RESEARCH PAPER

# MACROPHYTES AS INDICATORS OF THE ECOLOGICAL STATUS OF VALAAM ISLAND SMALL LAKES SYSTEM

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ABSTRACT. The article evaluates the ecological status of five small lakes on Valaam Island (Igumenskoe, Chernoe, Ossievo, Nikonovskoe, Krestovoe) using macrophytes as bioindicators. The methods proposed by Finland, Sweden, and Norway were used, to assess the state of eutrophication, the change in the composition of specific species, the change in the water level, and the state of acidification, according to different indexes (Reference index (RI), Trophic Macrophyte Index (TMI), Trophic Index (TIc), the Proportion of Type–Specific Taxa (PTST), the Percent Model Affinity (PMA), Water level Index (WIc), and Acidification Index (SIc)). An analysis of the floristic composition for the period 2011 – 2020 was realized, including taxonomic analysis, ecogroup, and macrophyte diversity. The dominant taxon was *Elodea canadensis* Michx. in Igumenskoe, Chernoe, Ossievo lakes and *Calla palustris* L. in Nikonovskoe and Krestovoe lakes. The ecogroup hygrohelophyte was the most diverse in all lakes studied. The ecological status of the lakes according to each assessed parameter reflects that all lakes are characterized by a mesotrophic to eutrophic state, there is a variation in species composition of macrophyte and no water level change or acidification processes are presumed to occur in any of the lakes. In general, each method has its limitations, but it is suggested to continue studies for the RI, TMI, PTST, and PMA indices, and to integrate them with other national physicochemical or biological indices.

KEYWORDS: Aquatic flora, Bioindication, Biodiversity, Ecological status, Karelia, North-West of Russia

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## INTRODUCTION

An ecosystem, like any system, is a set of different elements that interact with each other and behave as a unit. This close interaction between the elements of the ecosystem allows one element to be used as an indicator of the properties of another element (Brönmark and Hansson 2005; Lampert and Sommer 2007). In this study, macrophytes were used as bioindicators of the properties of the aquatic environment, specifically, as bioindicators of the ecological state of a group of small lakes in the Valaam archipelago.

The Valaam archipelago is located in the north of the Lake Ladoga and consists of more than 50 islands, of which the largest is Valaam Island, on which there are eleven small forest lakes characterized by low transparency (0,3 – 4,6 mSD), medium – high chromaticity (40 – 296°Pt-Co), medium – high content of organic matter (7,0 – 58,2 mgO/L) (Rumyantsev and Kondratiev 2013; Stepanova et al. 2016; Voyakina 2017).

The anthropogenic impact on the ecosystem has increased in recent years, especially since 2007, due to the construction of roads, new monastery hermitages, restoration and development of agricultural land, tourism, and recreational activities; further exacerbating concern about the disturbances of the natural environment, such as depletion of natural resources, change in the hydrological regime and the microclimate, accumulation of waste (municipal, agricultural, etc.), disappearance or reduction of species, chemical alteration of water, soil and air composition, erosion processes, and others (Litovka and Samokhin 1991; Stepanova et al. 2016). In the southern part of Ossievo and Chernoe lakes, pastureland improvement is developed; also, nearby is located the Valaam farm, which is expanding its production area. Since 2007, 15% of the Nikonevsky Lakes basin has been taking place in the process of meadows reclamation, which has affected the decrease in lake transparency (Stepanova et al. 2016).

The relevance of the study is linked to the contribution to the research being conducted in Valaam lakes, the evaluation of the implementation of assessment methods proposed by neighboring countries, the recognition of the importance of using bioindicators (as a complement to physicochemical assessments), the evaluation of the use of macrophytes as a good bioindicator (not limited to the more commonly used organisms such as phytoplankton and fish), the identification of a negative impact promptly to implement necessary actions to ensure a good condition, the integration and the comparison of the results obtained with the beginning of a future proposal for sampling, monitoring, and modeling.

The present study's main objective is to assess the ecological status of five small lakes in the Valaam archipelago, using methods with the macrophyte bioindicator. In accordance with the aim, an analysis of the floristic composition of macrophytes was also included, to have a more complete overview.

## MATERIALS AND METHODS

### Morphological and physicochemical characteristics of the studies of lakes

The present study involved the analysis of the characteristics of the Konevsky Lakes group (consisting of three lakes connected by channels: Igumenskoe, Chernoe, and Ossievo), Nikonovskoye, and Krestovoe Lakes (see Fig. 1). The five forest lakes are characterized by small areas (0,003 – 0,022 km²), low – medium depth (1,3 – 4,5 m), humic – very humic (55 – 212 °Pt-Co), and slightly acid – neutral pH (5,6 – 8,6) (Stepanova et al. 2016; Voyakina 2017, Stepanova et al. 2021). The most important features of this group are given in Table 1 (Stepanova et al. 2021).

### Macrophytes data for the period 2011 – 2020

In this study, the data corresponding to the period 2011 – 2018 was collected by N.V. Zueva. The data for 2020 were collected by B.B. Buenano and N.V. Zueva. The base for the fieldwork was the educational and scientific station of the Russian State Hydrometeorological University (RSUH).

Macrophyte sampling was carried out in all the lakes studied, during July and August, when the plants were well developed enough to be identified. Data for the years 2011 and 2018 are available for all studied lakes, while data for the year 2012 are available only for the Konevsky Lakes.

At the end of August 2020, according to the characteristics of lakes, especially their small size (<0,05 km²), samplings were performed over the entire area of the lake (with special attention to the coastal zone), except for areas where there were no macrophytes (British Standards Institution 2007; European Commission, Joint Research Centre and Institute for Environment and Sustainability 2014; Kuoppala et al. 2008; Swedish Agency for Marine and Water Management 2015). The method of sampling and abundance measurement is presented in Table 2. Macrophyte species were identified in-situ by N.V. Zueva; when a confirmation in the determination of the specie was needed, it was taken to the RSHU scientific station, where after herbarium processing and microscopic identification was done, it was sent to the Herbarium of the Papanin Institute for Biology of Inland Waters Russian Academy of Sciences (IBIW) for storage. The identification of hydrophytes was confirmed by the expert of the Laboratory of Systematic and Geography of Aquatic Plants – A.A. Bobrov. Identification of mosses was performed by O.G. Grishutkin.

### Taxonomic, ecogroup and biodiversity analysis of Macrophytes

Macrophytes were identified to the species level, and they were analyzed according to two parameters: taxonomic level (GBIF 2021) and lifestyle (ecogroup according to Table 3) (Papchenkov 2003). Macrophytes were identified exclusively up to the hygrophyte level (IV).

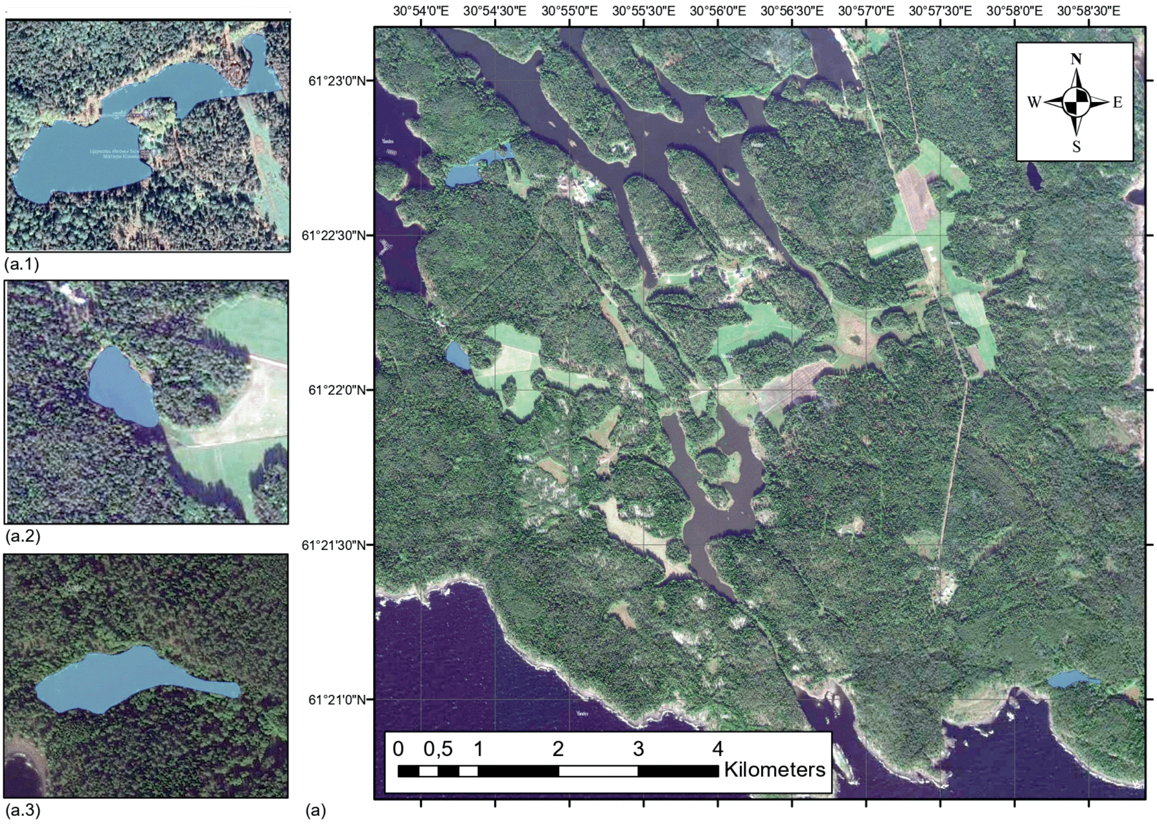


**Fig. 1. (a) Location of the studied lakes on Valaam Island: (a.1) Konevsky Lakes (left to right: Igumenskoe, Chernoe, and Ossievo lakes), (a.2) Nikonovskoe lake, (a.3) Krestovoe lake**

**Table 1. General characteristics of the group of lakes studied**

| Characteristics | The Konevsky Lakes (Igumenskoe, Chernoe and Ossievo) | Nikonovskoe Lake | Krestovoe Lake |
|---|---|---|---|
| pH | 5,6 – 7,5 | 5,8 – 7,6 | 7,3 – 8,6 |
| Area [km²] | 0,003 – 0,022 | 0,011 | 0,014 |
| Depth [m] | 1,5 – 4,5 | 2,5 | 1,3 |
| Humic [°Pt-Co] | 55 – 110 | 90 – 260 | 80 – 212 |

**Table 2. Description of the characteristics of the sampling carried out in 2020**

| Parameter | Description |
|---|---|
| Macrophytes | Any macrophyte that was in contact with water (hydrophytes and helophytes). |
| Method | Whole lake survey: longitudinal transect (maximum 100 m) divided into sub-transects of 10 m long, and from the shore to the maximum depth of macrophyte growth (perpendicular to the shore). |
| Abundance meters | Percentage scale (0,5 to 100%) and semi-quantitative (1 = rare, <1%; 2 = scattered, 1 – 10%; 3 = common or frequent, 10 – 25%; 4 = locally dominant or abundant, 25 – 75%; and 5 = dominant, > 75%). |
| Number of sampling sites | The number of transects sampled was 5 (Lake Igumenskoe), 3 (Lake Chernoe), 3 (Lake Ossievo), 5 (Lake Nikonovskoe) and 3 (Lake Krestovoe). |
| Criteria for reference lake | < 10% of the total catchment area with the presence of anthropogenic activity such as agriculture, grazing, deforestation, or land-use change; <0,1% with the presence of urban areas, no abrupt water level variations, no point sources of domestic or industrial water pollution. |

For biodiversity analysis, specifically, the frequency of occurrence of species, the following indices were used (Death 2008; Fedor and Spellerberg 2013; Fedor and Zvaríková 2019; Ingram 2008): species richness (Margalef and Menhinik indices), diversity (Shannon – Wiener index), and equitability (Pielou and Berger – Parker index), according to Table 4. Furthermore, the verification of the species found in the lakes was realized according to the international and local red list (Republic of Karelia) (Artemyev et al. 2020; UICN 2021).

## Assessment of ecological status using macrophytes

The ecological status is assessed as the degree of change of the lake in relation to its natural conditions (Brönmark and Hansson 2005; Kuoppala et al. 2008; Leka et al. 2008). The assessment of the ecological status can be analyzed by different methods, but, by the geographical location of the Valaam archipelago, methods developed in neighboring countries – Finland, Sweden and Norway (see Table 5) were used (European Commission, Joint Research Centre, Institute for Environment and Sustainability 2014; Leka et al. 2008; Norwegian Environment Directorate 2018; Swedish Maritime and Water Authority 2019). From the different indices available for assessing ecological status, it was decided to use six indices: three for assessing eutrophication status (RI, TMI, TIc), two for assessing change in species composition (PTST, PMA), and one for change in water level (WIc) and one for acidification process (SIc).

**Table 3. Classification of macrophytes according to their life-form**

| Code | Ecogroup | |
|---|---|---|
| I.1 | Hydrophyte | Hydrophyte 1. Macroalgae and aquatic mosses |
| I.2 | | Hydrophyte 2. Hydrophytes, freely floating in the water column |
| I.3 | | Hydrophyte 3. Submerged rooting hydrophytes |
| I.4 | | Hydrophyte 4. Rooting hydrophytes with leaves floating on the water |
| I.5 | | Hydrophyte 5. Hydrophytes, freely floating on the surface of the water |
| II.6 | Helophyte | Helophyte 6. Short grass helophytes |
| II.7 | | Helophyte 7. Tall grass helophytes |
| III | Hygrohelophyte | |
| IV | Hygrophyte | |
| V | Hygromesophyte and mesophyte | |

**Table 4. Biodiversity indices**

| Parameter evaluated | Index | Equations | |
|---|---|---|---|
| Species richness | Margalef | $D_{Mg} = \frac{S-1}{\ln(N)}$ | $S$ – total number of species<br>$N$ – total number of individuals<br>$n_i$ – total number of species $i$<br>$\log_2(S)$ – maximum diversity ($H_{max}$)<br>$N_{max}$ – number of individuals in the most abundant species (abundance of the dominant species) |
| | Menhinick | $D_{Mn} = \frac{S}{\sqrt{N}}$ | |
| Species diversity (specific richness + uniformity) | Shannon – Wiener | $H = -\sum_{i=1}^{S}\left(\frac{n_i}{N} \times \log_2\left(\frac{n_i}{N}\right)\right)$ | |
| Evenness vs equitability | Pielou | $J = \frac{H}{\log_2(S)}$ | |
| | Berger – Parker | $d = \frac{N_{max}}{N}$ | |

**Table 5. Ecological status parameters evaluated with the use of Macrophytes**

| Parameter assessed | Indices | | |
|---|---|---|---|
| | Finland | Sweden | Norway |
| Eutrophication | Reference index (RI) | Trophic Macrophyte Index (TMI) | Trophic Index (TIc) |
| Change in species composition | The proportion of type–specific taxa (PTST) and the percent Model Affinity (PMA) | – | – |
| Water level change | – | – | Water level Index (WIc) |
| Acidification | – | – | Acidification Index (SIc) |

**Eutrophication.** The trophic status of a water body is assessed based on a list of sensitive, tolerant, and indifferent species (specific in each country) to nutrient load and the effect of lake eutrophication on macrophytes, by the species found and identified (only hydrophytes in each country's lakes. The indices are calculated as shown in Table 6 (European Commission, Joint Research Centre, Institute for Environment and Sustainability 2014; Leka et al. 2008; Norwegian Environment Directorate 2018; Swedish Maritime and Water Authority 2019), the EQR value – (Ecological Quality Ratio) corresponds to the normalized value in base one of the indices.

**Change in species composition.** The PTST index considers the possible extinction of specific species and the emergence of new species, and the PMA index describes the composition and proportions of the number of species about the reference community of the specific lake type (equations in Table 7) (European Commission, Joint Research Centre, Institute for Environment and Sustainability 2014; Leka et al. 2008).

**Water level changes and Acidification.** The WIc index evaluates the water level change and reflects the impact on the coastal zone and biological conditions, the index uses a group of species (only hydrophytes) that are sensitive, tolerant, or indifferent to these changes. The SIc index evaluates the acidification, which is related to the carbon uptake preferences of some macrophyte (only hydrophytes) species, that are sensitive, tolerant, and indifferent to acidification, due to the content of dissolved $CO_2$ under acidic conditions (Norwegian Environment Directorate 2018). The equations for the calculation are in Table 8.

For the calculation of each index, the specific lists (for each country) of macrophyte species that are classified as sensitive, tolerant or indifferent, to nutrient loading and the effect of lake eutrophication (RI, TIc, and TMI), changes in the level of water and biological conditions in the coastal zone (WIc), acidification and the level of carbon uptake (SIc), were used (Joint website of Finland's environmental administration 2019; Norwegian Environment Directorate 2018; Swedish Maritime and Water Authority 2019). Likewise, each method establishes its limits into the five categories: excellent, good, satisfactory/regular, moderate and poor/bad.

Previously, the type of lake to which the five lakes studied correspond was defined, to compare the calculated values with the ranges established for each category as indicated. Thus,

**Table 6. Equations of the assessment method for Reference index (RI), Trophic Index (TIc) and Trophic Macrophyte Index (TMI)**

| Index | Equations of RI, TIc, TMI | | Equations of EQR | |
|---|---|---|---|---|
| RI (Finland) | $RI \text{ and } TIc = \frac{N_s - N_r}{N} \times 100$ | $N_S$ – number of sensitive species<br>$N_T$ – number of tolerant species<br>$N$ – total number of species (sensitive, tolerant and indifferent) | $EQR = \frac{OV + 100}{RV + 100}$ | *OV* – observed (calculated) value<br>*RV* – reference value |
| TIc (Norway) | | | | |
| TMI (Sweden) | $TMI = \frac{\sum_{i=1}^{n} (IV \times WF)}{\sum_{i=1}^{n} VF}$ | *IV* – indicator value (1 to 10)<br>*WF* – weight factor (0,1 to 1)<br>Low values of *IV* and *WF* correspond to sensitive species | $EQR = \frac{OV - 1}{RV - 1}$ | |

**Table 7. Equations for evaluation of PTST and PMA indices**

| Index | Equations of PTST and PMA | |
|---|---|---|
| PTST (Finland) | $PTST = \frac{\sum k_{ji}}{\sum k_j}$ | $k_{ji}$ – number of species specific to lake type<br>$k_j$ – total number of species in the lake (in the sampling) |
| PMA (Finland) | $PMA = 1 - 0,5 \sum \lvert a_i - b_i \rvert$ | $a_i$ – relative proportion (%) of taxon i in the reference community (data)<br>$b_i$ – relative proportion (%) of taxon i in the community assessed (in the sampling) |

**Table 8. Equations of the assessment method for Water level Index (WIc) and Acidification Index (SIc)**

| Index | Equations of PTST and PMA | |
|---|---|---|
| WIc (Norway) | $WIc \text{ and } SIc = \frac{N_S - N_T}{N} \times 100$ | *$N_S$ – number of sensitive species*<br>*$N_T$ – number of tolerant species*<br>*N – total number of species (sensitive, tolerant and indifferent)* |
| SIc (Norway) | | |

according to the methods in Finland, lakes Igumenskoe and Chernoe correspond to the "Ph" type (small and humic lakes: <5km$^2$, 30 – 90 mg Pt/L) and the rest of the lakes correspond to the "Mh" type (shallow and humic lakes: <3m, 30 – 90 mg Pt/L); according to the method in Sweden, all the lakes correspond to the type "Northern boundary of Limes Norrlandicus"; and according to the method in Norway, all the lakes correspond to the type "Humic (>30 mg Pt/L) lakes with low alkalinity (1 – 4 mg Ca/L)" (Joint website of Finland's environmental administration 2019; Norwegian Environment Directorate 2018; Swedish Maritime and Water Authority 2019).

According to the five lakes, Lake Krestovoe is the one that has the characteristics of a reference lake as mentioned in the methods used by the countries, mainly because of its low impact on anthropogenic activity (agriculture, livestock farming, urbanization, etc.), due to its location which makes it difficult to access easily in the island (European Commission, Joint Research Centre, Institute for Environment and Sustainability 2014).

## RESULTS AND DISCUSSION

### Taxonomic, ecogroup and biodiversity analysis of Macrophytes

The main results of sampling realized in 2020 are summarized in Table 9. The area occupied by macrophytes remains around 10 to 20%, except in the smallest lake, Lake Ossievo, where the macrophytes occupied about half of the lake area, even some macrophytes were found in the center of the lake. In comparison to the values reported in 2010 (Zueva 2010), the lake area occupied by the macrophytes has increased in the Konevsky Lakes and Nikonovskoe Lake from a range of 6 – 25% to 11 – 48%; likewise, it occurs in Krestovoe Lake from 5% to 16% (see Table 10), although there is a reduction in the number of species from 20 to 11 species. Suggesting a higher nutrient availability in lakes with surrounding anthropogenic activity (agriculture, livestock, and other) compared to the lake with the lowest of anthropogenic impact (Lake Krestovoe).

In general, in all lakes surveyed the taxonomic composition consists mainly of Tracheophyte (approx. 90%), followed by Bryophytes (approx. 10%, with two genus *Sphagnum* sp. and *Calliergon* sp.), and only in Chernoe Lake Charophyta phylum (*Nitella* sp.) was identified. A predominance of hydrophytes (44 – 73% of a total number of species, see Table 9) observed in 2020 is not recent, however, it increased compared to 2010 (Table 10) when values reported were within the range of 30 – 50% (in the Konevsky Lakes and Nikonovskoe Lake) and 45% (in Krestovoe Lake) were reported (Zueva 2010; Stepanova et al. 2021).

The composition and variation (in the years 2011, 2012, 2018, and 2020) of macrophyte ecogroups in the Konevsky Lakes are shown in Fig. 2, while the variation (in 2011 and 2020) for Nikonovskoe and Krestovoe is shown in Fig. 3. According to the period 2011 – 2020, ecogroup III was the most diverse in all lakes studied.

In Igumenskoe Lake, ecogroup I.1 was represented by genre *Calliergon* sp. and *Sphagnum* sp.; ecogroups I.2 (*Utricularia* sp.) and II.6 (*Alisma* sp., *Sparganium* sp.) were absent in 2012 and 2018, in ecogroup I.3 was identified a new species in 2020 (*Potamogeton alpinus* Balb.), ecogroups I.4 and I.5 have no variation, in ecogroup II.7 the specie *Typha latifolia* L. was observed only in 2009; and ecogroup IV was decreased to a single specie (*Lycopus europaeus* L.).

In Chernoe Lake, ecogroup I.1 and I.2 were stably represented by genre *Sphagnum* sp. and specie *Utricularia minor* L., respectively; in ecogroup I.3 were two genre (*Elodea* sp., *Potamogeton* sp.), ecogroup I.4 was represented only by specie *Nuphar lutea* (L.) Sm., in ecogroup I.5 was two species: *Hydrocharis morsus-ranae* L. and *Lemna minor* L., in ecogroups II.6 and II.7 *Sparganium minimum* Wallr. and *Naumburgia thyrsiflora* (L.) Rchb. were the species that were regularly observed, respectively; and ecogroup IV was represented by genres *Juncus* sp., *Lycopus* sp., *Lysimachia* sp., *Ranuculus* sp.

In Ossievo Lake, ecogroups I.1, I.2, I.3, I.4, I.5, II.6 do not show a considerable variation; in 2020, new species were identified for ecogroup I.1 (*Calliergon megalophyllum* Mikut., *Sphagnum squarrosum* Crome), ecogroup I.2 (*Utricularia vulgaris* L.), I.3 (*Callitriche cophocarpa* Sendtn., *Potamogeton berchtoldii* Fieber), I.4 (*Potamogeton natans* L.), I.5 (two species: *Hydrocharis morsus-ranae* L. and *Lemna minor* L.), II.7 (*Equisetum fluviatile* L., *Typha latifolia* L.), IV (*Bidens tripartita* L., *Juncus conglomeratus* L., *Juncus filiformis* L.).

**Table 9. Taxonomic composition of lakes sampled in August 2020**

| Lake | Lake area occupied by macrophytes [%] | Maximum growth depth [m] | Total number of species (% hydrophytes) | Frequent and dominant species |
|---|---|---|---|---|
| Igumenskoe | 11,1 | 1,8 | 24 (48%) | *Elodea canadensis* Michx., *Calla palustris* L., *Potamogeton alpinus* Balb; *Utricularia vulgaris* L., *Hydrocharis morsus-ranae* L., *Nuphar lutea* (L.) Sm. |
| Chernoe | 21,5 | 1,5 | 29 (45%) | *Elodea canadensis* Michx., *Calla palustris* L., *Nuphar lutea* (L.) Sm. |
| Ossievo | 47,8 | 1,8 | 36 (52%) | *Calliergon megalophyllum* Mikut., *Elodea canadensis* Michx., *Utricularia vulgaris* L., *Hydrocharis morsus-ranae* L. |
| Nikonovskoe | 21,2 | 1,0 | 28 (44%) | *Calla palustris* L., *Cicuta virosa* L., *Potamogeton berchtoldii* Fieber |
| Krestovoe | 16,5 | 1,5 | 11 (73%) | *Calla palustris* L., *Hydrocharis morsus-ranae* L. |

**Table 10. Comparison of floristic composition between 2010 and 2020**

| Lake | Lake area occupied by macrophytes [%] | | Total number of species | | Percentage of hydrophytes [%] | |
|---|---|---|---|---|---|---|
| | 2010 | 2020 | 2010 | 2020 | 2010 | 2020 |
| Konevsky and Nikonovskoe | 5 – 25 | 11,1 – 47,8 (increase) | 17 – 24 | 24 – 36 (increase) | 30 – 50 | 44 – 52 (increase) |
| Krestovoe | 5 | 16,5 (increase) | 20 | 11 (decrease) | 45 | 73 (increase) |

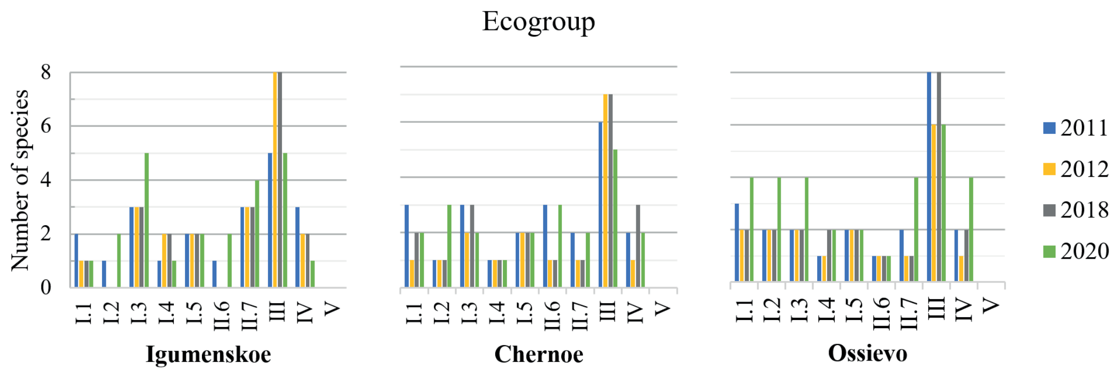


**Fig. 2. Variation in the number of species by ecogroup in Igumenskoe, Chernoe, and Ossievoe Lakes in a period of 2011 – 2020**

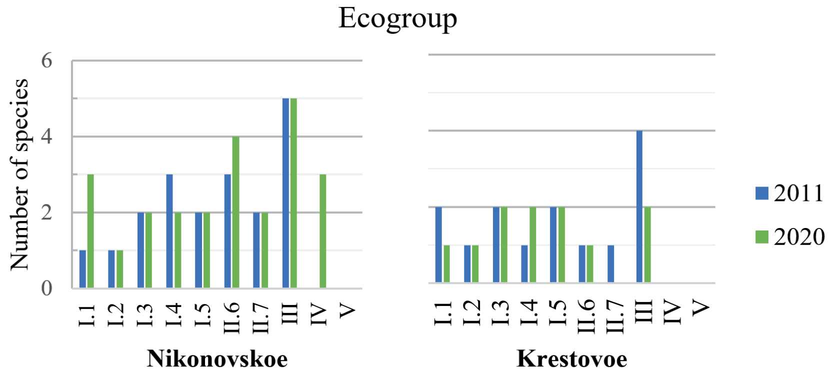


**Fig. 3. Variation in the number of species by ecogroup in Nikonovskoe and Krestovoe in a period of 2011 – 2020**

In the case of Nikonovskoe and Krestovoe lakes, only sampling data from 2011 and 2020 were available. In Nikonovskoe lake ecogroups I.2, I.3, I.5, II.7, III did not show a variation, in 2020 new species were identified for ecogroups I.1 (*Calliergon megalophyllum* Mikut., *Sphagnum squarrosum* Crome), II.6 (*Alisma plantago-aquatica* L.), II.7 (*Naumburgia thyrsiflora* (L.) Rchb.), III (*Cicuta virosa* L.), IV (*Bidens tripartita* L., *Lycopus europaeus* L., *Lysimachia vulgaris* L.), and other species were not observed for the ecogroups I.4 (*Nymphaea candida* J. Presl & C. Presl), II.7 (*Typha latifolia* L.), III (*Carex rostrata* Stokes). In Krestovoe lake ecogroups I.2, I.3, I.5, II.7, III did not show a variation, in 2020 some species were not observed for ecogroups I.1 (genre *Sphagnum* sp.), I.3 (*Potamogeton gramineus* L.), II.7 (*Sparganium emersum* Rehmann); and new species were identified for ecogroup I.1 (*Calliergon megalophyllum* Mikut.), I.3 (*Callitriche cophocarpa* Sendtn.), I.4 (*Nymphaea candida* J. Presl & C. Presl).

The calculated biodiversity values for the period of 2011 – 2020, in the Konevsky Lakes, show an increase of species richness ($D_{Mg}$ and $D_{Mn}$) in the three lakes, but especially in Lake Ossievo, as it appreciated from the taxonomic and ecogroup analysis. The $D_{Mg}$ index values were in a range 4,1 – 6,3, the maximum value correspond to Lake Ossievo in 2020; the $D_{Mn}$ index values were in the range 2,3 – 3,1, with the same trend as the Margalef index. The diversity (H) of the Konevsky group has remained stable (4,2) with a slight tendency to increase in Ossievo Lake (4,9). Since 2011, equitability (J and d indices) has been high and stable in the community, with no major variations (0,98 and 0,10, respectively), despite an increase in the number of species.

Nikonovskoe Lake the species richness and biodiversity increased, while the uniformity remained low, which contributed to the dominance of some species over others; in Lake Krestovoye, species richness, uniformity and biodiversity were decreased.

Regarding the conservation status of the species identified in the lakes mentioned in this study, no species is on the Red List of the database for the Karelia region or UICN (Artemyev et al. 2020; UICN 2021).

## Assessment of ecological status using macrophytes

Table 11 summarizes the results obtained for all the indices that use macrophytes as bioindicators, to assess eutrophication (RI, TMI and TIc), change in species composition (PTST and PMA), change in water level (WIc) and acidification (SIc) in 2020.

**Eutrophication.** When analyzing the trophic state, it should be considered that in all methods only hydrophytes species are used, so that the eutrophication state is associated with the aquatic environment. As a rule, in all Valaam lakes studied, tolerant species predominate, which determines the mesotrophic or eutrophic status.

According to the three indices used, the Norwegian TIc index is the one that rates the lowest status ("bad") for all lakes studied. Compared to lakes monitored for eutrophication in Norway, such as Lake Bergesvatnet (lowland, humus, shallow lake) which went through a process of eutrophication by agricultural activities in 1984 – 2001, where a moderate status (EQRTIc =0,84) was reported in 2016 and 2020 (Schartau et al. 2017; Schartau et al. 2021), it is suggested that it is perhaps not advisable to use this index for Valaam's lakes, because the list of species it uses is not in accordance; even because the reference lake (Lake Krestovoe) also obtained a low status.

Sweden's TMI index rates all lakes as moderate status, although it implements weight factors (WF) in the calculation, it remains to be considered whether the species list is in line with Valaam's lakes. While the species list used in Finland seems to be closer to the Valaam species list, it has also an important role to define correctly the type of lake (in our case Mh and Ph types), because according to the type of lake, will be the status ranges values, as it is observed the reference lake (lake Krestovoe) which is a more humic than the rest and has a lower status rating.

**Table 11. Results of Eutrophication index (RI, TMI, TIc), Water level change index (WIc), Acidification index (SIc) and Species composition change index (PTST and PMA) in 2020**

| Lake | RI | TMI | TIc | WIc | SIc | PTST | PMA |
|---|---|---|---|---|---|---|---|
| Igumenskoe | 0,48 Satisfactory | 0,79 Moderate | 0,41 Bad | 70 Excellent | 1,02 Excellent | 0,52 Satisfactory | 0,75 Good |
| Chernoe | 0,44 Satisfactory | 0,75 Moderate | 0,50 Bad | 65 Excellent | 1,25 Excellent | 0,36 Moderate | 0,77 Good |
| Ossievo | 0,44 Satisfactory | 0,80 Moderate | 0,37 Bad | 64 Excellent | 1,37 Excellent | 0,35 Moderate | 0,61 Good |
| Nikonovskoe | 0,46 Satisfactory | 0,70 Moderate | 0,56 Bad | 55 Excellent | 1,26 Excellent | 0,22 Moderate | 0,42 Satisfactory |
| Krestovoe | 0,38 Moderate | 0,79 Moderate | 0,56 Bad | 33 Excellent | 1,09 Excellent | 0,55 Satisfactory | 0,36 Moderate |

Some of the lakes that are located in the Karelia region (on the border of Finland and Russia) and share the "moderate" status are Korpijärvi (Mh), Ylä-Tyrjä (Ph), Juurikkajärvi (Mh), Hanelinlampi (Mh), Puruvesi (Saimaa), Ristilahti (Ph), among others (SYKE, 2022).

**Change in species composition.** As mentioned, it is important to properly define the lake type in the method used in Finland. The overall species composition (relative percentage – PMA) reaches a "good" status in the Konevsky Lakes, however, for the case of Krestovoe lake the status is reduced to "moderate", even though it is considered that it has received the least anthropogenic disturbance. Also, the results obtained for the PTST index show no lake reaches a "good" status of species composition according to the species composition in the reference lakes of Finland (natural level), so, that indicates the species composition has had a great change (due to anthropogenic activities), or the possibility of better defining the lake type as was mentioned.

**Water level changes and Acidification.** According to the results of the WIc and SIc indices, all lakes have an "excellent" status, there is no concern for a process of water level variation or an acidification process.

Based on the precautionary principle of nature, the ecological status rating corresponds to the lowest rating obtained "bad" or "moderate". Despite the limitations of each method, it is recommended to follow the methodology of Finland and Sweden, and to implement the chemical status and other bioindicators, in order to have a complete overview. Regardless of the methodology used, it is recommended to continue with the monitoring program, preferably on an annual basis.

## CONCLUSIONS

The aquatic flora has been varying over the years, but maintains a relative rich with a predominance of hydrophytes, which in 2020 represented between 44 and 73% of the total number of species.

The dominant taxon for all the studied lakes is Traqueophyte (90%). The families with the largest number of species overall in 2020 were Cyperaceae, Potamogetonaceae, Lentibulariaceae. The species with the highest occurrence were Elodea canadensis Michx. (in Igumenskoe, Chernoe and Ossievo lakes), Nuphar lutea (L.) (in Igumenskoe and Chernoe lakes), Calliergon megalophyllum Mikut. (in lake Ossievo), Calla palustris L. (in lakes Nikonovskoe and Krestovoe). The ecogroup III. Hygrohelophyte was the most diverse in all lakes studied.

All lakes can be attributed to mesotrophic and eutrophic types, because tolerant hydrophytes species are predominate in most lakes, even in the reference Krestovoe, therefore, it can be assumed that the studied lakes maybe naturally have a high level of trophic, but require additional research. No signs of changes in the water level on the banks or acidification processes were found.

In the future, it is proposed to conduct sampling in specific sectors of the lakes, and to classify macrophytes into zones of growth: helophytes, submerged hydrophytes and floating hydrophytes as proposed in the method of Finland, in order to better control and monitor the growth and change in the number and type of macrophytes.

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