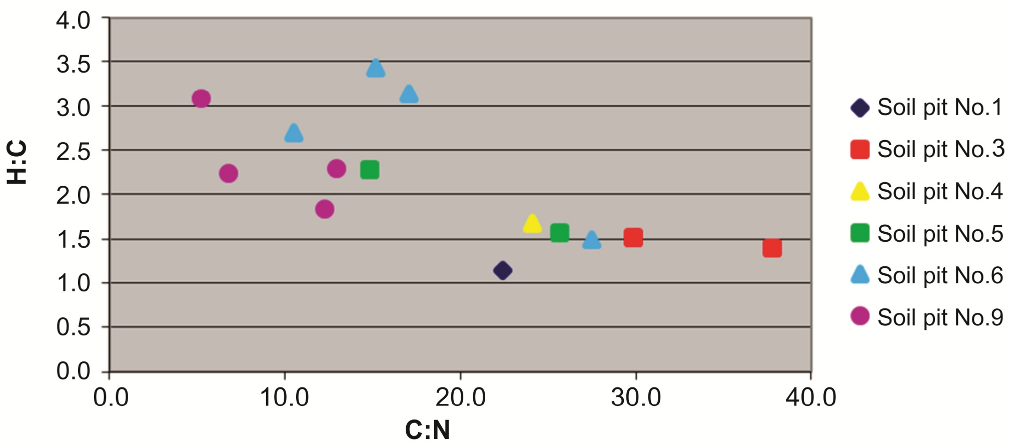


Figure 9. Soil organic matter Van Krevelen diagram of fallow soils on Gogland: ratios H:C and C:N (No. of soil pits, according to Figure 7).

The trace element status of the soils investigated in terms of heavy metals is shown in Table 1.

Table 1. Trace elements status of studied soils (numerator is heavy metals content, mg kg^{-1}; denominator is Igeo).

No. of Soil Pit	Horizon	Cu	Pb	Zn	Cd	Ni	Cr	Zc	Trace Elements Status
Humus petrozem formed on rock material (Leptosol (Humic)—WRB)									
1	W	0.19 −7.15	1.03 −4.80	3.16 −4.35	0.07 −1.94	0.40 −5.84	0.74 −4.66	−3.40	allowable
Dry−histic lithozem formed on rock material (Histic Leptosol—WRB)									
3	O	5.38 −2.33	39.10 0.45	25.90 −1.32	0.47 0.89	3.90 −2.56	3.00 −2.64	2.00	allowable
3	TJ	0.65 −5.38	2.94 −3.29	6.93 −3.22	0.06 −2.09	0.60 −5.26	0.90 −4.38	−3.30	allowable
Petrozem formed on rock material (Leptosol—WRB)									
4	O	0.97 −4.80	10.50 −1.45	11.00 −2.56	0.11 −1.17	0.96 −4.58	0.95 −4.31	−2.40	allowable
Sandy loam histic−podzol−eluvozem formed on a bouldery moraine (Histic Cambisol—WRB)									
5	TE	0.89 −4.92	3.06 −3.23	6.75 −3.26	0.13 −0.94	0.80 −4.84	0.92 −4.35	−2.80	allowable
5	T	0.65 −5.38	3.21 −3.16	5.04 −3.68	0.06 −2.13	0.83 −4.79	1.16 −4.01	−3.30	allowable
Illuvial−ferruginous podzol formed on a sandy loam bouldery moraine (Albic Podzol—WRB)									
6	O	0.52 −5.70	3.38 −3.08	5.65 −3.52	0.14 −0.91	0.66 −5.12	0.67 −4.81	−2.80	allowable
6	E	0.13 −7.70	0.98 −4.87	2.91 −4.47	0.13 −0.98	0.34 −6.06	0.48 −5.28	−3.10	allowable
6	BF	0.65 −5.38	2.94 −3.29	6.93 −3.22	0.06 −2.09	0.60 −5.26	0.90 −4.38	−3.30	allowable
6	C	0.20 −7.08	0.33 −6.43	3.88 −4.06	0.13 −0.97	0.33 −6.12	0.77 −4.61	−3.10	allowable
Gley soddy−podbur on stratified marine sandy−loamy sediments (Entic Stagnic Tidalic Gleyic Podzol—WRB)									
9	AY	15.65 −0.79	207.30 2.85	86.00 0.41	0.17 −0.57	1.89 −3.60	9.47 −0.99	10.80	allowable
9	BF	39.22 0.54	147.50 2.36	81.40 0.33	0.17 −0.58	1.44 −4.00	7.37 −1.35	8.90	allowable
9	C	0.32 −6.40	0.79 −5.17	5.85 −3.47	0.14 −0.87	0.40 −5.84	0.88 −4.41	−3.00	allowable
Post hoc test		$p < 0.05$	$p < 0.05$	$p < 0.05$	0.15	$p < 0.05$	$p < 0.05$	$p < 0.05$	
Significance of differences		Sign.	Sign.	Sign.	Insign.	Sign.	Sign.	Sign.	

The total pollution indicator in the upper horizons is characterized by low values (Zc < 16), which means they are within the permissible (tolerable) level of contamination. The calculation of the geoaccumulation index (Igeo) and its environmental interpretation [46] showed that the soils are moderately/heavily polluted by only one element: Pb (in the case of gley soddy-podbur on stratified marine sandy-loamy sediments; there is no pollution in other cases). There were weak levels of technogenic pollution by Cu, Zn, Cd, Ni, and Cr for all studied soils (Table 1). Therefore, Pb should be considered as a priority pollutant among all heavy metals in these soils. The same information was shown for other external islands of the Gulf of Finland [23]. The difference between heavy metal contents was statistically significant for all elements ($p < 0.05$).

The results obtained are confirmed by previously conducted pedo-environmental studies [47] in the Leningrad region. A comparison of the actual concentrations of heavy metal's mobile forms in soil samples with their control content in soils was performed. The control value was the content of element's mobile forms in the arable layer of the natural soddy-podzolic soil in the northwest of Russia (Table 2) [48].

Table 2. Microelements mobile forms content in soils of the north-west of the European part of Russia, mg kg^{-1} of air-dry soil.

Soil	Mn	Zn	Cu	Co	Mo
Northwest and North of the European part of Russia					
Soddy-podzolic soils (Umbric Albeluvisols—WRB)	62.00–274.00	0.90–1.50	2.70–5.50	0.50–1.13	0.13–0.16
Peaty-podzolic soils (Histic Albeluvisols—WRB)	4.00–83.00	0.68–2.90	1.40–2.00	0.06–0.33	0.10–0.33

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

For example, the actual copper mobile forms content in almost all samples is below the control value (Table 2) (gley soddy-podbur on stratified marine sandy-loamy sediments (Entic Stagnic Tidalic Gleyic Podzol—WRB) is an exception—about 15.6 mg kg^{-1} at AY horizon and 39.2 mg kg^{-1} at BF horizon). The average zinc content remarkably exceeds the control and reaches 86.0 mg kg^{-1}. Nevertheless, soils are assessed as uncontaminated.

Based on the results of the study, it can be concluded that the soil contamination of the surveyed areas is not of priority with mobile forms of copper and zinc. A high anthropogenic impact on the soils of external islands is noted, while zinc and copper pollution is non-specific and does not always manifest.

Therefore, Gogland is a key object with high pedodiversity and a low level of soil contamination, and that makes it possible to consider it as an area with ideal conditions for the development of natural complexes and conservation of a unique natural area with little influence by mankind—as a nature reserve. Specially protected natural areas are the most promising objects in terms of integrating ecosystem services into economic mechanisms and developing markets for these services, since, due to their status and management features, they can act as providers of ecosystem services.

The ecosystem services of Gogland are insufficient in terms of current regional economics, but in the future, under conditions of developing tourism, they can become more refined, especially in terms of recreational and aesthetic ecosystem functions. However, the nature of Gogland has long attracted attention for its unique beauty and the ecosystem services it provides. The island of Gogland has the following potential:

- The potential of location advantage—the island is located in the center of the Gulf of Finland, equally distant from the largest port cities of northern and southern coasts of the Gulf of Finland. There are sea routes along the island leading to the largest cities in the region;
- The territorial potential—a huge area of the island, exceeding the area of the island of Kotlin; it has great potential in the structure of territorial planning of the entire region;
- The recreational potential—a diverse flora and fauna composition, picturesque landscapes and a uniqueness of the entire natural complex as a whole, these are former Finnish settlements where residents worked and rested;
- The social and cultural potential—the island's history, existing for millennia, creates a rich cultural heritage, which is represented in the natural monuments, culture, and scientific achievements;
- The research potential—the group of external islands of the Gulf of Finland is an exclusive object of research in various fields of scientific activity. They may include: archeology, both underwater and terrestrial; botany; geology; meteorology; astronomy;

biology; geography; history and other sciences. This is confirmed by the great interest of the Russian Geographical Society;

- The economic potential—the development of Gogland territory will strengthen the economic and touristic basis of the Leningrad region;
- The touristic potential—all of the above factors have a favorable effect on tourism development, both domestic (including agrotourism in abandoned arable lands) and international;
- The yacht potential—the island based on its location is interesting as an intermediate stopover point for small boats running between the ports of the Gulf of Finland.

The soil of Gogland performs many ecological functions in ecosystems, and individual soil properties or their complex are involved in the implementation of certain ecosystem services provided. The transformation of soil indicators under the influence of various factors can lead to a change in the quality of ecosystem services. The regulatory ecosystem service "filtration and accumulation of chemical elements in ecosystem" correlates with a wide range of soil properties (bulk density, pH, particle size distribution, humus stocks, and trace metal pollution). Providing ecosystem services as a genetic material of the biota are determined by the number and biomass of soil biota from the selected soil indicators: bacteria, fungi, and actinomycetes. "Weathering and soil formation processes" correlates with such soil properties as, for example, a decrease in the thickness of humus stratum due to several factors and basal respiration as a parameter of biological activity.

However, any island ecosystems are too vulnerable to withstand the increasing anthropogenic impacts. The greatest danger to the island's natural complexes may arise during the minerals development, an increase in unorganized tourists' flows, and the laying of the North European Gas Pipeline route.

The most effective way to preserve the island nature can be an organization of a protected area. Moreover, the creation of protected areas in Gogland will not contradict the idea of organizing an international tourist center, since they are designed to serve for preserving natural complexes and objects, which will conserve the island's picturesque nature and, of course, increase its attractiveness for tourists. At the same time, protected objects of the island will be defended by environmental legislation from negative forms of economic impact and will allow regulating recreational and economic loads.

This is the first attempt to identify and assess the main ecosystem services of Gogland, but considering the results obtained during this edaphic research, the island could perform many more ecosystem services. These ecosystem services should be assessed in future investigations. The assessment of ecosystem services, including those provided by protected natural areas, is relevant, since it makes it possible to determine a more complete structure of benefits received from protected areas and contribute to the internalization of the positive external effects associated with them, including through payment mechanisms for ecosystem services.

4. Conclusions

As a result of the research, a soil map of Gogland was produced. Gogland lands are characterized by a wide diversity of soils patterns at different stages of development. The specificity of island soil cover is characterized by sufficient diversity, the presence of soils at initial stages of development, soils with a fully developed differentiated profile with a pronounced eluvial process—eluvozems (Cambisols—WRB), and various podzols (Podzols—WRB), as well as the rarest, organogenic soils—bog and bog-gley soils (Histosols—WRB).

The pH_{H2O} varies from a strongly acidic reaction to a neutral one, increasing towards the lower horizon, while pH_{KCl} is characterized by a very strongly acidic to weakly acidic reaction. The carbon content in upper soil horizons showed relatively high variability. This was due to the different rates of former anthropogenic fertilization of the soil and the time since the land was last used. The total pollution indicator in the upper horizons was characterized by a tolerable contamination.

The island of Gogland performs few ecosystem services. The island ecosystems are too vulnerable to withstand the increasing anthropogenic impacts. The most effective way to preserve the island's nature would be to organize its status as a protected area. Thus, these unique soils of mentioned areas could be used for the evaluation of long term evolution of anthropogenically developed soils after further 70 years of abandoned (fallow) state.

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