YRKESHÖGSKOLAN NOVIA

The occurrence of macrophyte species in relation to water quality parameters in shallow bays along the coast of Southern Finland

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BACHELOR'S THESIS

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Title: The abundance of macrophyte species in relation to Chlorophyll-*a*, fDOM and Turbidity in shallow bays in the coast of Southern Finland, illustrated in ArcGIS.

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Abstract

Shallow bays are a common along the Finnish coastline and, due to low water exchange, they are very vulnerable to both human induced impact and natural processes. The bays studied, Pojoviken and Dragsfjärdsviken, at the coast of Southern Finland, are both considered as very vulnerable areas in the Habitat Directive of the European Union. This is the reason they have been researched more often in the past few decades.

The material used originates from two projects focused on collecting data that describe the state of eutrophication in the coastal waters in Hanko and Raasepori area. The material contains datasets of mapped macrophytes and "in situ" collected data on water quality parameters.

In this study, the relative abundance of nine selected macrophyte species were related to interpolated values of Chlorophyll-*a*, fDOM and turbidity in a NMDS ordination plot.

The results suggest that *Myriophyllum sp*. is clearly benefiting from higher levels of eutrophication and to some degree also *Nitellopsis sp*., *Nitella sp*. and *Chara sp*. are more sensitive to eutrophication. This suggests that there is some degree of relationship between the relative occurrence of macrophyte species and water quality parameters, indicating eutrophication.

Language: English
Key Words: eutrophication, turbidity, fDOM, Chl-*a,* Nitellopsis, Nitella, Chara, Myriophyllum

EXAMENSARBETE

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Abstrakt

Det finns en stor mängd grunda vikar längs den finska kusten. Detta habitat är mycket känsligt för både mänsklig påverkan och naturliga processer p.g.a. väldigt långsamt vattenutbyte. Vikarna, Pojoviken och Dragsfjärdsviken, belägna i södra Finlands skärgård, är båda klassificerade som väldigt känsliga områden i Europeiska Unionens habitatsdirektiv. Detta är orsaken till ökad forskning i dessa områden de senaste årtiondena.
Materialet som har använts för denna studie härstammar från projekten Havmanualen och Havsmanualen 2, vilka har samlat data för att kunna beskriva och åtgärda graden av övergödning på kusten runt Hangö och Raseborg. Den samlade datan innehåller en kartläggning av makrofyter och in situ mätt data för miljövariabler.

Denna studie jämför dessa dataset på nio makrofyters abundans och interpolerade värden, i ArcGIS, av klorofyll- *a*, fDOM och turbiditet, och som en NMDS ordination graf.

Resultaten tyder på att arterna i *Myriophyllum sp*. helt klart skulle gynnas av högre grad av övergödning, också *Nitellopsis sp*. till en viss grad. Däremot tyder resultaten på att *Nitella sp*. och *Chara sp*. är känsligare för den allt högre graden av övergödning. Detta tyder på att det finns en viss korrelation mellan abundansen av makrofyterna och värdena på miljövariablerna som indikerar övergödning.

Språk: Engelska
Nyckelord: Övergödning, turbiditet, klorofyll-*a*, fDOM, Nitellopsis, Nitella, Chara, Myriophyllum

OPINNÄYTETYÖ

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Tiivistelmä

Suomen rannikolla on paljon matalia lahtia, jotka ovat hitaan veden vaihtuvuuden takia erittäin herkkiä ihmisen toiminnalle sekä luonnollisille prosesseille. Suomen etelärannikolla sijaitsevat Pohjanpitäjänlahti sekä Dragsvikinlahti ovat molemmat luokiteltu Euroopan Unionin luontodirektiivissä erittäin haavoittuvaisiksi alueiksi. Tämä on syy, miksi näitä elinympäristöjä on ruvettu tutkimaan enemmän viime vuosikymmeninä.

Tässä tutkinnossa käytetyt tiedot ovat peräsin Havsmanualen ja Havsmanualen 2 projekteista, joissa on kerätty dataa makrofyyttien levinneisyydestä sekä tehty in situ mittauksia eri ympäristömuuttujista.

Tässä tutkinnossa verrataan yhdeksän makrofyyttien levinneisyyttä sekä ArcGIS-ohjelmalla tehtyjä interpolaatio-karttoja klorofylli-*a*:sta, fDOM:sta sekä sameutta, ja NMDS-diagrammia.

Tulokset viittaavat, että *Myriophyllum sp*. lajit hyötyvät selkeästi korkeammasta rehevöitymisasteesta, ja myös *Nitellopsis sp*. lajit jossain määrin. Sen sijaan *Nitella sp*. and *Chara sp.* lajit ovat herkempiä rehevöitymiselle. Tämä viittaa, että makrofyyttien levinneisyys ja ympäristömuuttujien arvot korreloi keskenään.

Kieli: Englanti
Avainsanat: Rehevöityminen, sameus, klorofylli-*a*, fDOM, Nitellopsis, Nitella, Chara, Myriophyllum

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1 Introduction

Shallow bays are a common habitat along the Finnish coastline. This habitat is largely influenced by run-off from land and accumulation of organic material from the sea and is therefore naturally rich in nutrients and organic matter. Because the bays are protected from waves and have a high retention time, the water usually warms more rapidly than open coastal environments. All these features promote a more productive environment with a rich plant community. Little research has traditionally been conducted in these bays. However, due to the implementation of the European Union Habitats Directive (Council Directive 92/43/EEC), more research is now being conducted. The directive emphasizes the importance of the shallow, sheltered inlets of the Baltic Sea. More research has been conducted related to the ecology, macrophytes, fish, zooplankton and the food web. Now there is a lot more knowledge about the ecology in these shallow bays, that shows a strong reaction in flora and fauna related to natural environmental gradients. The most important factor, explaining the composition of organisms in shallow bays, has been identified to be the degree of isolation and therefore the level of water exchange. (Hansen 2012)

The coastal areas are densely populated, which results in a high concentration of nutrients, especially nitrogen and phosphorus, in wastewater and runoff from the catchment area. This contributes to the rising level of eutrophication. The overabundance of nutrients leads to massive algal growth, and growth of macrophytes, in the growing season. This causes increased turbidity and therefore lower penetration of the sunlight to the bottom of the sea. This affects the whole food web. When the growing season is over, the dead organic material is sedimented on the bottom of the sea for decomposition. The microbes that decompose the material uses oxygen in the water and this may lead to hypoxia or even anoxia. (HELCOM 2018)

Over the past decades the nutrient load has been reduced, but no significant improvement of the sea can yet be seen. The reason for this is the internal load that is maintaining the eutrophication.

Practical measures to reduce the nutrient load need to be implemented. The projects Havsmanualen and Havsmanualen 2 have collected data that describes the state of eutrophication in the coastal waters in Hanko and Raasepori area. The goal of both projects was to identify practical measures that can be used to improve the ecological status of the coastal waters. In the Havsmanualen project macrophytes were mapped in over 5000 locals in Raasepori area in the years 2014 and 2015. In the Havsmanualen 2 project data on environmental variables was collected by automatic sensors in 2019. When data from both projects are combined, the results should indicate what kind of water quality conditions a macrophyte species prefers.

The study area for this study is two shallow bays in Raseborg, Southern Finland: Pojoviken and Dragsviksfjärden. The modified datasets, from Havsmanualen and Havsmanualen 2, were analyzed and illustrated in ArcGIS, and analyzed in R as a NMDS ordination, chosen species, in relation to the environmental variables Chl-*a*, fDOM and turbidity. Higher values of these variables act as indicators for eutrophication.

The species chosen for this study are members of *Myriophyllum sp*., *Chara sp.*, *Nitella sp*. and *Nitellopsis sp*. The *Myriophyllum sp.* and *Nitellopsis sp.* are expected to be abundant in areas with higher levels of eutrophication. *Chara sp.* and *Nitella sp.* are more sensitive species to higher levels of eutrophication and are expected to be abundant mostly in areas with a lower degree of eutrophication. Is there a correlation between the distribution and abundance of macrophyte species and the interpolated values on the environmental variables, Chl-*a*, fDOM and turbidity, describing eutrophication? (Hansen 2012)

2 Background

2.1 Havsmanualen

Havsmanualen was a two-year project managed by the Environmental Office of Raseborg and implemented by Novia University if Applied Sciences. The project consisted of underwater mapping of aquatic plants and macroalgae and the results were combined with already existing environmental information.

Havsmanualen 2 was a project managed by the Environmental Office of Hangö and implemented by Pro Litore. Data on environmental variables, such as Chl-*a*, fDOM, turbidity, salinity, CO_2, pH, conductivity and temperature, was collected with automatic sensors in the archipelago of Hangö and Raseborg. The route of the boat collecting data went near the coastline (Figure 1). This study area is only a small part of the full study area.

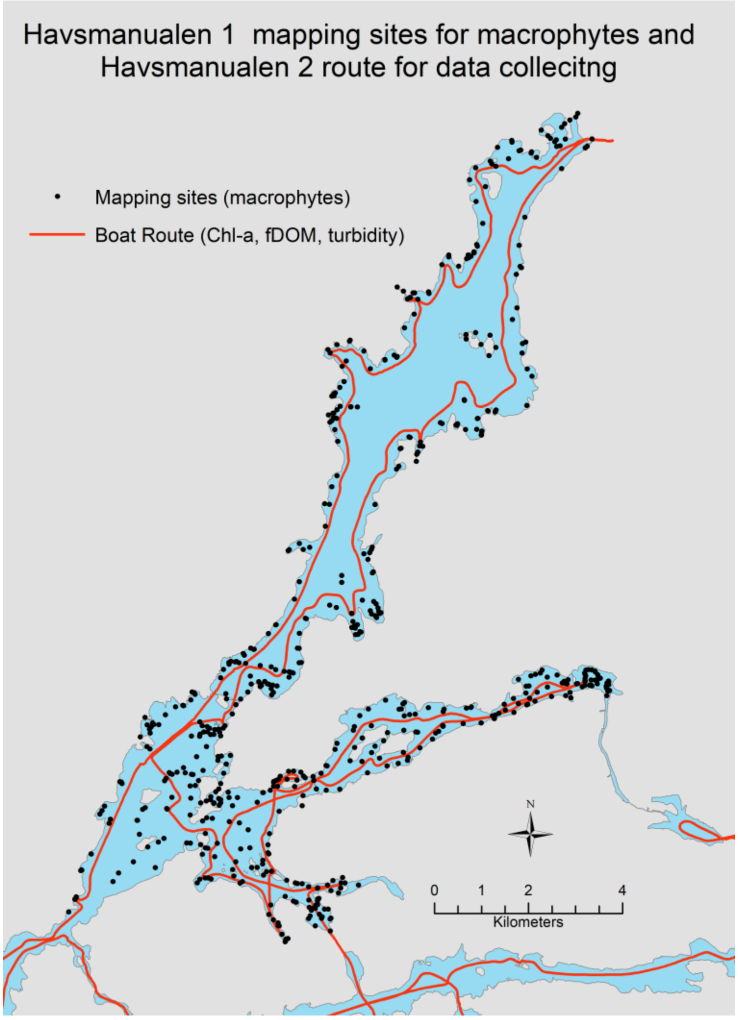

Figure 1 The mapping sites for macrophytes in Havsmanualen 1 and boat route (R6) for data collection for environmental variables in Havsmanualen 2. The maps are zoomed to the study area, the full study area of the Havsmanualen project is larger.

2.1.1 Mapping of macrophytes

The mapping of the macrophytes was conducted in late summer and autumn 2014 and 2015, during the high season for macrophytes. The mapping covers the entire inner and middle archipelago of Raseborg and consists of over 5000 mapping sites. Only a part of the mapping points is used in this study (Figure 1). The macrophytes in the different sites were mainly sampled using Luther rakes and aquatic binoculars and the abundance was determined on a 4-degree scale (Ekholm 2014 & The Municipality of Raseborg 2019).

2.1.2 Water quality parameters

The spatially detailed and extensive in situ data on the surface water for the environmental variables, Chl-*a*, fDOM and turbidity (also salinity), were collected by an automated underway measurement system with optical sensors. The sensors are connected to a rigid inflatable boat (BRIG N210H) with 0,4 m draft and water intake for the flow through system at 0,5 m depth. The data were recorded constantly together with geospatial information at 5 s intervals by an EXO2 multiparameter sonde and an associated Handheld unit (Xylem Inc.). The traveling speed was about 12 m/s, and therefore most of the data was logged at 60 m intervals. The Data was collected in the archipelago of Raseborg and Hangö, along a 830 km long route (Scheinin & Asmala 2020)

Data used in this study was collected in ten separate rounds conducted in three weeks intervals. The first round was conducted week 17 in April 2019, when the ice cover was gone, and the last round was week 44 at the turn of October and November 2019 (Table 1). The collecting of the data only for Pojoviken and Dragsviksfjärden was conducted during one day in the four consecutive days of collecting data.

Round	Date
R2	23.4-26.4.2019
R3	13.5-16.5.2019
R4	3.6-7.6.2019
R5	24.6-27.6.2019
R6	15.7-18.7.2019
R7	5.8-9.8.2019
R8	26.8-29.8.2019
R9	16.9-19.9.2019
R10	7.10-10.10.2019
R11	28.10-1.11.2019

Table 1 The dates for the data collection in Havsmanualen 2

2.2 Study area

The study area covers two bays, located in Ekenäs archipelago, in southern coast of Finland, in northern Baltic proper (Figure 2). The bays studied are Pojoviken and Draksviksfjärden. The growing season, for the macrophytes, is from April to October, and it is normally ice-covered in the winter, December to April. The dates for the data collection are therefore during this season. Due to the restricted exchange of water, Pojoviken and Dragsviksfjärden are largely affected by natural and anthropogenic factors from the surrounding land areas and are therefore very vulnerable to eutrophication.

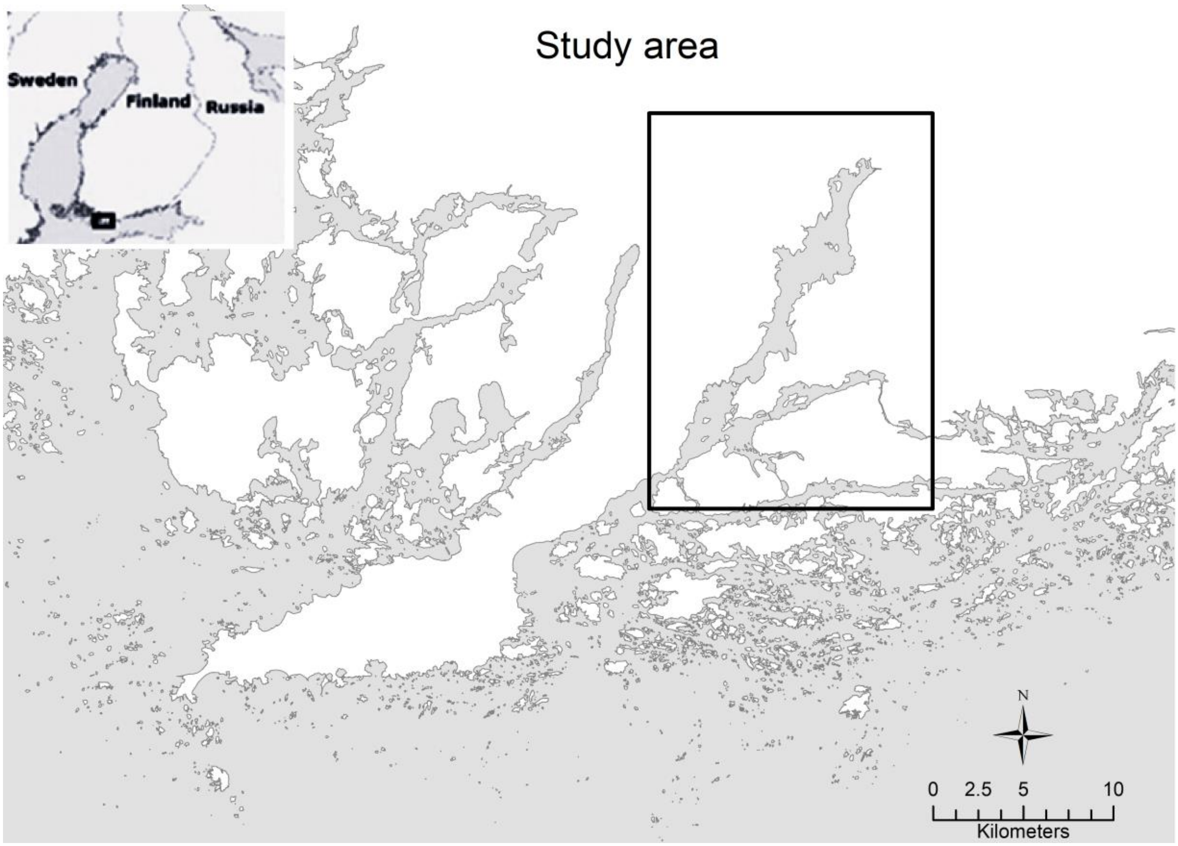

Figure 2 The Study area is in southern Finland in Raseborg. It covers Pojoviken in the north and Dragsviksfjärden in the east.

2.3 Research question

Is there a relationship between the distribution and abundance of macrophyte species and the interpolated values on the environmental variables, Chl-*a*, fDOM and turbidity, describing eutrophication?

3 Study subjects

3.1 Environmental variables

The environmental variables that describe the water quality, in this study, are Chlorophyll-*a*, dissolved organic material (fDOM) and turbidity. These variables are all water quality elements and can be measured with optical sensors. They are indicators of eutrophication and reduce the photic zone and the oxygen level and increase the sedimentation (Gholizadeh et al., 2016).

3.1.1 Chlorophyll-a

Chlorophyll-*a* (Chl-*a*) is a photosynthetic pigment found in plants, algae and cyanobacteria, that make the water look green Chl-*a* in the water is mainly in phytoplankton and are therefore the prime indicator of eutrophication and for nutrient pollution (Carlson 1977).

3.1.2 Fluorescent dissolved organic matter (fDOM)

Dissolve organic matter varies in color from yellow to brown and consists of naturally occurring, water-soluble organic material (Aiken et al., 1985). fDOM is representative as parameter for dissolved organic carbon, which is vital for functioning ecosystems (Niu et al., 2014).

3.1.3 Turbidity

Turbidity scatters light, rather than absorbing it. It does not affect the color of the water, in the same way as fDOM and Chl-*a*, but it affects the clarity of the water. Turbidity is a measure of suspended particles in water. Turbidity has been shown to have a negative impact on macrophyte cover in coastal areas (Sand-Jensen et al. 2008), because of reduced light penetrating the water. The consequence of this is reduced photosynthetic activity of the macrophytes. Also, the sedimentation on macrophytes, due to particle suspension, is negatively affecting macrophytes (Henricson et al. 2006).

3.1.4 Myriophyllum sp

Myriophyllum spicatum and *Myriophyllum sibiricum* are very similar species. Both are positively influenced by eutrophication, tolerate different conditions well and prefer sheltered environments. The species have low requirement of light, which means that it can flourish in turbulent waters. (Pitkänen et al., 2013)

Myriophyllum verticillatum grows mainly in fresh water but also in less saline brackish water. It prefers sheltered living environment and is not sensitive to eutrophication. (Pitkänen et al., 2013)

3.1.5 Charophytes

Chara aspera is a charophyte that grows up to 30 cm high and lives in both fresh and brackish water (Langangen et al., 2002). It has a wide tolerance in exposure and different conditions but is negatively influenced by eutrophication (Pitkänen et al., 2013).

Chara canescens is a charophyte, that is up to 25 cm high. It thrives in brackish water, in sheltered places covered with other vegetation (Langangen et al., 2002).

Chara globularis is a green charophyte that grows up to 50 cm high. It grows in both fresh and brackish water and it is very common in Scandinavia (Langangen et al., 2002).

Chara tomentosa grows up to 50 cm high, in fresh and brackish waters (Langangen et al., 2002) and does not tolerate wave movements. It is common in the Baltic Sea, and it is mainly abundant in sites with soft sediments with much organic material (Pitkänen et al., 2013). Increased turbidity, caused by boat traffic and large amounts of phytoplankton, have negative impact on the abundance of *C. tomentosa*.

Nitellopsis obtusa is a dark green charophyte, that can grow up to 60 cm high. It is very rare in the Baltic Sea, but it is abundant in Pojoviken. It is very typical that N. *obutosa* grows in clusters, without any other species absent. Abundance has increased over the period 1970 to early 21st century. The pattern of the spreading of this species implies that it is steered by the growing nutrient levels (Pitkänen et al., 2013). (Langangen et al., 2002)

Nitella flexilis is a charophyte, which height is 9-30 cm and has a clear green color. The species thrives in oligotrophic lakes and rivers, but it also grows in brackish water, such as the Baltic Sea. It is very common in Scandinavia, and it tolerates and even profits from some degree of eutrophication (Langangen et al., 2002).

4 Methods

To be able to get some results from the raw data, the material needs to be modified to the format needed for the analyses. The datasets were analyzed and illustrated in ArcGIS (ArcMap 10), and analyzed in R as a NMDS ordination, with all species in relation to Chl-*a*, fDOM and turbidity.

4.1 Modification and sorting raw data

The amount of raw data from the automatic sensor was massive and in need of some modification. The raw data was collected by several automatic sensors, which recorded the data for specific variables. The raw data from the sensors was gathered in one Excel table. The data contains several data series, which were combined to one series. The timestamp on the data sets (from the different sensors) did not automatically match, so it had to be manually modified to match. When a variable was missing values for a measuring point, the nearest value was copied and pasted to make the series complete and to avoid false zero-value in the interpolation of the data. The values from the raw data for Chl-*a* and fDOM were calibrated by the results from manually taken water samples (Scheinin & Astamala 2020).

4.2 ArcMap

The Excel sheet with all the measuring points from the automatic sensors was imported to ArcMap. Firstly, the XY data for the dataset was defined, exported to points and projected to the right coordinate system. A few outliers were manually removed from the dataset. Due to technical issues, there were points with null geometry that had to be removed from the dataset. This was performed by using the tool “Repair Geometry”. The points with null geometry were marked and deleted.

The coordinates of the mapping points of the macrophytes did not match coordinates of the measuring points for the environmental variables. Therefore, the environmental variables needed to be interpolated to get the estimated values for the mapping points. Before the interpolation, a 1000-meter buffer is made around the points. The best tool, in ArcMap, for this was Diffusion Kernel (Geostatistical Analyst-Interpolation with barrier). The other interpolation methods could not consider the land as a barrier, and therefore did not give a truthful outcome. To get interpolated values for the whole coastline, the coastline itself was not used as barrier feature. As barrier dataset, a polygon that is 20 meters from the coastline (on land) was used, to prevent the cells, cut by the coastline, from not being interpolated. The 20 meters was determined to be the most suitable to cover the whole coastline with interpolated values, keeping the barrier representative. The bandwidth was set to 1000 meters. The output is a raster, with cell size 10 meters x 10 meters.

This has been done to all ten datasets from the different rounds and at this point there are ten raster datasets for every variable. To combine the ten raster datasets, for the same variable, to one raster consisting of the mean values, Cell Statistics in Spatial Analyst is used. The ten raster datasets are chosen as input raster and mean value is chosen as overlay statistics. After this step there is only one raster per variable.

The exact values of the environmental at the locations of the mapping point is needed, to be able to do the R- Multivariate statistical analysis (4.3). The interpolated values for the environmental variables were extracted to the locations of the mapping points by using the tool “Extract multi values to points”. To get the information from the attribute table to an Excel file, the tool “Table to Excel” was used.

4.3 R-analysis

A Non-metric Multi-dimensional Scaling (NMDS) ordination analysis was done using the vegan library in R (Oksanen et. al., 2022) and the metaMDS function. The default Bray-Curtis dissimilarity index was used. The dissimilarity between sampling sites and abundance of macrophytes was analyzed and related to the variables Chl-*a*, fDOM and turbidity. The result of this analysis is illustrated in a NMDS ordination plot.

5 Results

The results consist of maps and a NMDS plot (Figure 3) showing the similarity between the macrophytes species (600 mapping points) and the relationship with the interpolated values of the environmental variables; fDOM, Chl-*a* and turbidity. The variations for the measured values are Chl-*a* 1,86-16,24 µg/L, fDOM 32,11-57,04 QSU and turbidity 1,40-5,53 FNU. There are 600 mapping points in the study area. The interpretations are that species closer to each other are more similar and the environmental variables are plotted on top. The tolerant species are more similar to each other and are located to the left side of the plot while the more sensitive species are located to the right.

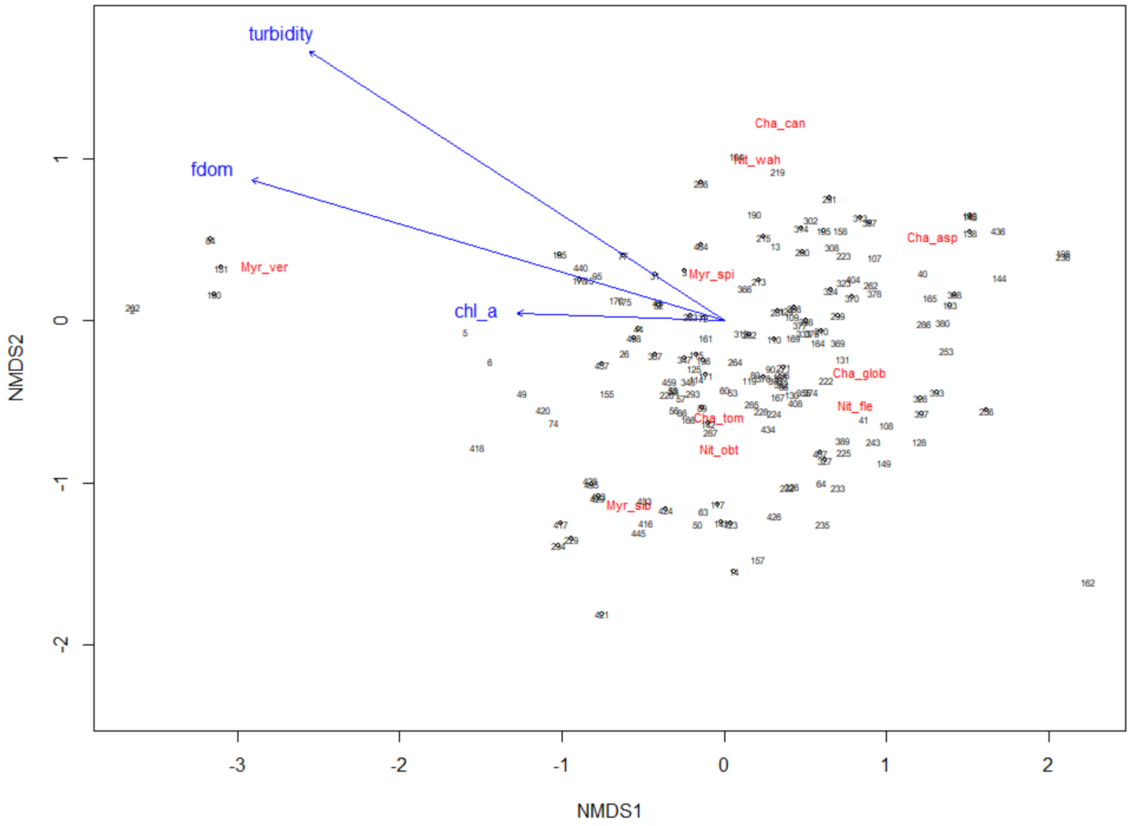

Figure 3 A NMDS plot describing the relationship between the abundance of macrophytes and interpolated values of Chl-*a*, fDOM and turbidity.

5.1 *Myriophyllum sibiricum*

Myriophyllum sibiricum is only abundant in the southern parts of the study area. The mapping sites where *Myriophyllum sibiricum* is highly abundant are located in areas with higher Chl-*a* concentrations (5-16 µg/L) (Figure 4). The species is abundant in sites that have both high and low fDOM values (30-50QSU) (Figure 5). The turbidity varies from 1-

6 FNU in the same sites (Figure 6). The NMDS plot (Figure 3) shows that *Myriophyllum sibiricum* is favorable by higher values of Chl-*a*, as also Figure 4 is showing.

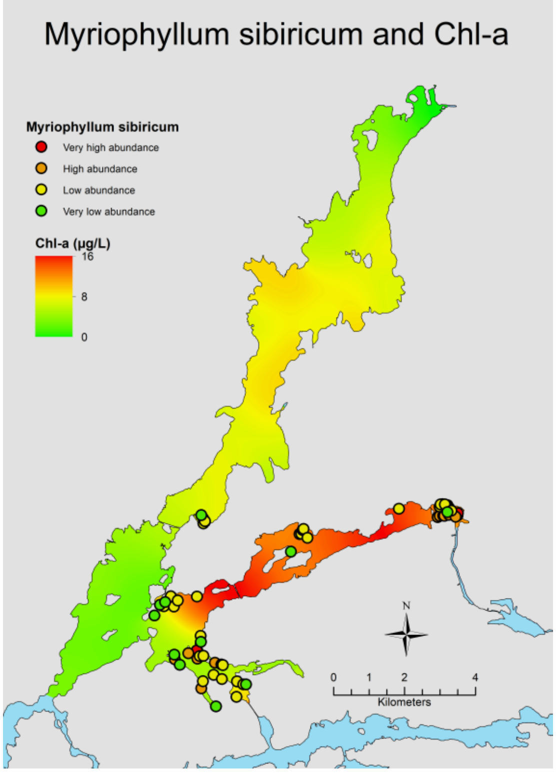

Figure 4 The abundance of *Myriophyllum sibiricum* and the interpolation of Chl-*a*.

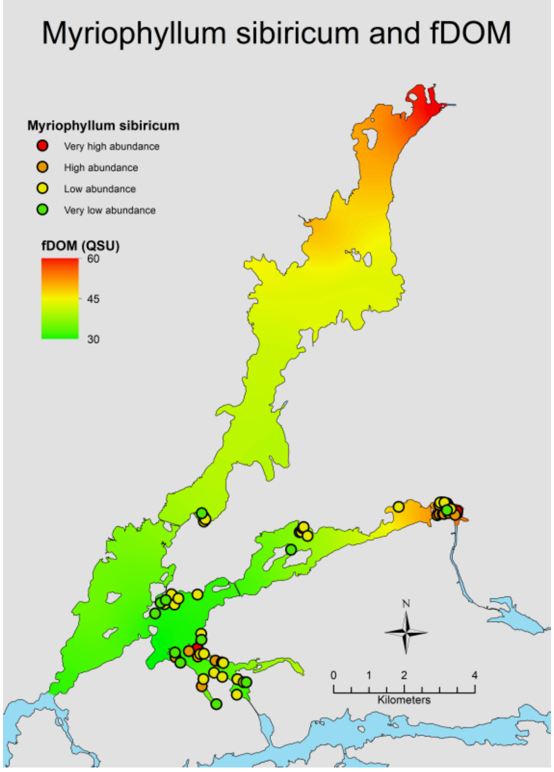

Figure 5 The abundance of *Myriophyllum sibiricum* and the interpolation of fDOM.

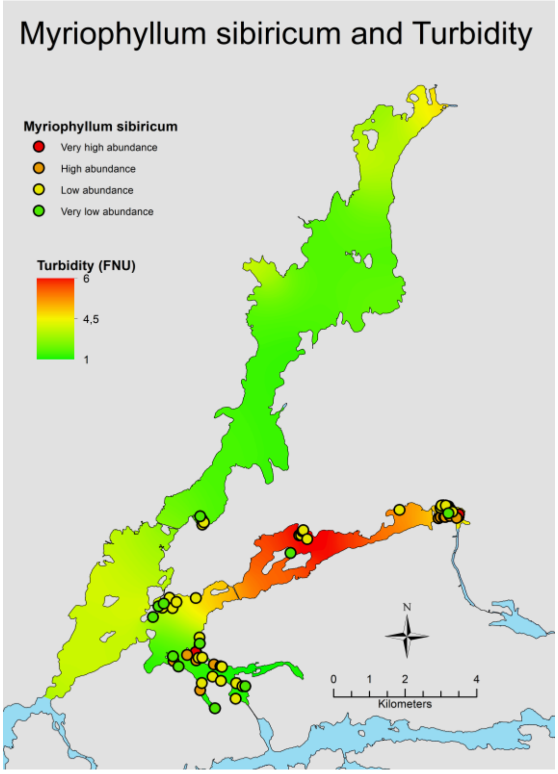

Figure 6 The abundance of *Myriophyllum sibiricum* and the interpolation of turbidity.

5.2 *Myriophyllum spicatum*

Myriophyllum spicatum is abundant in 336 mapping sites, spread evenly in the study area. The highest abundance is in the areas with high Chl-*a* levels (10-16µg/L) (Figure 7), but it is also abundant in areas with lower Chl-*a* levels. There is no clear correlation between the abundance and the fDOM value (Figure 8). The turbidity value is higher in the area with very high abundance of the species, but the species is also highly abundant in areas with low turbidity (Figure 9). According to the NMDS plot (Figure 3), *Myriophyllum spicatum* is not clearly favoring of disfavoring any of the studied environmental variables, as also is shown in Figure 7, Figure 8 and Figure 9,

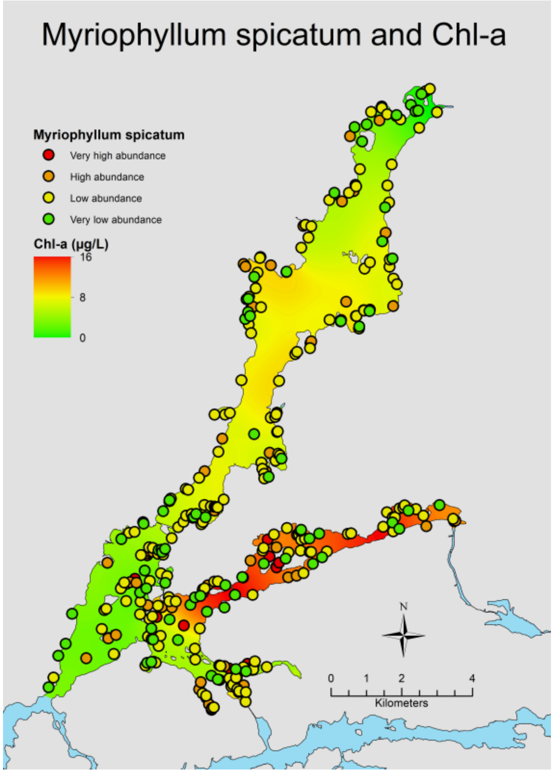

Figure 7 The abundance of *Myriophyllum spicatum* and the interpolation of Chl-*a*.

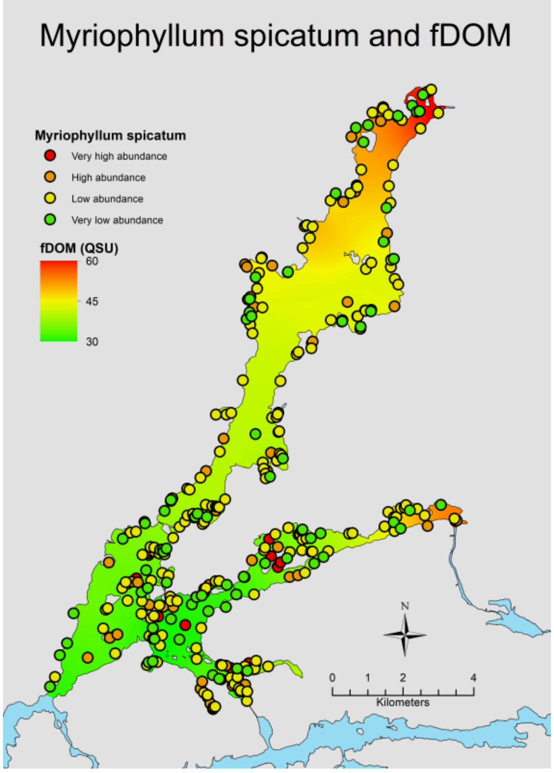

Figure 8 The abundance of *Myriophyllum spicatum* and the interpolation of fDOM.

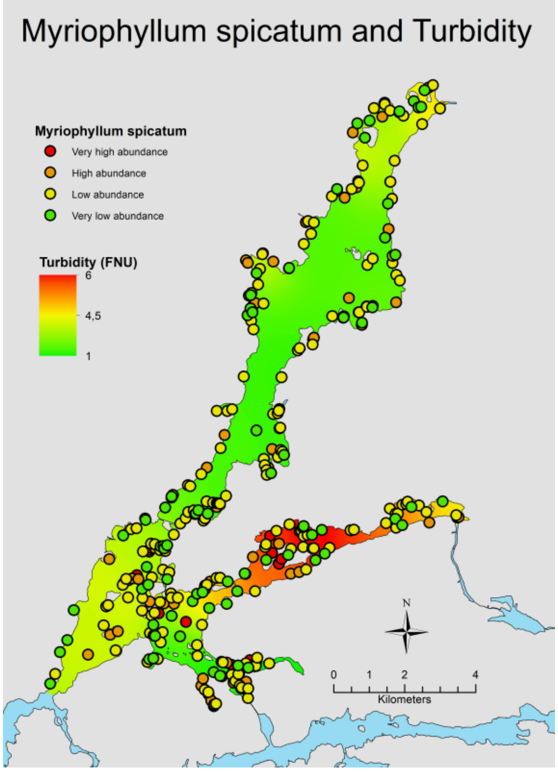

Figure 9 The abundance of *Myriophyllum spicatum* and the interpolation of turbidity.

5.3 Myriophyllum verticillatum

Myriophyllum verticillatum is present in only 31 mapping sites but it is spread even in the study area. The abundance is highest in areas with higher fDOM values (50-06 QSU) (Figure 11). The species is abundant in areas with lower turbidity values (1-5 FNU) (Figure 12). There is no clear correlation between the abundance and Chl-*a* concentration (Figure 10). The NMDS ordination plot (Figure 3) shows that *Myriophyllum verticillatum* is strongly favored by high values of all studied environmental variables, especially by fDOM, which can also be seen in Figure 10, Figure 11 and Figure 12.

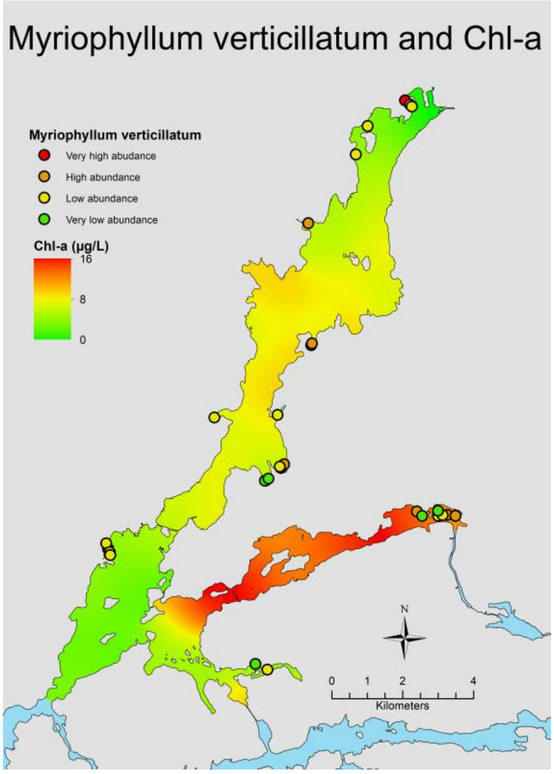

Figure 10 The abundance of *Myriophyllum verticillatum* and the interpolation of Chl-*a*.

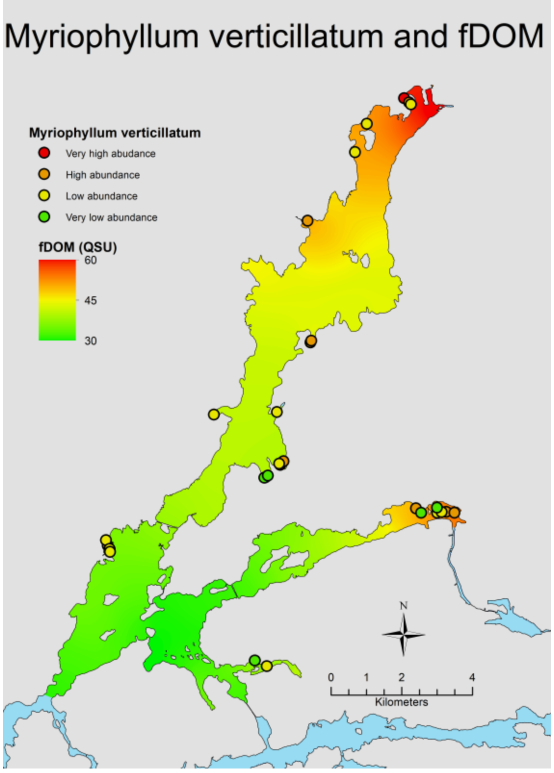

Figure 11 The abundance of *Myriophyllum verticillatum* and the interpolation of fDOM.

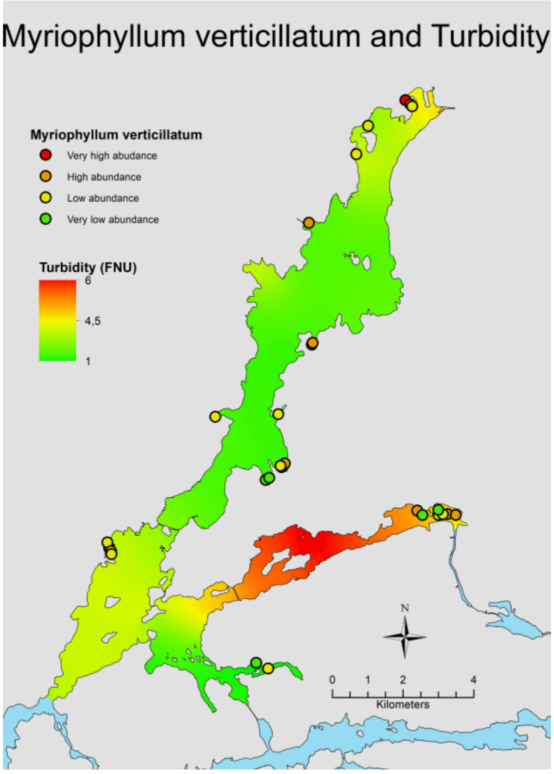

Figure 12 The abundance of *Myriophyllum verticillatum* and the interpolation of turbidity.

5.4 *Chara aspera*

Chara aspera is abundant in 68 mapping sites and is very high abundant in areas with Chl-*a* values less than 9µg/L (Figure 13). There is also a correlation with abundance and both low fDOM (Figure 14) and low turbidity values (Figure 15). It shows clearly, in the NMDS ordination plot (Figure 3), that *C. aspera* is favored by low values of all studied environmental variables, especially turbidity.

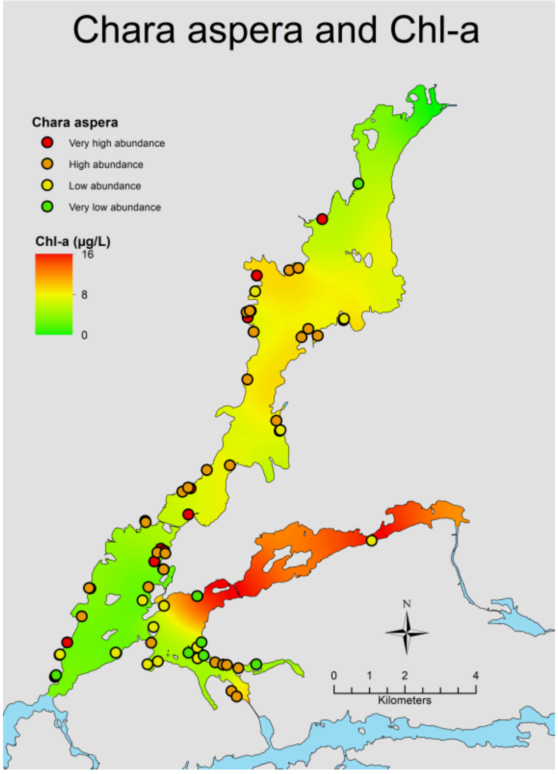

Figure 13 The abundance of *Chara aspera* and the interpolation of Chl-*a*.

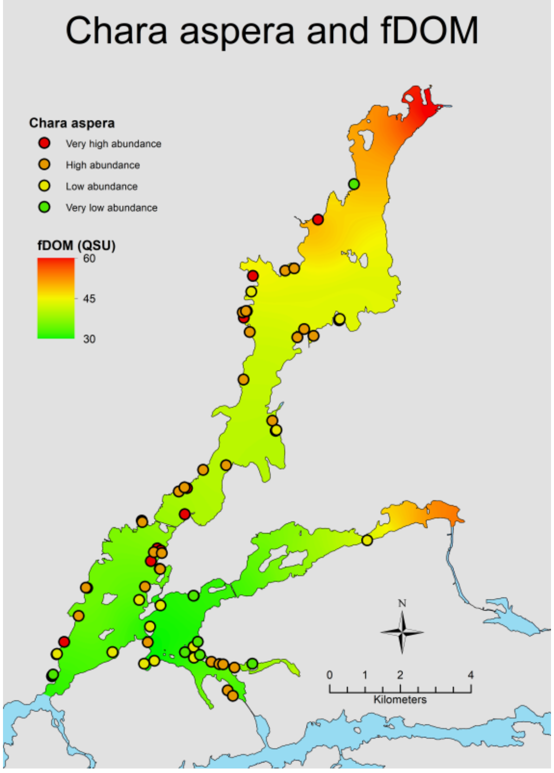

Figure 14 The abundance of *Chara aspera* and the interpolation of fDOM.

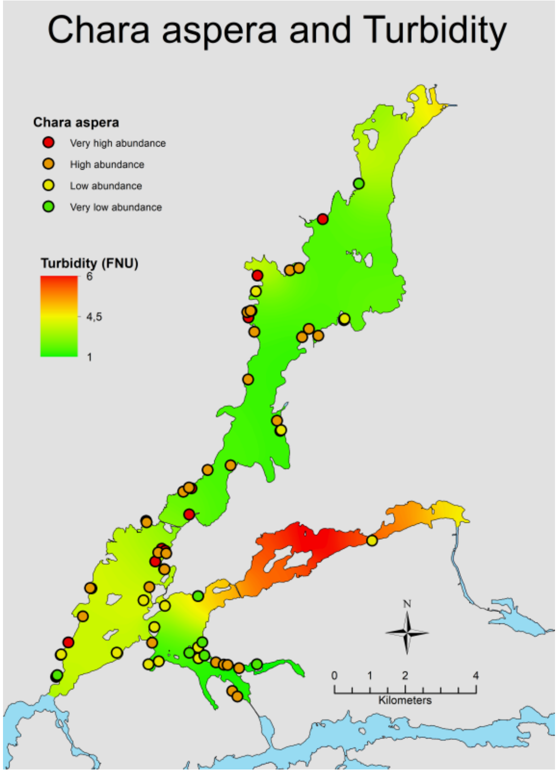

Figure 15 The abundance of *Chara aspera* and the interpolation of turbidity.

5.5 *Chara canescens*

The abundance of *Chara canescens* is very low, it is abundant in only two sites. The Chl-*a* value is low in both sites, less than 6 µg/L (Figure 16) The fDOM is also very low in both sites, less than 40 QSU (Figure 17). Also, turbidity is low in both sites, less than 4 FNU. According to the NMDS plot (Figure 3), *C. canescens* is favoring especially lower turbidity values, but also low Chl-*a* and fDOM.

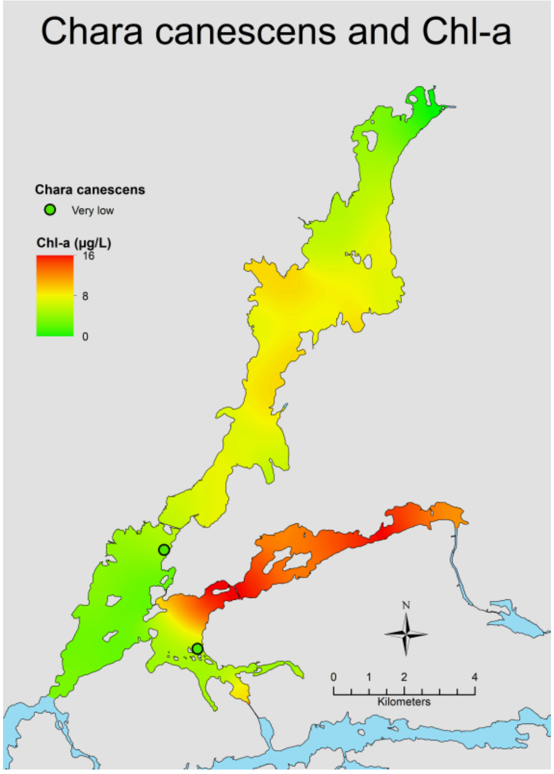

Figure 16 The abundance of *Chara canescens* and the interpolation of Chl-*a*.

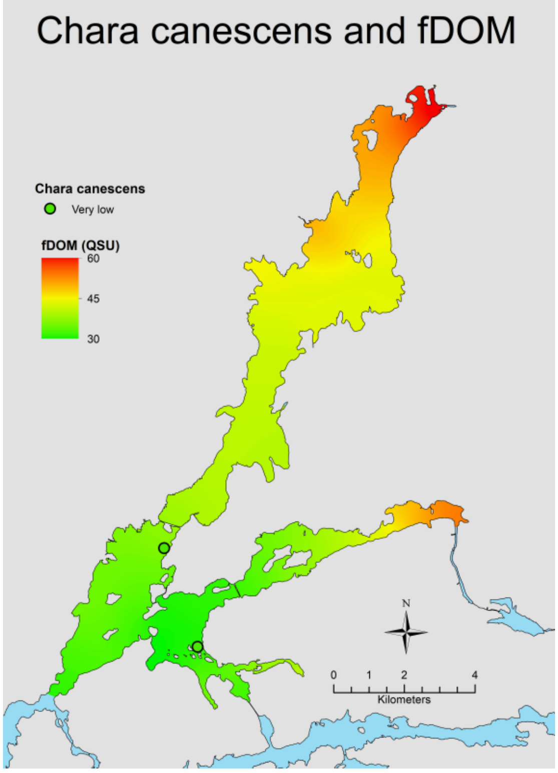

Figure 17 The abundance of *Chara canescens* and the interpolation of fDOM.

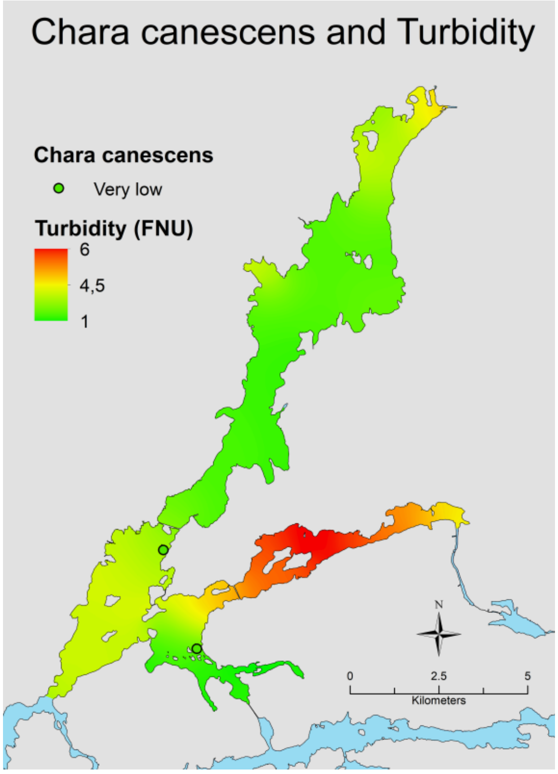

Figure 18 The abundance of *Chara canescens* and the interpolation of turbidity.

5.6 Chara globularis

Chara globularis is most abundant in the middle of the study area, in 121 mapping sites. The high abundance correlates with low turbidity, less than 4,5 FNU (Figure 21). The species is most abundant in areas with lower fDOM (Figure 20) and Chl-*a* values (Figure 19), but also exist in areas with higher levels. The NMDS plot (Figure 3) shows that *C. globularis* clearly favors low turbidity, but also low Chl-*a* and fDOM.

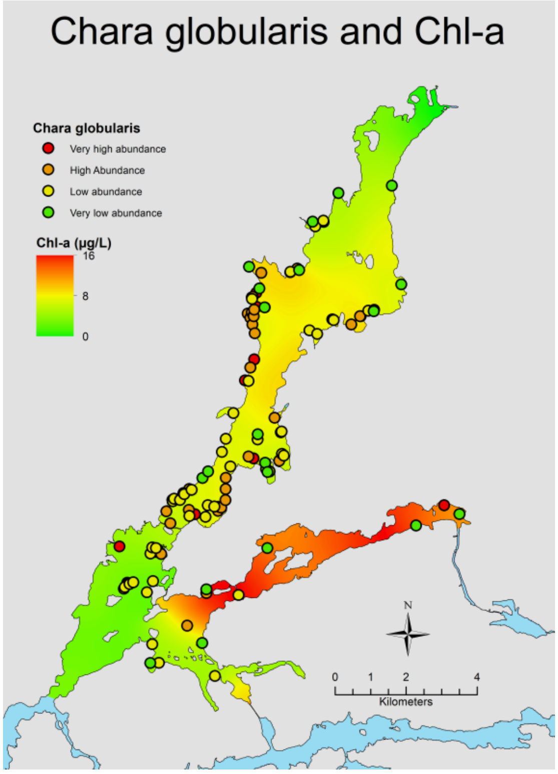

Figure 19 The abundance of *Chara globularis* and the interpolation of Chl-*a*.

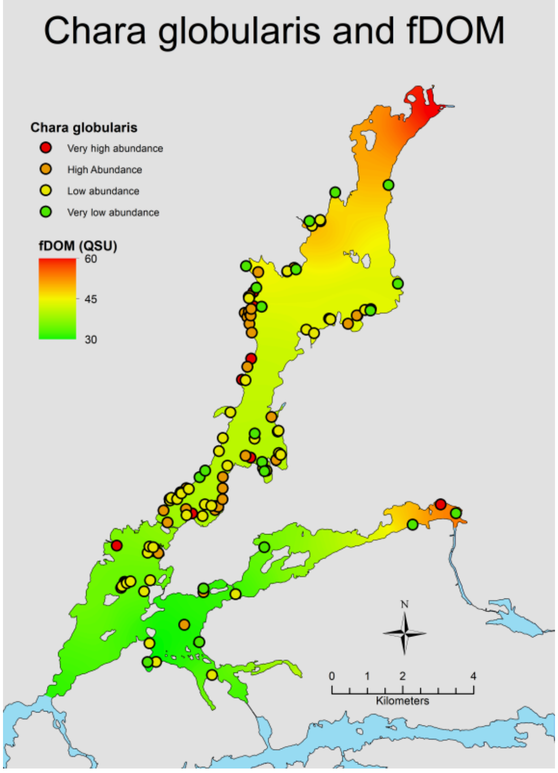

Figure 20 The abundance of *Chara globularis* and the interpolation of fDOM.

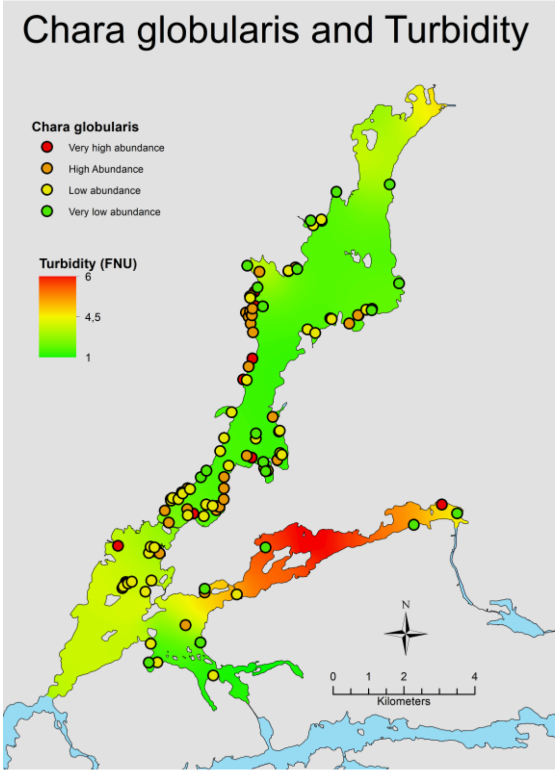

Figure 21 The abundance of *Chara globularis* and the interpolation of turbidity.

5.7 Chara tomentosa

Chara tomentosa is abundant in 37 mapping sites. It is mainly abundant in areas with Chl-*a* less than 8 µg/L, but in one small area it is abundant in an area with Chl-*a* 14-16 µg/L (Figure 22). The fDOM value is mainly low, less than 40 QSU, in the areas with *C. tomentosa*, but in the same small area, already mentioned, the value is higher than 50 QSU (Figure 23). Turbidity is less than 4,5 in the mapping sites with the species abundant (Figure 24). According to the NMDs plot (Figure 3), *C. tomentosa* is not favored by a specific variable.

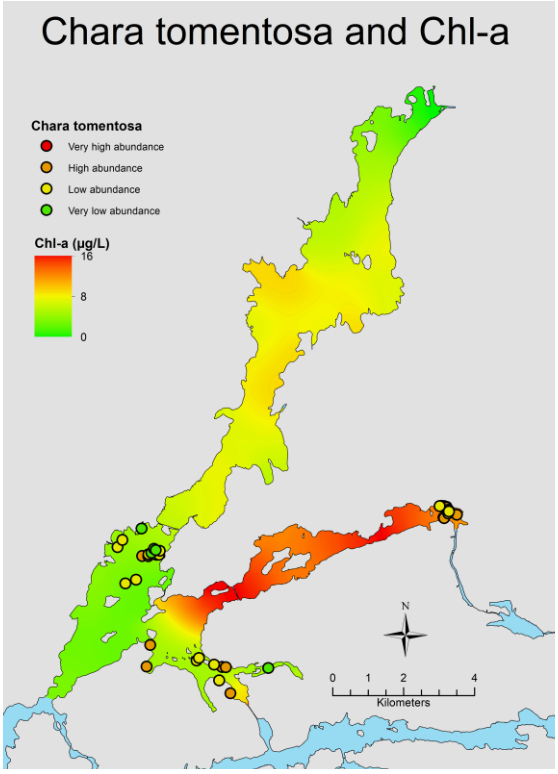

Figure 22 The abundance of *Chara tomentosa* and the interpolation of Chl-*a*.

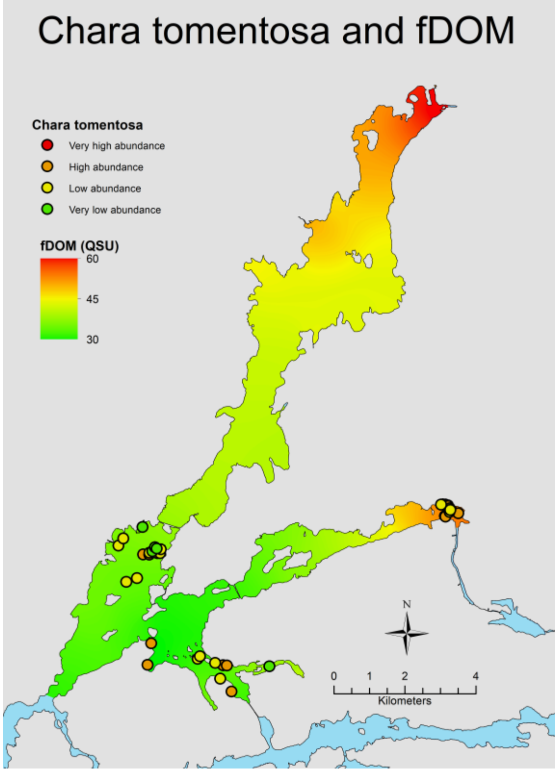

Figure 23 The abundance of *Chara tomentosa* and the interpolation of fDOM.

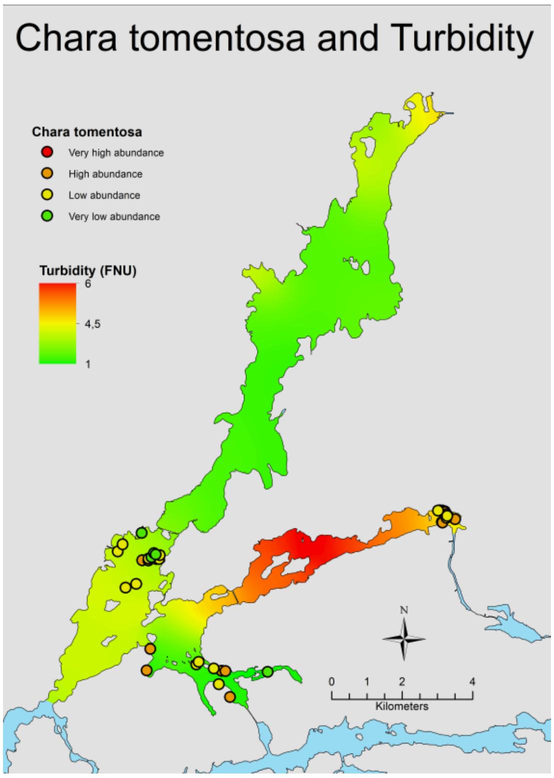

Figure 24 The abundance of *Chara tomentosa* and the interpolation of turbidity.

5.8 Nitella flexilis

Nitella flexilis is only abundant in a small area, in 15 mapping sites. The area has low concentration of Chl-*a*, less than 8 µg/L (Figure 25). The fDOM values are low, 30-40 QSU, in all sites without one, where it is 50 FNU (Figure 26). The turbidity is less than 4,5 in all mapping sites where this species is abundant (Figure 27). The NMDS order plot presents that *N. flexilis* is strongly preferring areas with low values of Chl-*a*, fDOM and turbidity.

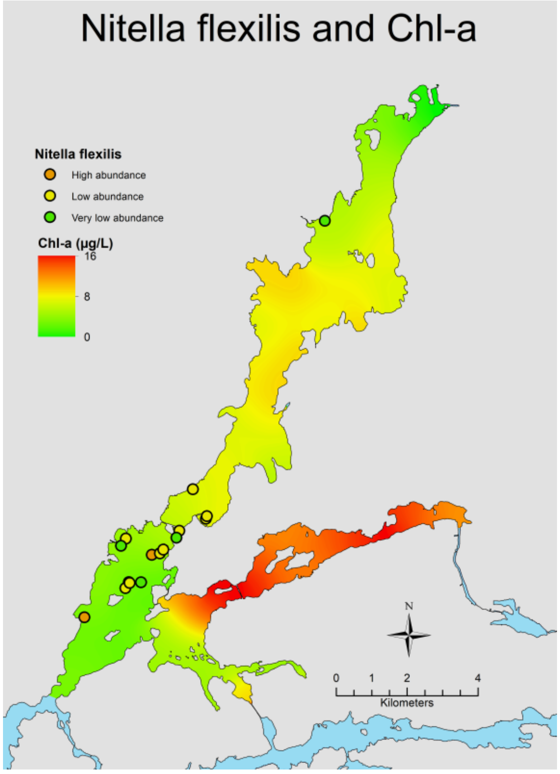

Figure 25 The abundance of *Nitella flexilis* and the interpolation of Chl-*a*.

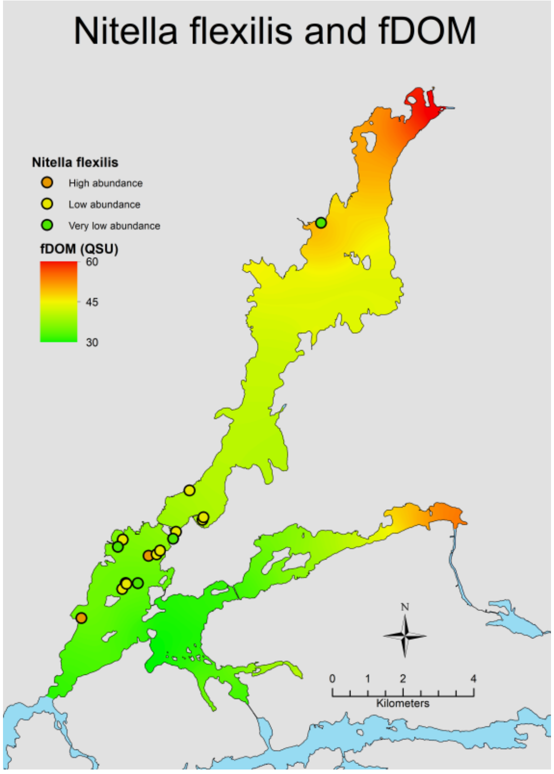

Figure 26 The abundance of *Nitella flexilis* and the interpolation of fDOM.

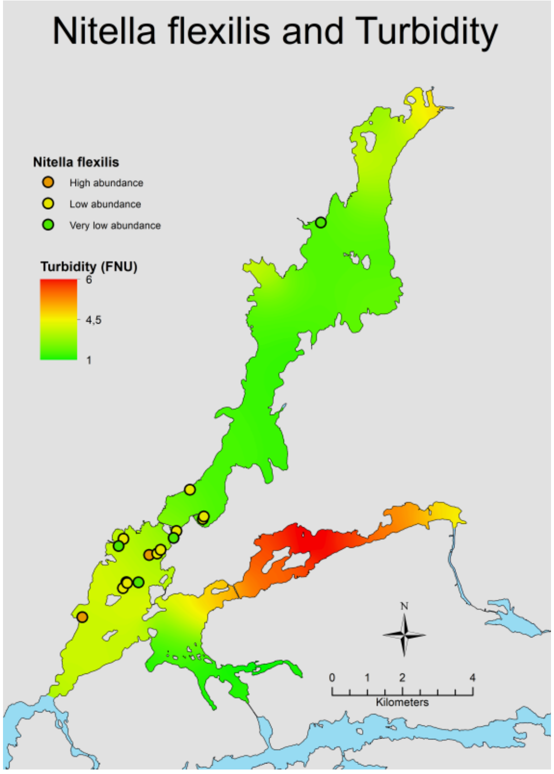

Figure 27 The abundance of *Nitella flexilis* and the interpolation of turbidity.

5.9 *Nitellopsis obtusa*

Nitellopsis obtusa is highly abundant in the southern part of the study area, but exists also a bit higher up, in total in 122 mapping sites. The species is most abundant in areas with low turbidity, less than 4,5 FNU, but is also abundant, in a lower degree, in areas with higher turbidity (Figure 30). The abundance is also high in areas with low fDOM (Figure 29) and Chl-*a* values (Figure 28), but small amounts of the species do also exist in areas with higher fDOM and Chl-*a* values. According to the NMDS plot (Figure 3), *N. obtusa* is not favoring any variable.

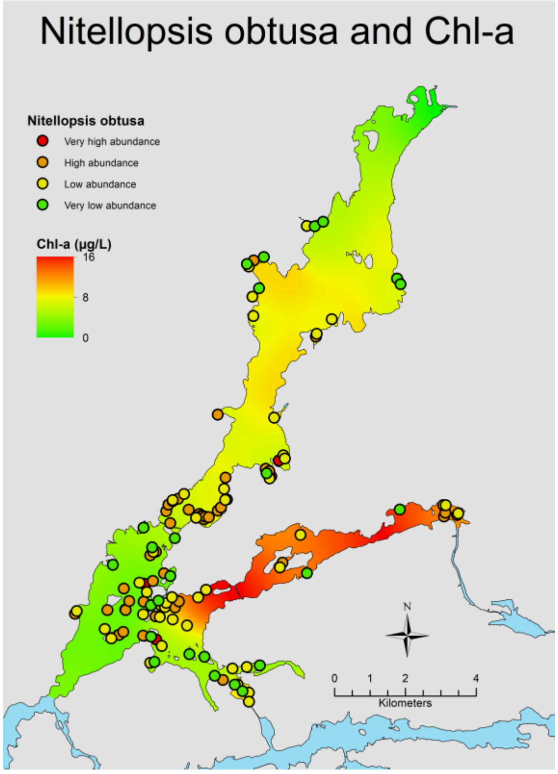

Figure 28 The abundance of *Nitellopsis obtusa* and the interpolation of Chl-*a*.

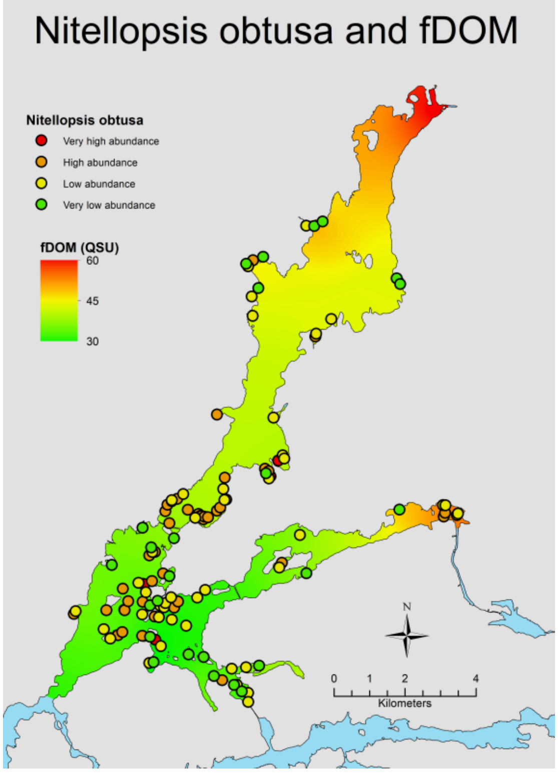

Figure 29 The abundance of *Nitellopsis obtusa* and the interpolation of fDOM.

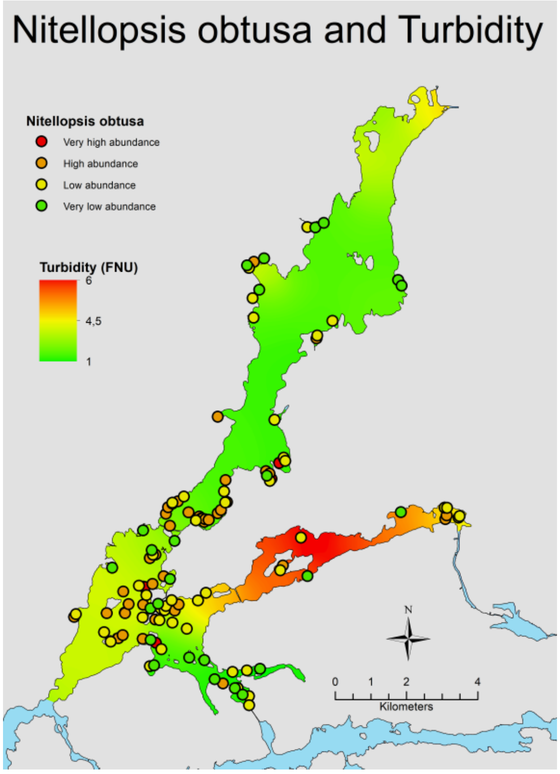

Figure 30 The abundance of *Nitellopsis obtusa* and the interpolation of turbidity.

6 Discussion

The findings of this study were as expected. *Myriophyllum sp.* are more frequent and abundant in areas with higher levels of Chl-*a*, fDOM and turbidity. According to Figure 3, the species that thrives the most by high levels of the variables is *M. verticillatum.* The result correlates with Munsterhjelm's (2005) study that shows the abundance of *M. verticillatum* doubled from the 1970's to the beginning of the 21st century in the same area. This strongly suggests that *M. verticillatum* is benefiting from the rising level of eutrophication and therefore, could possibly be considered as indicator for eutrophication. Most of the species with increased abundance are favored by higher concentrations of nutrients, is considered as an indicator for increased eutrophication (Pitkänen et al., 2013). The abundance of *M. spicatum* and *M. sibiricum*, which have a low requirement of light, have been increasing strongly. This is probably a result of the increased anthropogenic turbidity in these areas. (Pitkänen et al., 2013)

The results suggest that *N. obtusa* is a tolerant species, that grows in suitable places without any larger disruption from the variables. The abundance of *N. obtusa* has increased in the study area because it tolerates and even profits from some degree of eutrophication. (Pitkänen et al., 2013)

The results show that *C. aspera, C. canescens C. globularis, C. tomentosa* and *N. flexilis* are mainly abundant in areas with lower degree of eutrophication. The abundance of *C. globularis, C. tomentosa* and *N. flexilis* has clearly decreased from the 1970s to early 21st century. Of these species, *C. tomentosa* has decreased the most, while *C. globularis* and *N. flexilis* have decreased more moderately. These two, last mentioned, species tolerate conditions with moderate eutrophication level. (Pitkänen et al., 2013)

There are some insecurities about the results of this study. The mapping of the macrophytes is done in the years 2014 and 2015, while the data on the environmental variables are measured in 2019. It would also probably have been necessary to consider salinity as a variable in this study since some species are absent in a very limited salinity gradient. The interpolations of the variables, is an estimated value of the variables in the mapping points, not measured values. The interpolated map that was analyzed is a combination of the measurements from the whole season, from April to October, the values vary a lot between the datasets. If the analyzed dataset contained data from several seasons, the insecurity would be smaller.

7 Conclusion

The aim with this study was to analyze if there was a relationship between the abundancy of the chosen macrophytes and Chl-*a*, fDOM and turbidity values. The results of the study were as expected, as the abundancy of *Myriophyllum sp.* were higher in areas with higher values of Chl-*a*, fDOM and turbidity, than the abundance of *Chara sp*. and *Nitella sp.* There is in some level of correlation between these, but there are also insecurities in these results, i.e., the salinity gradient that was not taken in consideration and the dataset on abundancy of macrophytes was collected in 2014 and in 2015, while the measured data for the environmental variables was collected in 2019.

Rising levels of nitrogen and phosphorus in a habitat leads to changes in the whole species composition. Some species benefit from eutrophication, and some do not. The species diversity decreases when eutrophication increases. The more sensitive species may vanish in the area and more tolerant species may take over. The change in the macrophyte community changes the habitat completely, as food resource, spawning environment etc. (Pitkänen, 2013).

Mechanical alteration of the seafloor, such as dredging, is a way to reduce the internal nutrient load. But mainly it is done restoring or building marinas. Dredging is however a controversial method. The dredging is temporarily causing massive turbidity that disturbs the flora and fauna in the shallow bays. Marine activity, such as boating, is also increasing the turbidity. Chara tomentosa is reported to have vanished from 88% of its localities in the mainland zone since early 20th century, due to eutrophication and mechanical human impact. (Pitkänen, 2013)

Eutrophicated coastal water is a nuisance for humans too. The most noticeable are the algal bloom, the smell of decomposition of organic material, the larger abundance of aquatic plants and the change in (or even lack of) fish stock (Pitkänen, 2013).

This study can be used to identify point loads of nutrients. When identified, suitable measures should be implemented to fix them. The research in shallow bays has only begun in the last decades, and there is much more to be done. The data used in this study is limited and the variables and the abundance of the macrophytes should be monitored for a longer period to get more accurate results and to monitor the progress of eutrophication, to then be able to implement measures reducing the eutrophication. We need more research of the shallow bays, as they are important and very vulnerable habitats.

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