Teaching material – Remote sensing detection of Chlorophyll a and transparency for EU directives

FP-CUP Action 2020-3-24: Open Data Framework in the Baltic Sea Catchment Area

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Abstract

The teaching material includes exercises about retrieving Chlorophyll *a* (Chl a) and transparency in Estonian coastal areas and L. Peipsi, using the ESTHub satellite data processing portal by the Estonian Land Board and SeNtinel Application Program (SNAP).

The aim of the tutorial is to show how satellite-based products can support the monitoring under the EU Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD). We will cover the steps necessary for the task:

1) Single point time-series; 2) Spatial analyses 3) Status assessment according to WFD and MSFD classifications.

Additionally, a short overview of the MSFD and WFD is given with a more precise focus on detecting Chl a and transparency, which are the main direct indicators of eutrophication. This document includes information about the potential retrieval schemes of both parameters from Copernicus data for the Baltic Sea and Lake Peipsi.

Acknowledgements

We are thankful to the ESA Copernicus program and EUMETSAT for satellite data, Estonian Land Board for the ESTHub portal processing possibilities, and Brockmann Consult for the SNAP program. The *in situ* data were gathered in the frames of the Estonian national monitoring program by Marine Institute, University of Tartu. Shapefiles have been obtained from the Estonian environmental data portal and modified later.

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Contents

Introduction

The major goal of the EU Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD) is to acquire and maintain good ecological status in all waterbodies, including marine, coastal and inland waters. To achieve this, an extensive *in situ* monitoring program allows to get an overview with the help of various indicators about the past and present situation together with ongoing trends. However, as monitoring is expensive, remote sensing data can be a tool to add information for some parameters, especially in spatial scale.

1. Remote sensing possibilities for directives

Remote sensing allows the acquisition of additional information for characterizing some important eutrophication parameters - direct indicators, like Chl a and transparency (Figure 1).

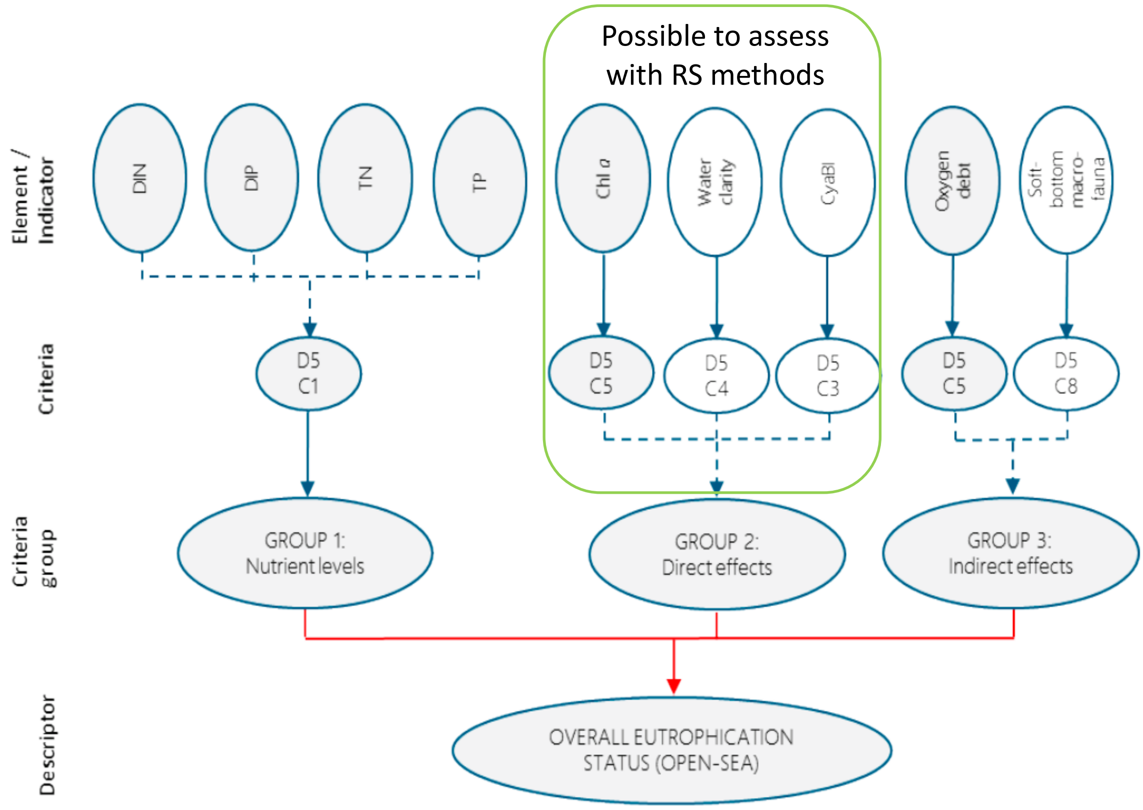


Figure 1. Structure of the eutrophication assessment for open-sea areas. Modified from HELCOM (2017).

These parameters are necessary for both, MSFD and WFD reporting. These direct indicators reflect the symptoms of eutrophication caused by excess nutrients. The Chl a content in the water column is used to characterize the biomass of phytoplankton, which is a direct indicator of eutrophication since phytoplankton directly depends on the nutrient's concentrations. Nitrogen and phosphorus are important nutrients for phytoplankton. Nutrients come from both, point and diffuse sources, and in the case of nitrogen, anthropogenic influence can also reach the water body through the air; in the case of phosphorus, the source can be bottom sediments. Cyanobacterial blooms are a common feature during summertime in the Baltic Sea and in Lake Peipsi.

Photic limit (characterized by Secchi transparency) is indirectly related to eutrophication. It is an important parameter reflecting the light regime and, thereby, the structure of primary production and the associated habitats (European Commission, 2022). Excess phytoplankton causes a direct decrease in water transparency. Still, transparency may decrease due to other reasons, including sediment stirring due to winds in shallow areas and riverine input of coloured dissolved organic matter (CDOM), especially during springtime. The transparency is measured *in situ* by lowering a Secchi disc (round, white disc of approximately 25 cm in diameter) from the surface towards the bottom. The visibility depth is the depth at which the disc disappears. While it is a crude measurement, its advantage is the large number of measurements available, going back over 100 years (Kahru et al. 2022). The method is still heavily exploited in national monitoring programs.

2. Study areas

2.1. Lake Peipsi

Lake Peipsi is a large transboundary waterbody (surface area 3555 km^2), shared between Estonia (44%) and Russia (56%). It consists of three parts – northern and largest Peipsi *sensu stricto* (*s.s.*), southern L. Pihkva and their narrow connection Lämmijärv. Lake Peipsi is the fourth largest lake in Europe, a shallow, eutrophic water body with yearly cyanobacterial blooms in summer.

2.2. Estonian coastal area and open Gulf of Finland

Estonia has four open marine areas according to the HELCOM division: Eastern Gotland Basin, Gulf of Finland, Gulf of Riga and Northern Baltic Proper and 16 coastal areas according to the Water Framework Directive (Figure 2, Table 1).

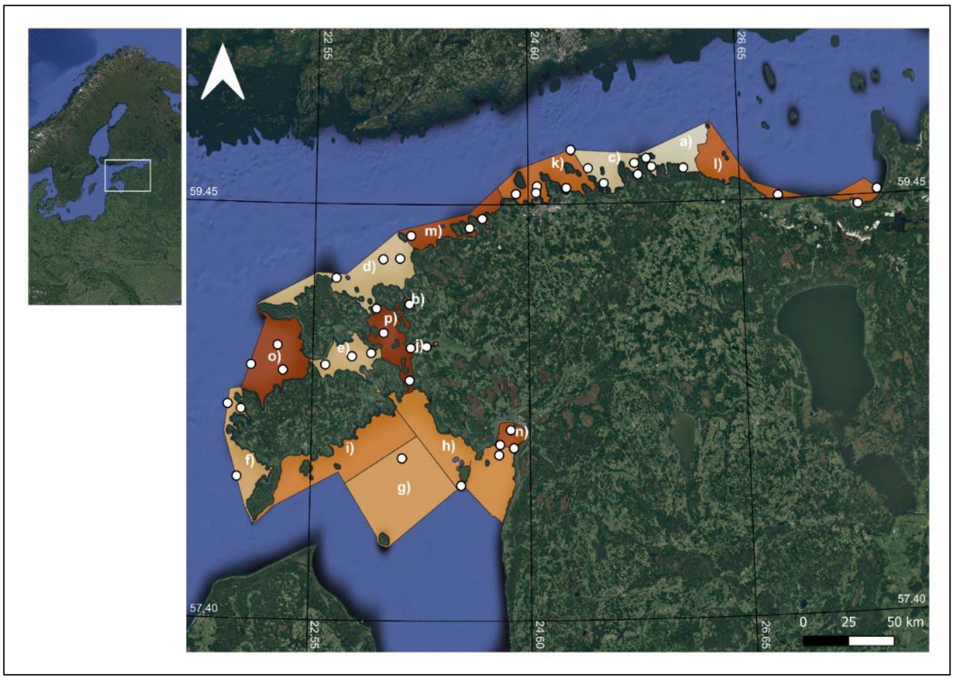


Figure 2. Coastal areas of Estonia and *in situ* sampling locations of national monitoring are represented as white points. (a) Eru-Käsmu Bay, (b) Haapsalu Bay, (c) Hara and Kolga bays, (d) Hiiu Shallow, (e) Kassari-Õunaku Bay, (f) Kihelkonna Bay, (g) Gulf of Riga (central), (h)

Gulf of Riga (NE), (i) Gulf of Riga (NW), (j) Matsalu Bay, (k) Muuga-Tallinna-Kakumäe Bay, (l) Narva-Kunda Bay, (m) Pakri bays, (n) Pärnu Bay, (o) Soela Strait, (p) Moonsund Sea. Base image: Google Hybrid (Rahn *et al*., 2023).

Table 1. Estonian marine areas, according to HELCOM, coastal areas with coding, together with coastal category subtypes.

Code	Coastal category subtype	Name	Category
EE_1	1	Narva-Kunda Bay	Coastal
EE_2	1	Eru-Käsmu Bay	Coastal
EE_3	3	Hara and Kolga Bay	Coastal
EE_5	3	Muuga-Tallinna-Kakumäe Bay	Coastal
EE_6	3	Pakri Bay	Coastal
EE_7	4	Hiiu Shallow area	Coastal
EE_8	5	Haapsalu Bay	Coastal
EE_9	5	Matsalu Bay	Coastal
EE_10	4	Soela Strait	Coastal
EE_11	4	Kihelkonna Bay	Coastal
EE_13	2	Pärnu Bay	Coastal
EE_14	5	Kassari-Õunaku Bay	Coastal
EE_16	5	Moonsund area	Coastal
EE_17	6	Gulf of Riga (NW)	Coastal
EE_18	6	Gulf of Riga (NE)	Coastal
EE_19	6	Gulf of Riga (central)	Coastal
EGB			HELCOM marine area
GOF			HELCOM marine area
GOR			HELCOM marine area
NBP			HELCOM marine area

Table 2. Coastal subtypes and their properties.

Coastal subtype	Location	Properties of the subtype
1	SE part of the Gulf of Finland	Oligohaline, open coastal water
2	Pärnu Bay	Oligohaline, semi-closed coastal water
3	W part of the Gulf of Finland	Mesohaline, deep coastal water
4	Western region of Western Islands	Mesohaline, shallow, open to wave activities
5	Moonsund area	Mesohaline, shallow, enclosed, mixed water
6	Gulf of Riga	Mesohaline, shallow, enclosed, seasonally stratified

Estonian coastal regions are divided into subtypes according to their location, salinity, and hydro-morphological properties (Table 2). **From the WFD point of view, status assessment is done according to the coastal subtype, not by specific area.**

3. Practical exercises

The following exercises will focus on the retrieval of the Chl a concentration and detection of the ecological status class according to WFD and MSFD, using Lake Peipsi and the Estonian coastal area as test regions. Copernicus Sentinel-3 OLCI data will be used, and image processing platform ESTHub by the Estonian Land Board for Sentinel data and a computer program Sentinel Application Platform (SNAP v9.0) will be used for image processing.

Establishment of the ESTHub account (national ID number is needed) – necessary pre-task before the course. More information: https://geoportaal.maaamet.ee/eng/Spatial-Data/National-Satellite-Data-Centre-ESTHub-p654.html

3.1. Time series for the specific locations

Background:

Chl a is a core indicator of eutrophication. Baltic Sea and Lake Peipsi waters are turbid and influenced by other optically active substances (e.g coloured dissolved organic material, total suspended matter), therefore the detection of Chl a may be challenging. Using satellite remote sensing for monitoring purposes could be a useful way to fill any gaps in the data and supplement the monitoring process. Different methods exist. The Case 2 Regional CoastColour (C2RCC) processor can be applied to Sentinel-3 OLCI data to derive Chl a in the Estonian coastal area (Rahn et al., 2023). This correction uses a set of neural networks and bio-optical model to retrieve Chl a among other optical parameters (Doerffer & Schiller, 2007, Pereira-Sandoval et al. 2019). For Lake Peipsi, where Chl a is more abundant than in Baltic Sea, Sentinel-3 OLCI Level-1 products are used and by simple empirical indices, Chl-a is derived (Alikas et al. (2010)).

Retrieval of the time series for one pixel is necessary for comparison with the *in situ* data gathered from the same location. In this exercise, Sentinel-3 OLCI data is extracted from the specific points from the Baltic Sea and compared against in situ measured values. The results will be later compared with the data exported from eutrophic Lake Peipsi.

3.1.1. Chl a and transparency in marine and coastal area

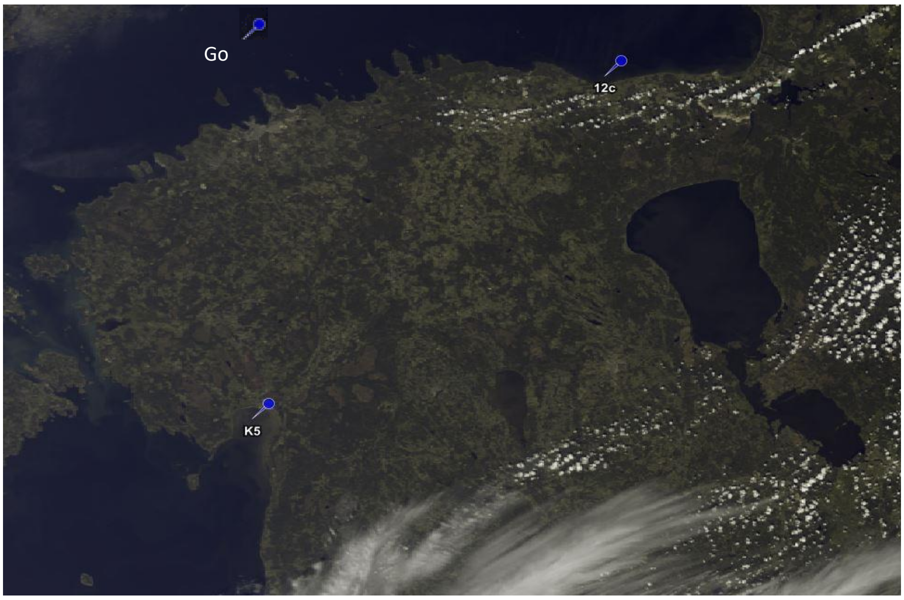
The focus is on retrieving Chl a time series for specific locations.

We will look at two points in the coastal area and one point in the open Gulf of Finland:

1) Pärnu Bay, point K5, with coordinates 58.3396 N and 24.4188 E,

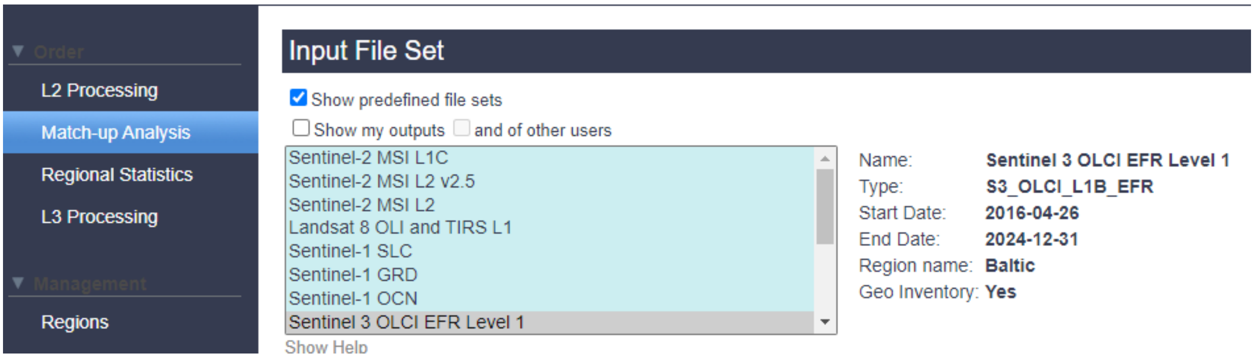
2) Narva-Kunda Bay, point 12c, with coordinates 59.4667 N and 27.0167 E.

3) Open Gulf of Finland, with coordinates 59.8383 N and 24.8383 E.

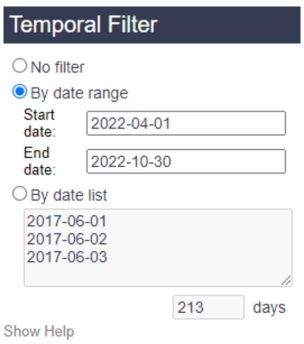


Login to ESTHub Processing Platform: https://ehcalvalus.maaamet.ee/calest/calvalus.jsp

In the ESTHub portal, select from the left pane: **Match-up Analysis**. Then select Sentinel 3 OLCI EFR (full resolution) Level 1.

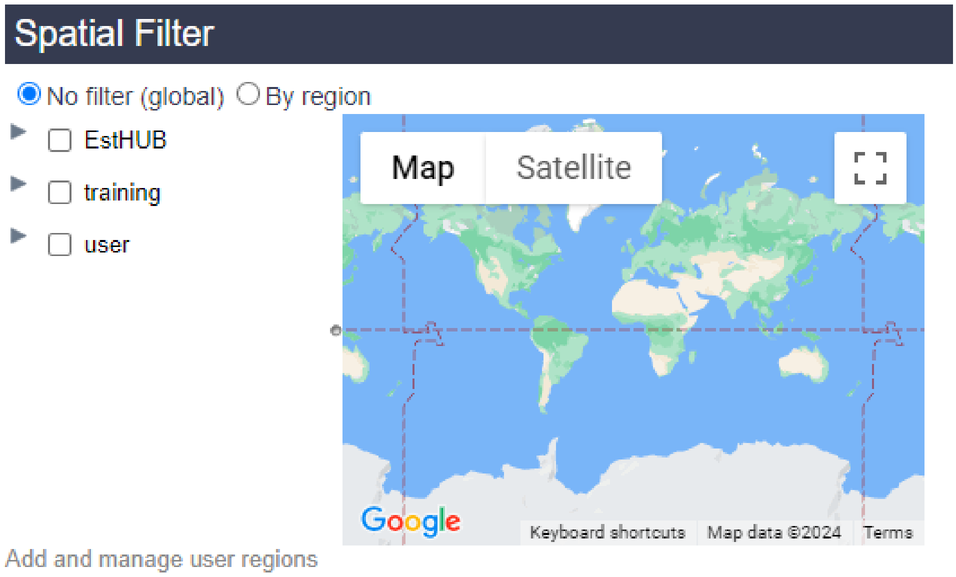


Temporal Filter allows to select the suitable time window. Period: Take the vegetation period Apr-Oct for 2022.

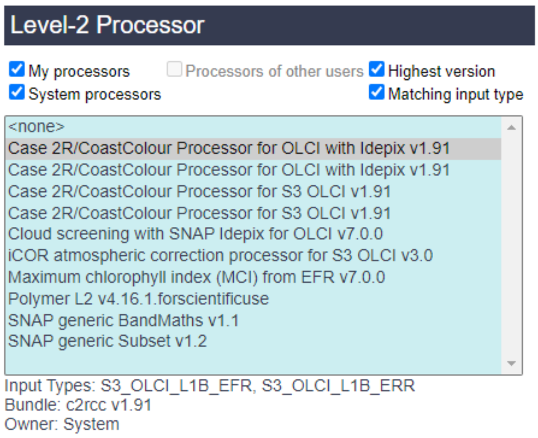


Note: This gives out information about both, Sentinel 3 A and B satellites.

Spatial filter: No filter (global)



<u>Level-2 Processor</u>: Case 2R/CoastColour Processor (C2RCC) for OLCI with Idepix v1.9.

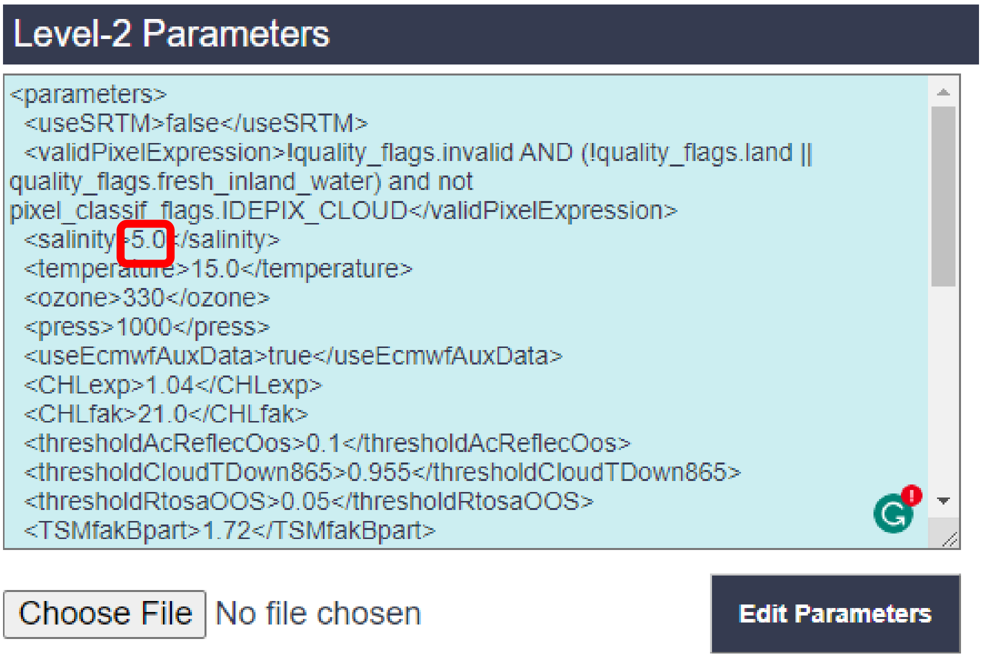


This processor applies atmospheric correction and bio-optical model to derive Chl a.

Note: Adding Idepix allows more cloud-flagging possibilities.

Important: C2RCC is sensitive to temperature and salinity.

<u>Level-2 Parameters</u>: In the ordinary processing scheme, the salinity is 35 and the temperature 15°C. Thus, when looking at the Estonian area, salinity needs to be corrected, e.g. to 5 (coastal areas) or 0.01 (lakes). If the period of interest is in spring, the temperature can be reduced. The temperature and salinity can be changed directly in the Level-2 Parameters code or Edit Parameters.



Match-up Analysis Parameters:

Data can be retrieved for specific locations, inserted in a certain way (an example of the suitable format is in Table 9) and saved as a tab-separated .txt file. Make the file for points 12c, K5, and GoF.

Table 9. An example of the acceptable file format.

A	B	C
name	lat	lon
K5	58.3396	24.4188
12c	59.4667	27.0167
GoF	59.8383	24.8383

Add -> Select your file. When the file is added, **you must also select it from the list;** otherwise, a default file will be used, and processing won't work.

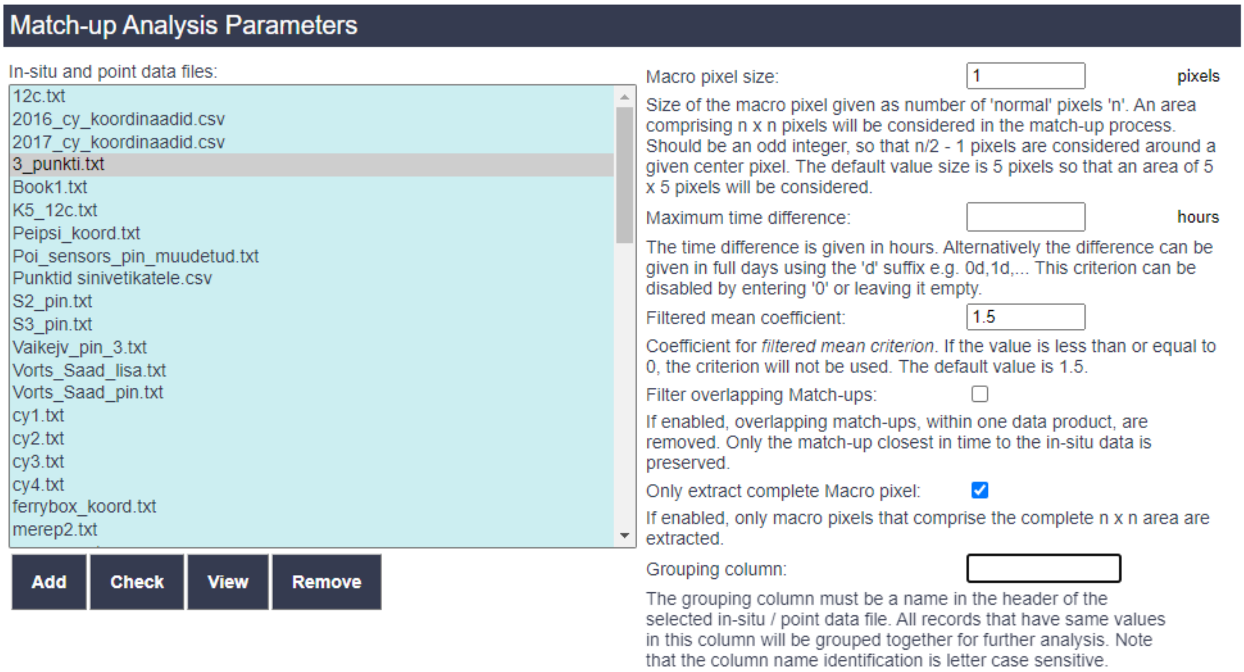
Data can be looked at per 1 pixel or covering a larger area, e.g. 3x3 pixels (Macro pixel size). This means information is retrieved for 1x1 pixel or averaged over larger region, e.g. 3x3 pixels.

Fill in the following:

Macro pixel size – 1. Take 1x1 pixel for analysis.

Maximum time difference – leave blank

Filtered mean coefficient – leave default 1.5



Grouping column – leave blank

<u>Good-pixel expression</u>: (flagging can be applied here or later, e.g. in MS Excel (0 and 1 values are shown, according to which data can be selected later)).

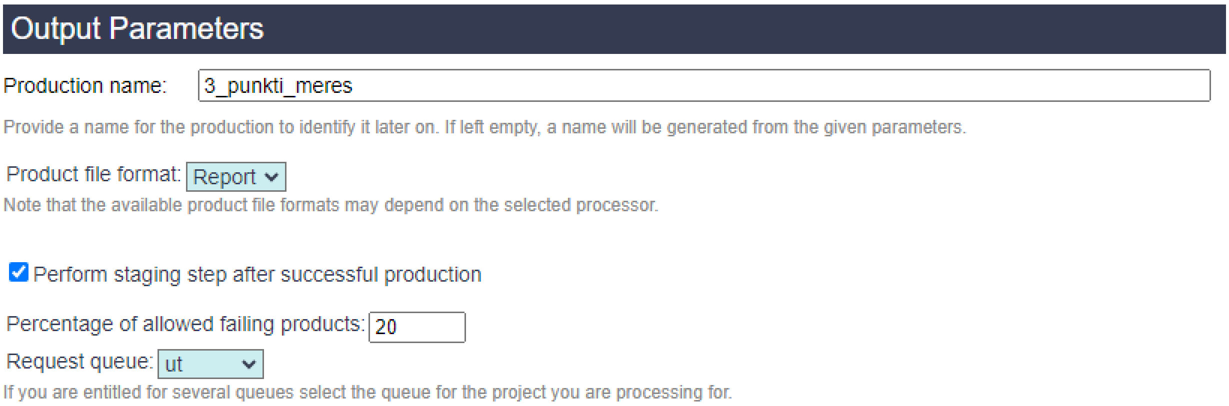
Note: Specific quality flagging allows to get only information of cloud-free water pixels without any Sun glint effect. Flagging is a processor-specific process (each processor has its own specific flags).

Suggested is the addition of the following flags: for C2RCC -> quality_flags.bright, quality_flags.straylight_risk, quality_flags.invalid, quality_flags.sun_glint_risk, cloud_risk and for IDEPIX idepix_invalid, idepix_cloud, idepix_cloud_ambiguous, idepix_cloud_sure, idepix_cloud_ buffer, idepix_cloud_shadow

Copy the following expression combining flags from C2RCC and Idepix:

not quality_flags.bright and not quality_flags.straylight_risk and not quality_flags.invalid and not quality_flags.sun_glint_risk and not pixel_classif_flags.IDEPIX_CLOUD and not pixel_classif_flags.IDEPIX_CLOUD_AMBIGUOUS and not pixel_classif_flags.IDEPIX_CLOUD_BUFFER and not pixel_classif_flags.IDEPIX_CLOUD_SHADOW and not pixel_classif_flags.IDEPIX_BRIGHT and not c2rcc_flags.Cloud_risk and not pixel_classif_flags.IDEPIX_CLOUD_SURE

Output Parameters:



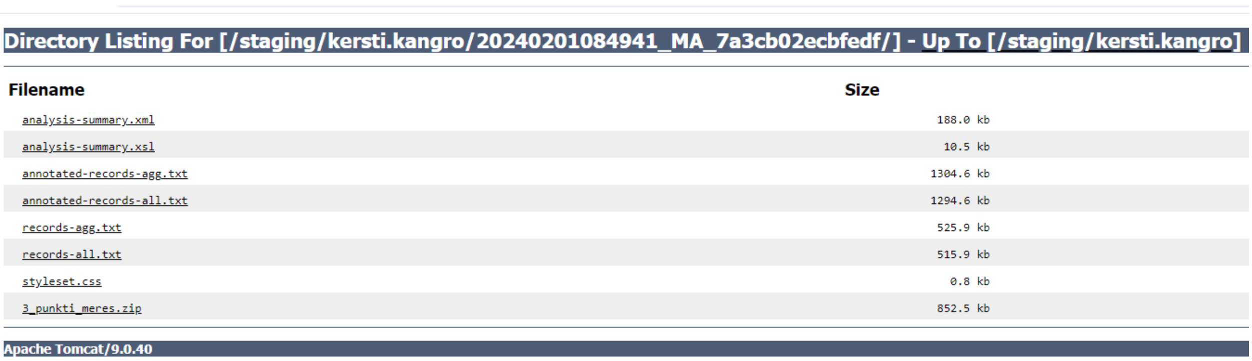
Define the output file name (e.g., 3_punkti_meres), and allow the percentage of failing products (if it is 0, then often an ERROR in the processing chain is retrieved; thus, this should be larger than 0), for example, 20.

Requested queue – general.

Then **Order Production**. Under left panel, on the **Productions**, it is visible, is it Running or Complete or got an Error.

Production	User	Processing Status	Processing Time
20240201084941_MA_7a3cb02ecbfedf 3_punkti_meres home/kersti.kangro/20240201084941_MA_7a3cb02ecbfedf	kersti.kangro	RUNNING (0.0%)	
20240124093307_L3_7a3cb02ecbfec0 2022_average_pe	kersti.kangro	COMPLETED	0:02:45
20240124085241_L3_7a3cb02ecbfebf 2023_average_pe	kersti.kangro	COMPLETED	0:02:29
20240124084228_L3_7a3cb02ecbfebe 2023_pe	kersti.kangro	COMPLETED	0:04:16
20240124083412_L3_7a3cb02ecbfebd 240706082023_pe	kersti.kangro	COMPLETED	0:01:59
20240123143721_L3_7a3cb02ecbfebc juuni_1	kersti.kangro	COMPLETED	0:02:15
20240123122538_L2Plus_7a3cb02ecbfebb 1407_regio	kersti.kangro	COMPLETED	0:01:04

When the processing is completed, files can be downloaded separately or as a .zip compartment. Click **Download**, and a new window opens.

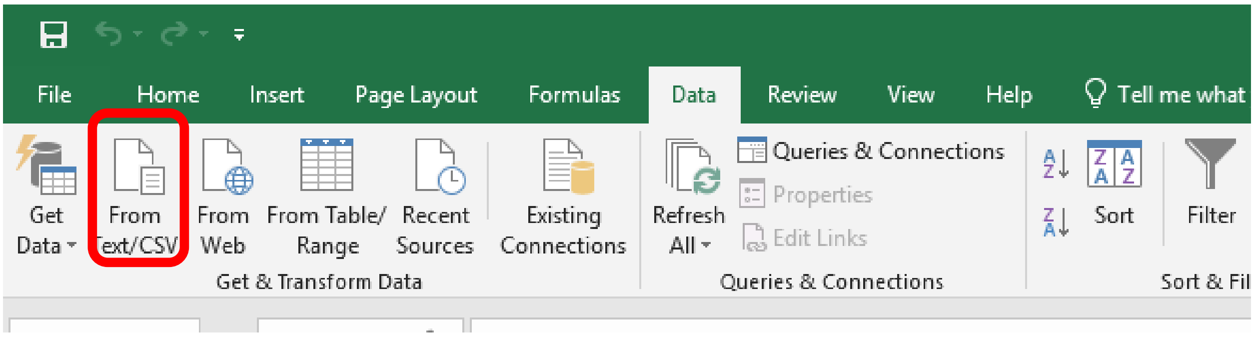

Directory Listing For [/staging/kersti.kangro/20240201084941_MA_7a3cb02ecbfedf/] - Up To [/staging/kersti.kangro]

Filename	Size
analysis-summary.xml	188.0 kb
analysis-summary.xsl	10.5 kb
annotated-records-agg.txt	1304.6 kb
annotated-records-all.txt	1294.6 kb
records-agg.txt	525.9 kb
records-all.txt	515.9 kb
styleset.css	0.8 kb
3_punkti_meres.zip	852.5 kb

Apache Tomcat/9.0.40

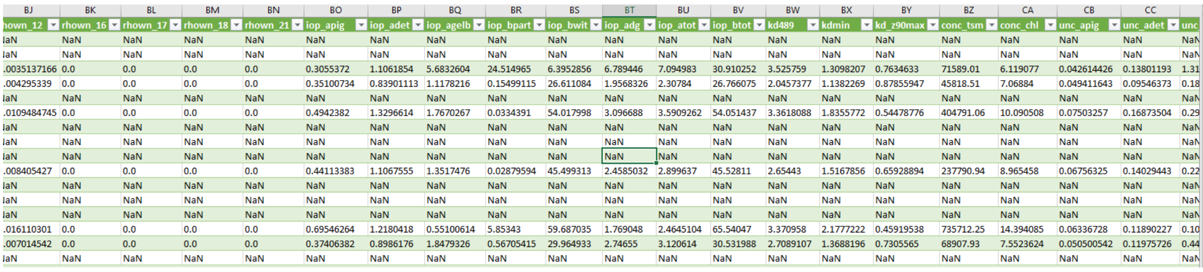
Download the zip file (by clicking on it). Annotated-records-all.txt gives values about the selected pixels.

Open the annotated-records-all.txt file in EXCEL. Under the tab “Data”, click “From Text/csv”.



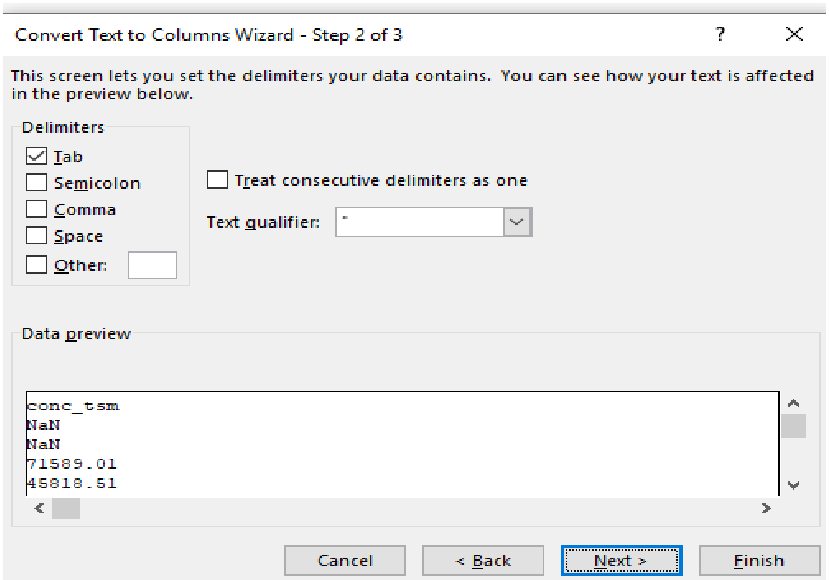
It gives the outputs of the C2RCC processor: reflectance values, concentrations, inherent optical properties, and information about flags and atmospheric parameters.

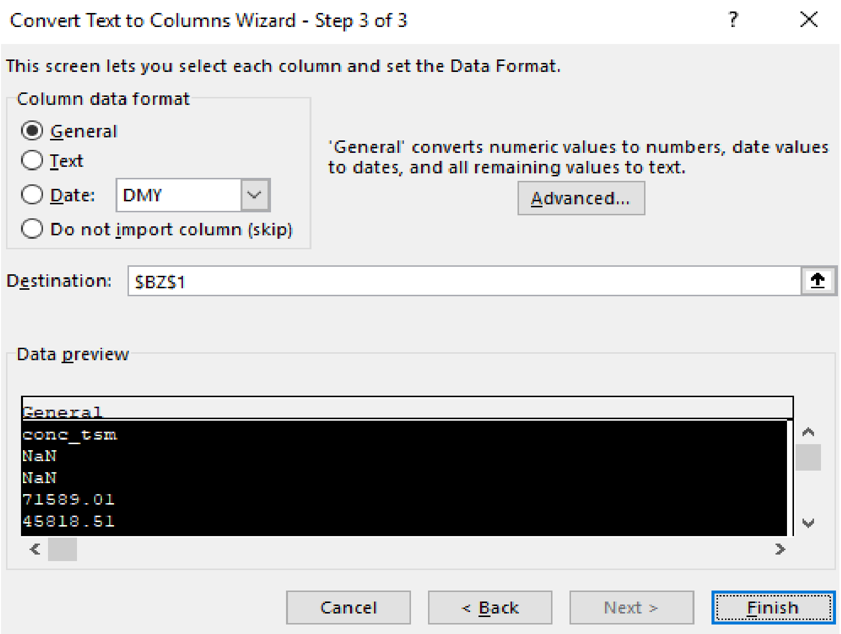
In the frames of this exercise, the interest is in **conc_chla (Chl a) and Kd489** (the diffuse attenuation coefficient for downwelling irradiance at 489 nm in m-1) products. Note the holes in the data caused by clouds.



BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	BX	BY	BZ	CA	CB	CC	
hown_12	rhown_16	rhown_17	rhown_18	rhown_21	iop_apig	iop_adet	iop_agelb	iop_bpart	iop_bwit	iop_adg	iop_atot	iop_btot	kd489	kdmin	kd_z90max	conc_tsm	conc_chl	unc_apig	unc_adet	unc
laN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
laN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
.0035137166	0.0	0.0	0.0	0.0	0.3055372	1.1061854	5.6832604	24.514965	6.3952856	6.789446	7.094983	30.910252	3.525759	1.3098207	0.7634633	71589.01	6.119077	0.042614426	0.13801193	1.31
.004295339	0.0	0.0	0.0	0.0	0.35100734	0.83901113	1.1178216	0.15499115	26.611084	1.9568326	2.30784	26.766075	2.0457377	1.1382269	0.87855947	45818.51	7.06884	0.049411643	0.09546373	0.18
laN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
.0109484745	0.0	0.0	0.0	0.0	0.4942382	1.3296614	1.7670267	0.0334391	54.017998	3.096688	3.5909262	54.051437	3.3618088	1.8355772	0.54478776	404791.06	10.090508	0.07503257	0.16873504	0.29
laN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
laN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
laN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
.008405427	0.0	0.0	0.0	0.0	0.44113383	1.1067555	1.3517476	0.02879594	45.499313	2.4585032	2.899637	45.52811	2.65443	1.5167856	0.65928894	237790.94	8.965458	0.06756325	0.14029443	0.22
laN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
laN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
laN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
.016110301	0.0	0.0	0.0	0.0	0.69546264	1.2180418	0.55100614	5.85343	59.687035	1.769048	2.4645104	65.54047	3.370958	2.1777222	0.45919538	735712.25	14.394085	0.06336728	0.11890227	0.10
.007014542	0.0	0.0	0.0	0.0	0.37406382	0.8986176	1.8479326	0.56705415	29.964933	2.74655	3.120614	30.531988	2.7089107	1.3688196	0.7305565	68907.93	7.5523624	0.050500542	0.11975726	0.44
laN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

Note: There is also a need to convert text to numbers.



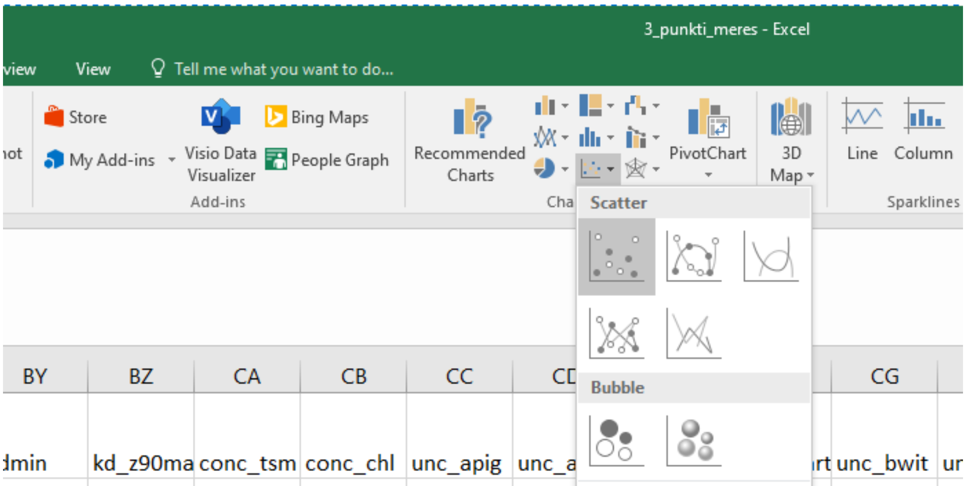


Note: a date column must be converted to Date.

Compare the results from 3 locations – where are the highest Chl a results? Is phytoplankton spring bloom (higher values in spring) visible in all three locations?

The retrieved time series can be looked at in comparison with *in situ* data. **Compare satellite retrievals with *in situ* data from the file "K5_12c_in_situ_andmed.xlsx" to the time series.**

One option is to use Scatter chart type in Excel to plot the time (column *pixel_time*) against Chl a (chl_conc).



Are the seasonal patterns similar in Copernicus and *in situ* data? Does the Copernicus data complement *in situ* estimates and vice versa? What is the benefit of merging two datasets?

You can do similar analyses on the water transparency (i.e. Secchi depth). **Secchi depth can be calculated from Kd_489 product (Alikas & Kratzer, 2017):**

Secchi depth = 2.39 * $(Kd\_489)^{-0.86}$

Which station has highest average transparency? Does it have seasonal dynamics? Can you see any patterns between Chl a and transparency?

Here are some optional exercises to practice image processing and data analyses:

1. **Take a look at the different year – 2017, for example. Were the years similar or different?**
2. **Repeat the processing, but with 3x3 pixels selection (Macro pixel size – 3). Compare the result with 1x1 pixel retrieval.**
3. **Create a scatter plot with same day *in situ* (X-axis) and Copernicus (Y-axis, 1x1 or 3x3 extraction) data. Pool together all points and both years. Add linear regression equation and R^2 value. How well does the satellite-derived product work compared to *in situ* data**?

3.1.2. Chl a in selected points in Lake Peipsi

Chl a in L. Peipsi can be calculated, e.g. using Sentinel-3 OLCI Level 1 Full resolution products and Maximum Chlorophyll Index (MCI) by Gower et al. (2008). Using Level 1 data allows to skip atmospheric correction, but for MCI application, the amount of Chl a in the lake should be larger than 20 µg/L to retrieve correct results, which suggests its usage in eutrophic and hypertrophic waterbodies. This index calculates the peak height at 709 nm:

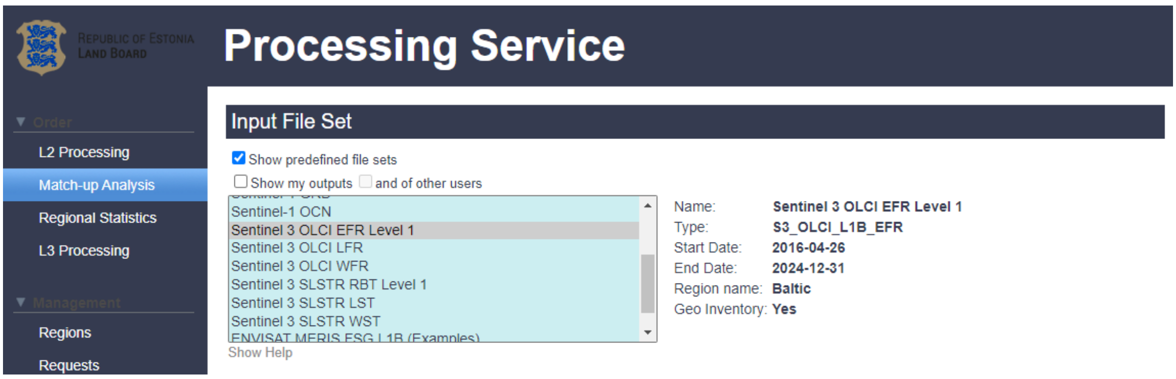
$$MCI = L_{709} - L_{681} - 0.389*(L_{753} - L_{681}),$$

where L is the top of the atmosphere radiance at specific wavelengths. In the case of Sentinel 3 OLCI, bands 10, 11 and 12 are used.

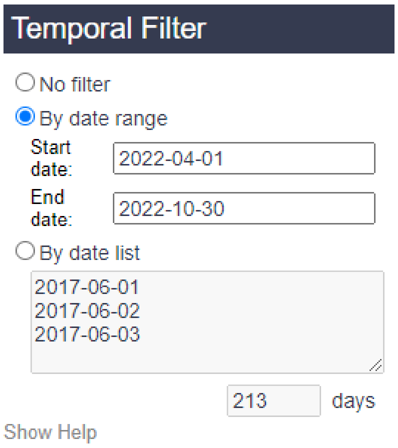
Chl a can be calculated with the lake-specific algorithm by Alikas et al. (2010):

$$Chl\ a = 10.9*MCI + 15.3$$

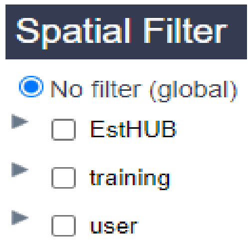
In this exercise, the MCI time series are calculated for L. Peipsi s.s. and Lämmijärv. Then, Chl a is calculated from MCI using MS Excel.



From ESTHub, take **Match-Up Analysis** and select Sentinel 3 OLCI full resolution (EFR) data.



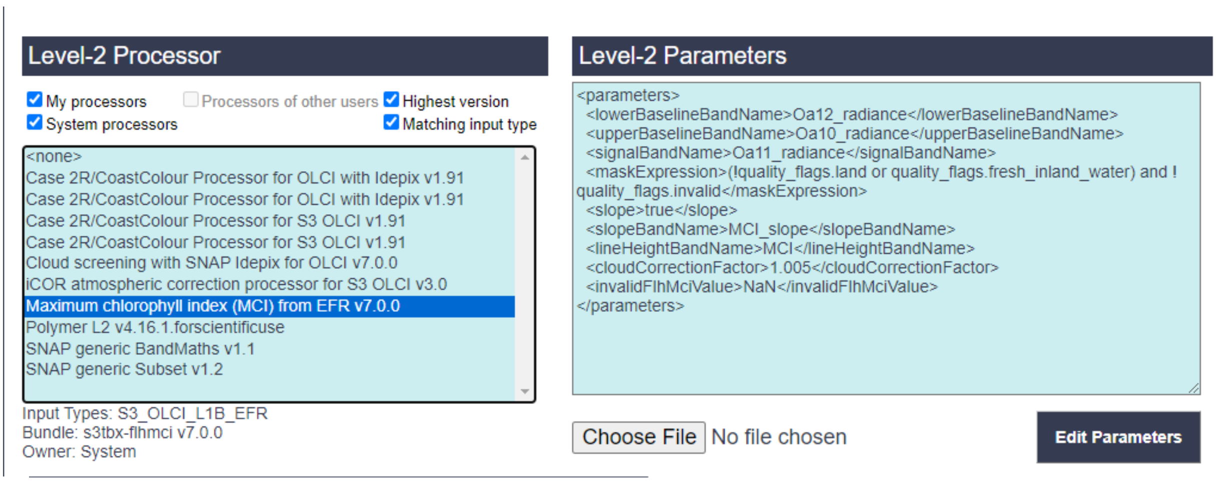
Again, select the vegetation period, **Apr 1st - Oct 30th, 2022.**

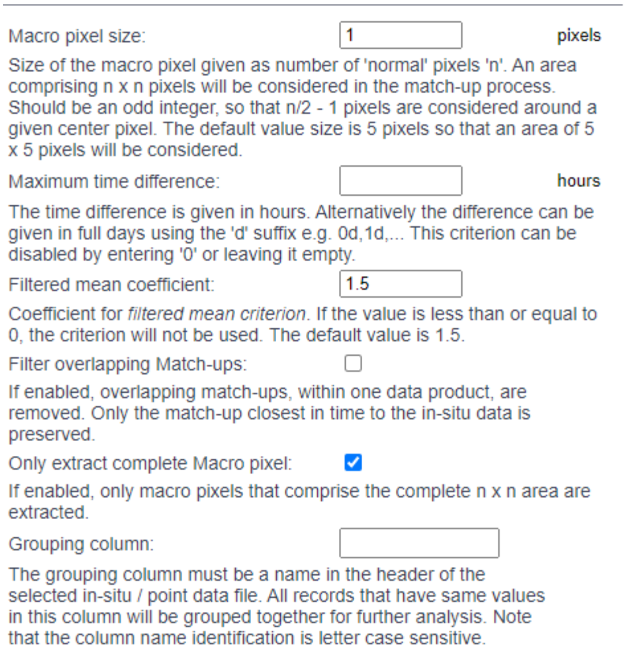


Select the Maximum Chlorophyll Index as the **Level-2 Processor**.

Make a txt file with coordinates, for **Lämmijärv, point 16 (58.2317 N and 27.48664 E) and L. Peipsi s.s., point 2 (58.78991 N, 27.19021 E).** Add the file with coordinates similarly to the previous exercise.

Under **Match-up Analysis Parameters,** fill in the following:





Macro pixel size – 1

Maximum time difference – leave blank

Filtered mean coefficient – leave default 1.5

Grouping column – leave blank

Flags are different this time, and there are fewer for Level 1 data. Use following **Good-pixel expression**: NOT quality_flags_bright and NOT quality_flags_invalid

Good-pixel expression: NOT quality_flags_bright and NOT quality_flags_invalid

The good-pixel expression is a SNAP band maths expression (refer to SNAP documentation) that is evaluated for each L2 processor output pixel. If it evaluates to the Boolean TRUE value, the pixel will be used for further analysis. For SNAP processors, you usually don't need to specify it, because SNAP products usually already have valid-masks attached to their geo-physical output variables.
For example: conc_chl < 50 AND Kd_490 > 0 AND NOT l2p_flags.OOTR

Good-record expression:

The good-record expression also is a SNAP band maths expression that is evaluated for each aggregated macro pixel (= record). For each geo-physical output variable *var* the following derived variables are usable in this expression:

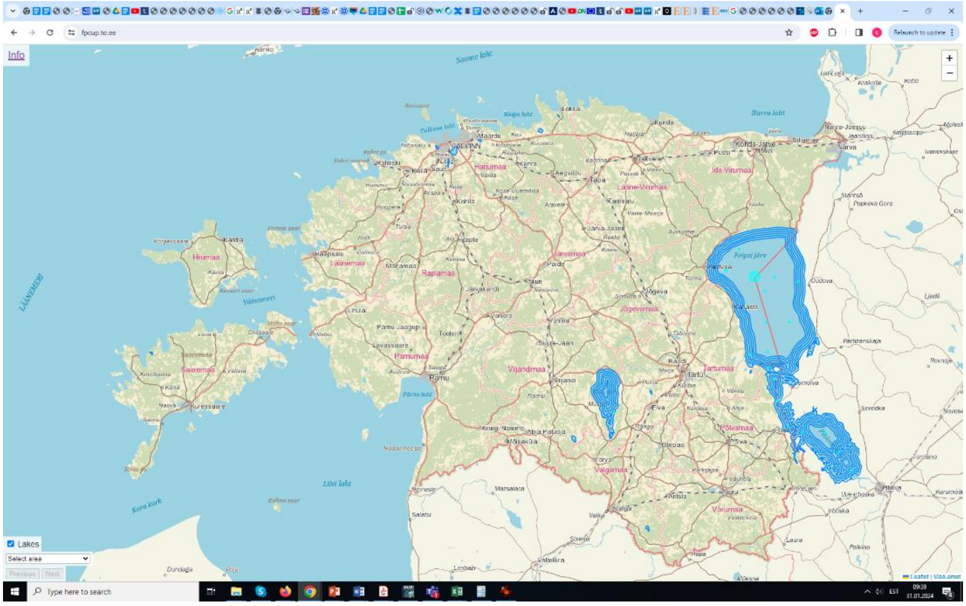
Click **Order Production**. Once finished, load the output file to MS Excel.

Use the column "MCI". **Calculate Chl a from the obtained results, using the formula by Alikas et al. (2010).**

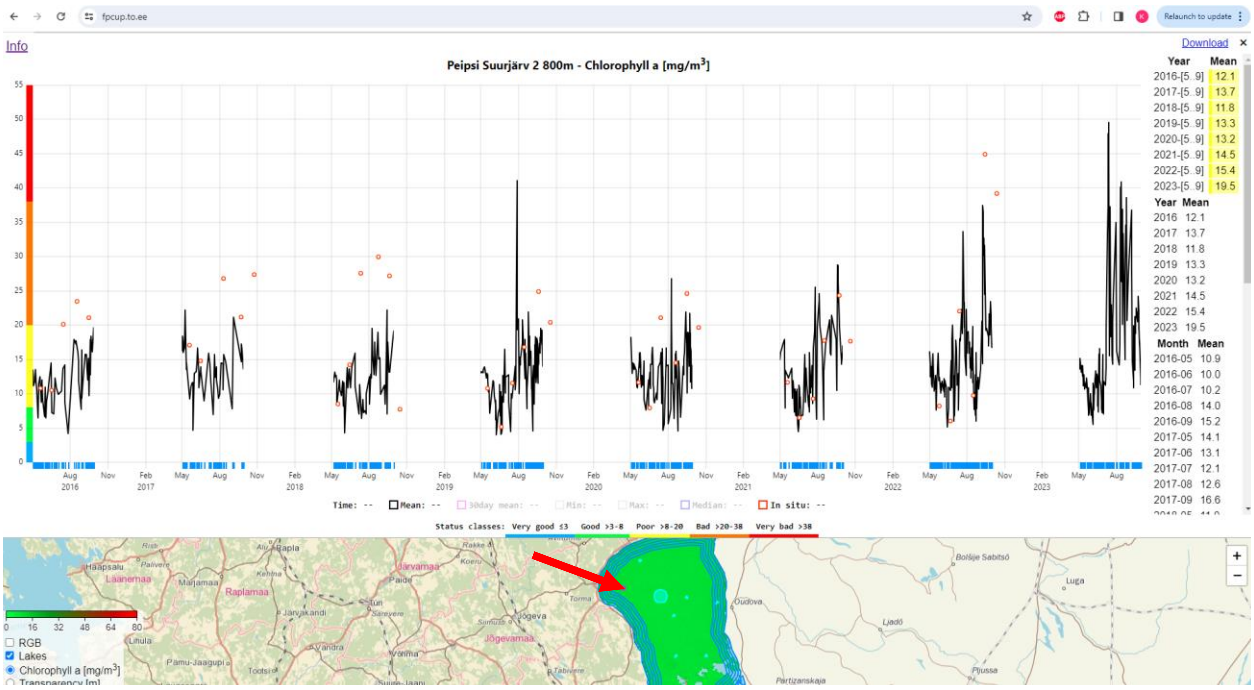
source_name	pixel_time	pixel_x	pixel_y	pixel_lat	pixel_lon	latitude	longitude	MCI	MCI_slope	quality_flags.land	quality_flags.coastline	quality_flags.fresh_inland_water
S3A_OL_1_EFR____20230401T091751_20230401T092051_20230402T100219_0179_097_150_198	01.04.2023 09:18	4011	903	58.539604	26.643581	58.539604	26.643581	-2.3595996	-0.32182533	1	0	1
S3A_OL_1_EFR____20230402T085140_20230402T085440_20230403T093502_0179_097_164_198	02.04.2023 08:52	2665	1295	58.538994	26.643892	58.538994	26.643892	1.5014937	-0.30514127	1	0	1
S3A_OL_1_EFR____20230403T082529_20230403T082829_20230404T090626_0179_097_178_198	03.04.2023 08:26	1286	1568	58.539967	26.643705	58.539963	26.643705	0.7141158	-0.23775908	1	0	1
S3A_OL_1_EFR____20230405T091406_20230405T091706_20230406T095939_0179_097_207_198	05.04.2023 09:14	3822	966	58.53877	26.645573	58.53877	26.645573	-4.024066	-0.2608367	1	0	1
S3A_OL_1_EFR____20230406T084756_20230406T085056_20230407T093102_0179_097_221_198	06.04.2023 08:48	2471	1340	58.53978	26.648035	58.539776	26.648035	-3.4073992	-0.2994972	1	0	1
S3A_OL_1_EFR____20230407T082145_20230407T082445_20230408T090434_0179_097_235_198	07.04.2023 08:22	1087	1597	58.53914	26.64695	58.539135	26.64695	0.35353294	-0.11071477	1	0	1
S3A_OL_1_EFR____20230409T091023_20230409T091323_20230410T095542_0179_097_264_198	09.04.2023 09:11	3633	1028	58.538414	26.645359	58.538418	26.64536	-0.1491742	-0.07130827	1	0	1
S3A_OL_1_EFR____20230410T084412_20230410T084712_20230411T092839_0179_097_278_198	10.04.2023 08:45	2275	1384	58.53885	26.641996	58.53885	26.641996	0.09158112	-0.06986902	1	0	1
S3A_OL_1_EFR____20230412T093250_20230412T093550_20230413T101621_0179_097_307_198	12.04.2023 09:33	4762	630	58.53838	26.643234	58.538376	26.643236	0.08022627	-0.02271968	1	0	1
S3A_OL_1_EFR____20230413T090639_20230413T090939_20230414T095436_0180_097_321_198	13.04.2023 09:07	3441	1085	58.538307	26.645622	58.538307	26.645624	0.47434455	-0.15355845	1	0	1
S3A_OL_1_EFR____20230414T084029_20230414T084329_20230415T092359_0179_097_335_198	14.04.2023 08:41	2079	1425	58.539967	26.642368	58.539967	26.642368	-0.15090118	-0.047318414	1	0	1
S3A_OL_1_EFR____20230416T092906_20230416T093206_20230417T101144_0179_097_364_198	16.04.2023 09:29	4576	701	58.538876	26.643473	58.538876	26.643473	0.13421793	0.0032091865	1	0	1
S3A_OL_1_EFR____20230417T090255_20230417T090555_20230418T094857_0179_097_378_198	17.04.2023 09:03	3249	1142	58.538605	26.646366	58.538605	26.646368	-1.2328044	-0.11485638	1	0	1
S3A_OL_1_EFR____20230418T083644_20230418T083944_20230419T091841_0179_098_007_198	18.04.2023 08:37	1882	1465	58.538498	26.646784	58.5385	26.646784	0.46593598	-0.042051014	1	0	1
S3A_OL_1_EFR____20230420T092521_20230420T092821_20230421T101842_0179_098_036_198	20.04.2023 09:25	4390	770	58.54054	26.64428	58.540535	26.64428	-0.17716546	-0.033765484	1	0	1
S3A_OL_1_EFR____20230421T085910_20230421T090210_20230422T095336_0179_098_050_198	21.04.2023 09:00	3056	1196	58.539883	26.643408	58.539883	26.643408	-0.3357924	-0.037665375	1	0	1

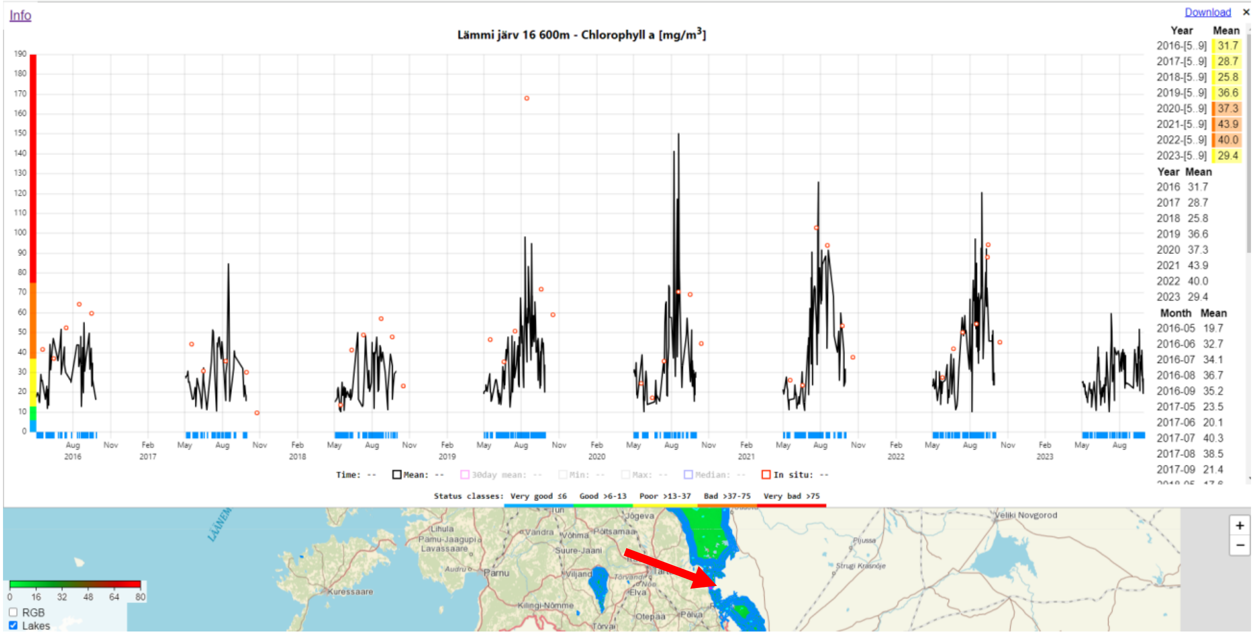
Compare the results about 2022 - where were the higher concentrations – in the lake or in the coastal area? Are the patterns in Chl a similar or different in the Baltic Sea and in the lake (dynamics, spring bloom, summer bloom)? Are Chl a concentrations similar in two monitoring points of L. Peipsi?

Check the webpage fpcup.to.ee



From there, you can check the results for specific locations (monitoring points 2 and 16) for different years – is 2022 a regular year?





For point 2 in L. Peipsi s.s. extraordinarily high *in situ* values in comparison with the two previous years. Peaks were visible in July and autumn from satellite data. For point 16, higher values were present at the end of August.

3.2. Spatial analyses

Spatial analyses include the processing over the entire water body, allowing to see spatial variability and bloom dynamics.

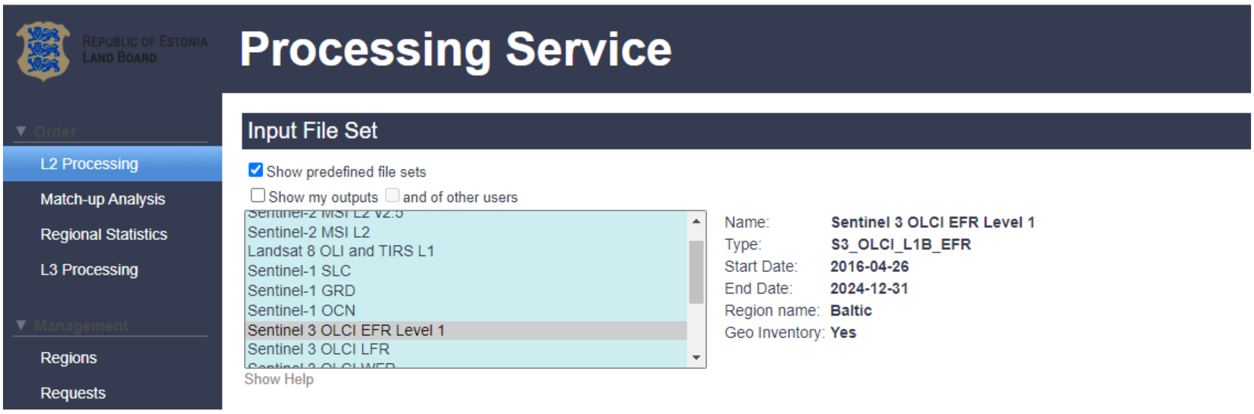
Preliminary task: Download SNAP – Sentinel Toolboxes from
https://step.esa.int/main/download/snap-download/

We will use ESTHub in combination with SNAP (SeNtinel Application Platform).

3.2.1. Chl a variation in spatial scale in L. Peipsi

The task is to perform analyses of spatial variability over the selected water bodies by combining Esthub Processing Service and image analysis in SNAP.

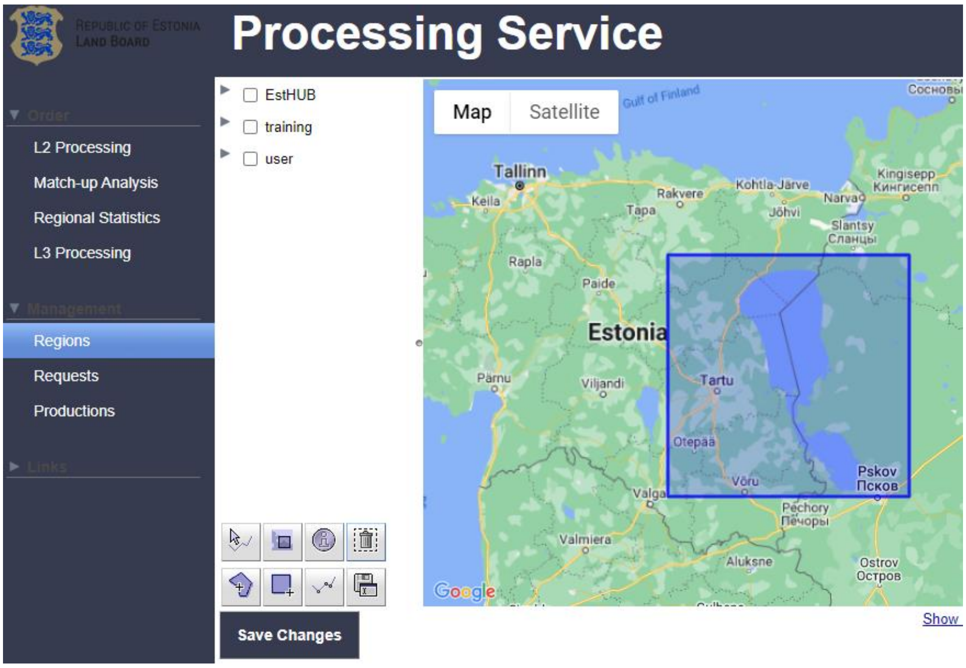
In ESTHub: Select **L2 Processing** from the left pane.



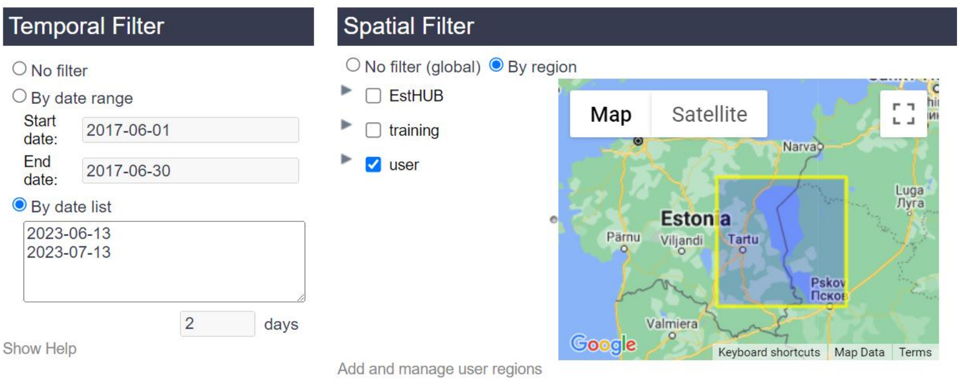
From **Input File Set**, select Sentinel 3 OLCI EFR Level 1.

From **Temporal Filter**, select **By date list**, and type dates for June 13th and July 13th, 2023 (example below).

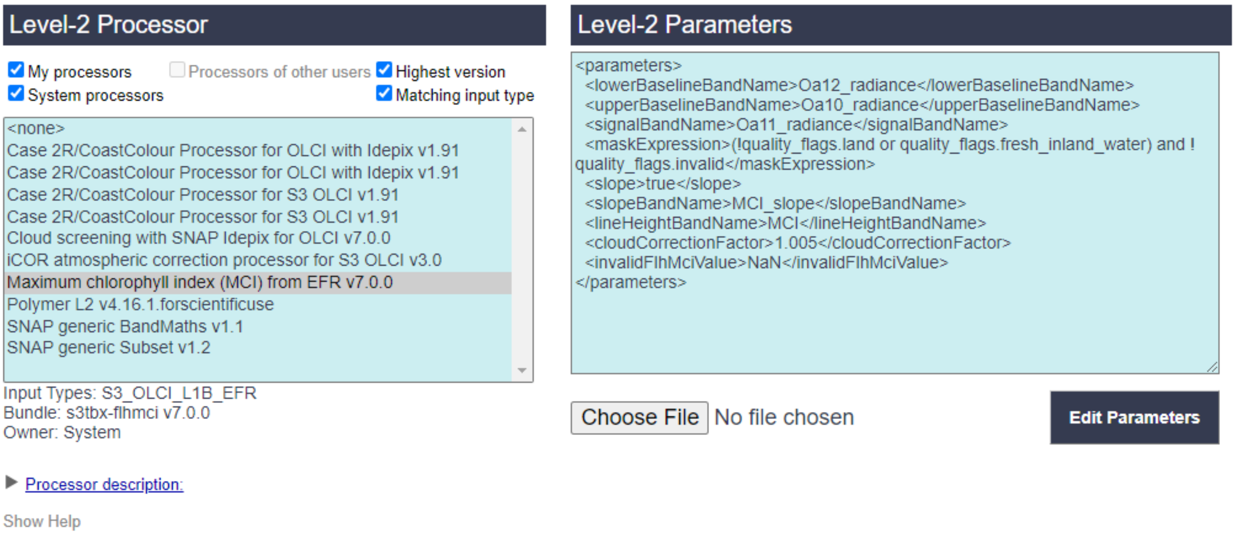
From **Spatial Filter** click on the **Add and manage user regions** and draw a box around L. Peipsi by clicking on the **New box region.**



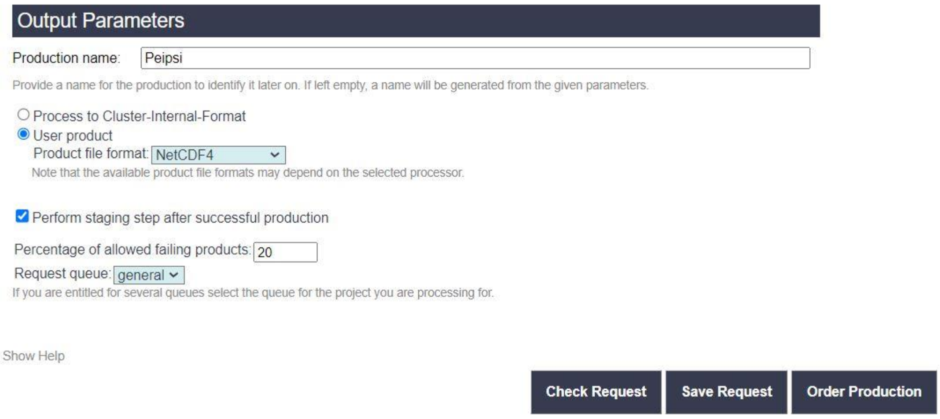
Save changes and return to **L2 Processing.** Click on the **user** defined **Spatial filter.**



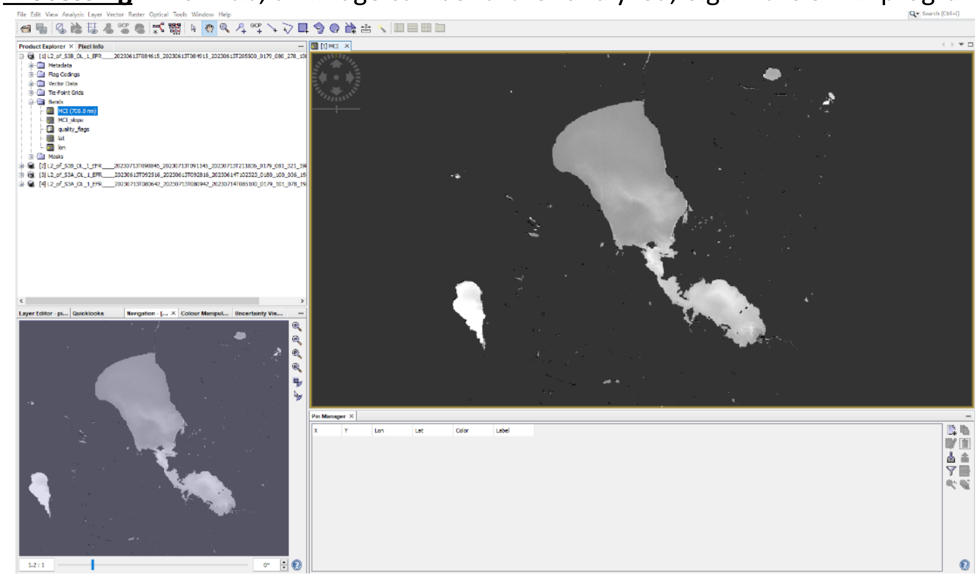
From **Level-2 Processor**, select Maximum Chlorophyll Index (MCI) from EFR v 7.0.0.



In **Output Parameters** – add a production name; User Product – NetCDF4, allow 20% of failing products.



Click on **Order Production**. **Download** the results after successful processing. After performing a **L2 Processing** in ESTHub, an image can be further analyzed, e.g. in the SNAP program. Level 2 images



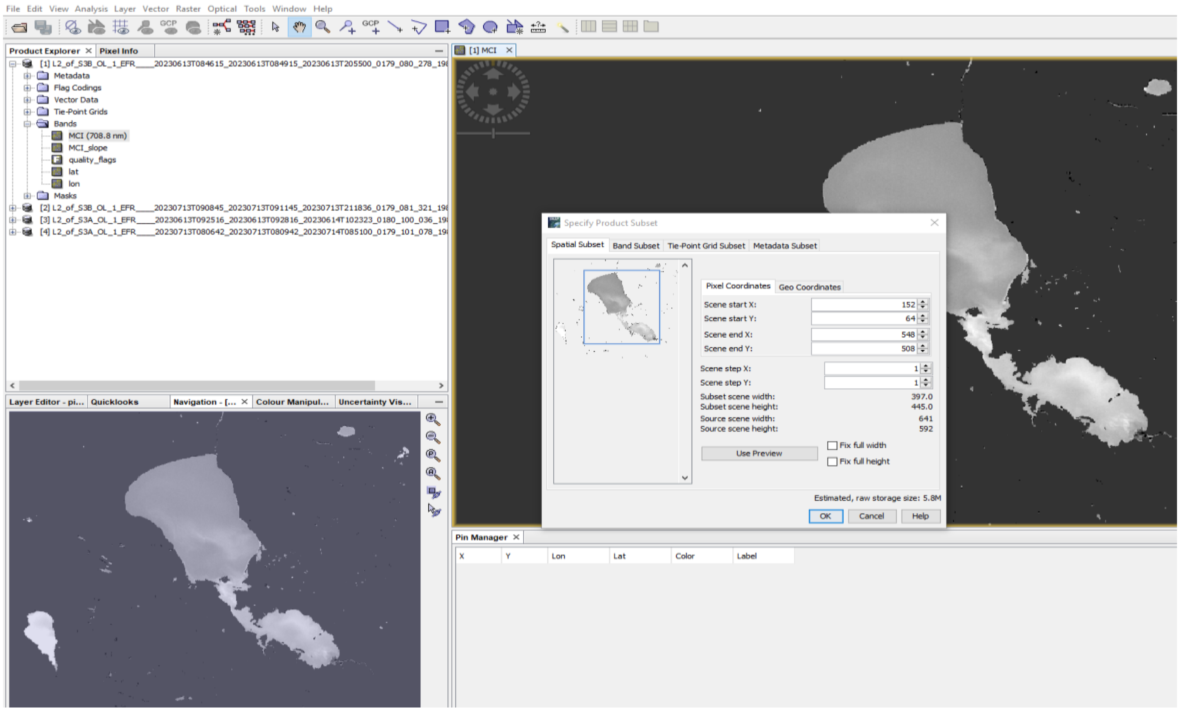
can be opened in SNAP:

In SNAP, drag the file to the **Product Explorer** window or click File -> Open -> File name. Select the band MCI by clicking on the

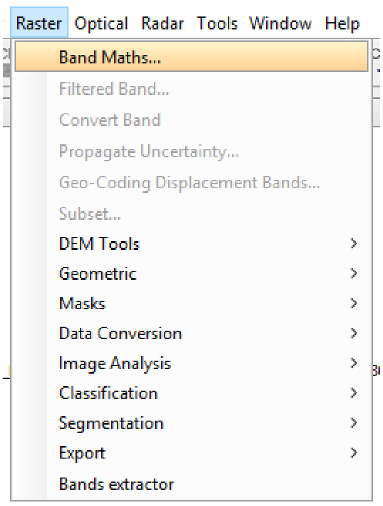
“+” sign in front of the file in the **Product Explorer** window -> Bands -> MCI. Double click on MCI product to open it.

A subset with the lake can be created – this gives a smaller image for further processing.

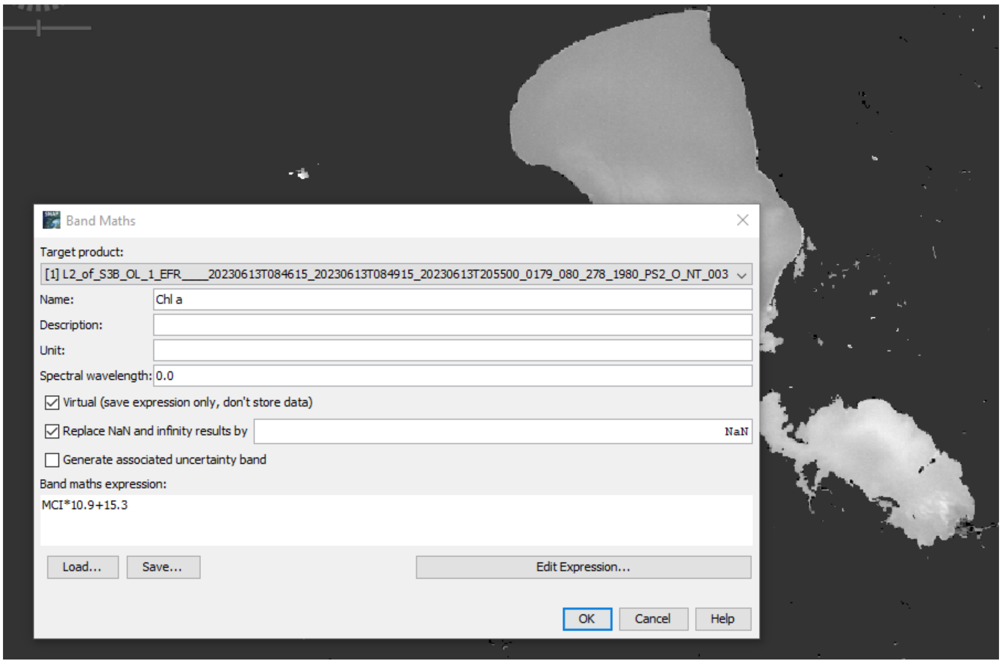
Right-click on the image, select “Spatial subset from the view”, and drag the blue box around Peipsi, click OK.



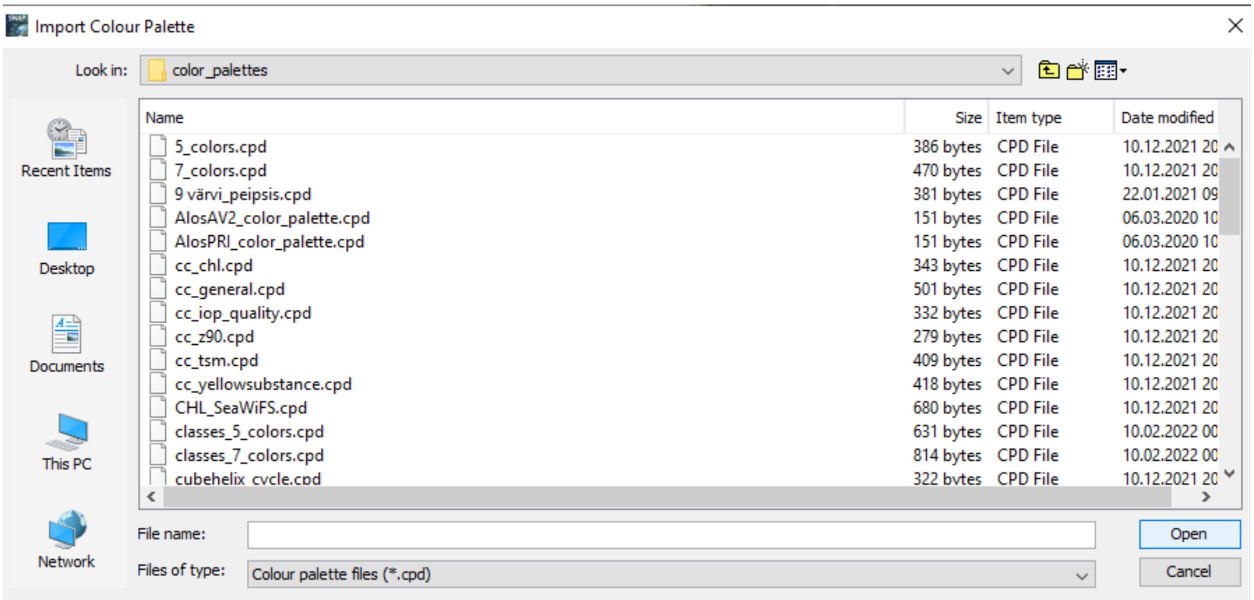
Smaller subset appears in the left corner (Product Explorer window)



For Lake Peipsi, MCI product can be used as an input to derive Chl a by applying a region-specific algorithm (Alikas et al. (2010). For this, use Raster (you will find it in the upper row)–> Band Maths. Give **Name** to new band by renaming new_band_1 as Chl a. Click on the **Edit Expression** to calculate Chl a: MCI*10.9+15.3. Click OK, new Chl a product opens automatically.

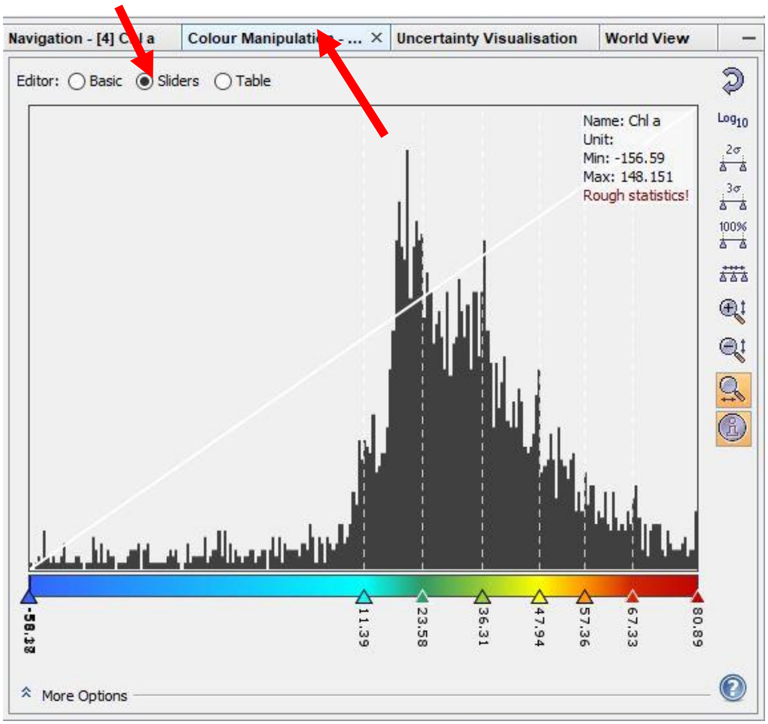


We can assign colours to Chl a product for better visualisation by using **Colour manipulation** tool. The Colour manipulation window is in the lower left corner in SNAP or you can find it from View-> Tool Windows. Open it, click on Basic ->  Import colour palette from text file ->

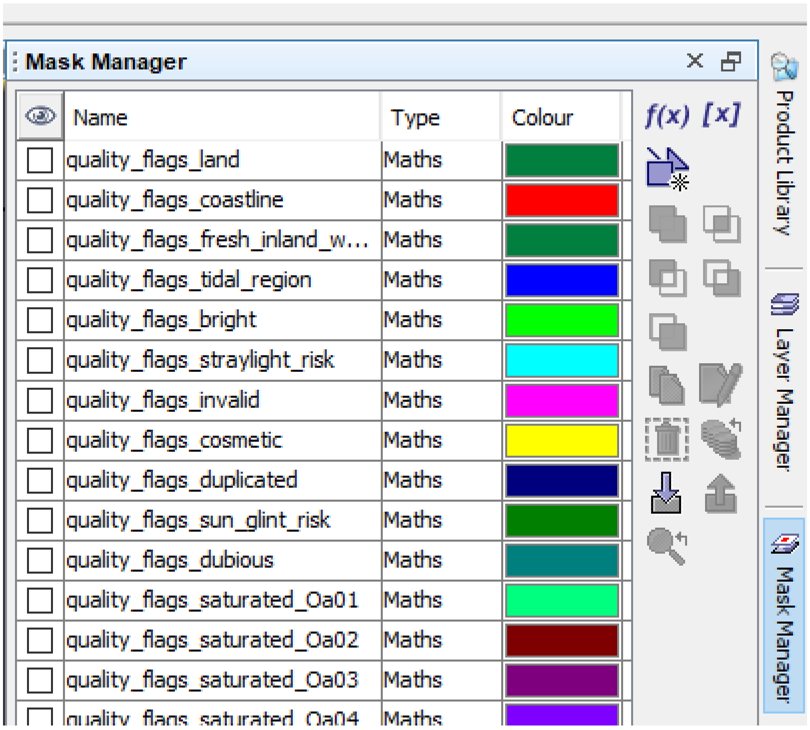


Select cc_chl.cpd.

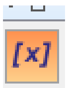
A new coloured image appears in the Main window. Click **Sliders** -> displace the arrows as needed to visualize the concentration variability better. Also, a **Table** view may be handy, as distinct classes can be applied, with the possibility of changing numbers to e.g. 10, 20, 30, 40, 50, 60, 70, 80, 100. This palette can be saved as a separate file and used again later.

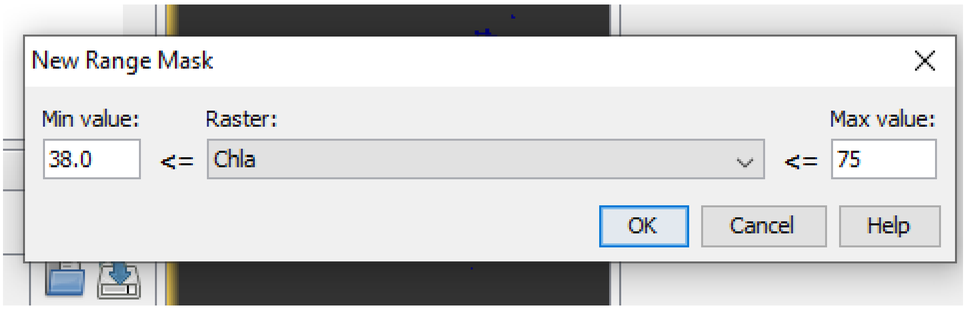


Look at two images (June 13th and July 13th, note you have 4 images as both Sentinel 3A and Sentinel 3B had overpass) – are the concentrations in all lake parts higher in July? Generate a mask Chl a from 38 to 75 µg/L by using the Mask Manager. According to WFD, this value range corresponds to the Bad ecological status class for L. Peipsi s.s. and accounts for the majority of the Poor class for Lämmijärv and L. Pihkva (Table 3, Table 4). Pixels can be exported using Export mask pixels.

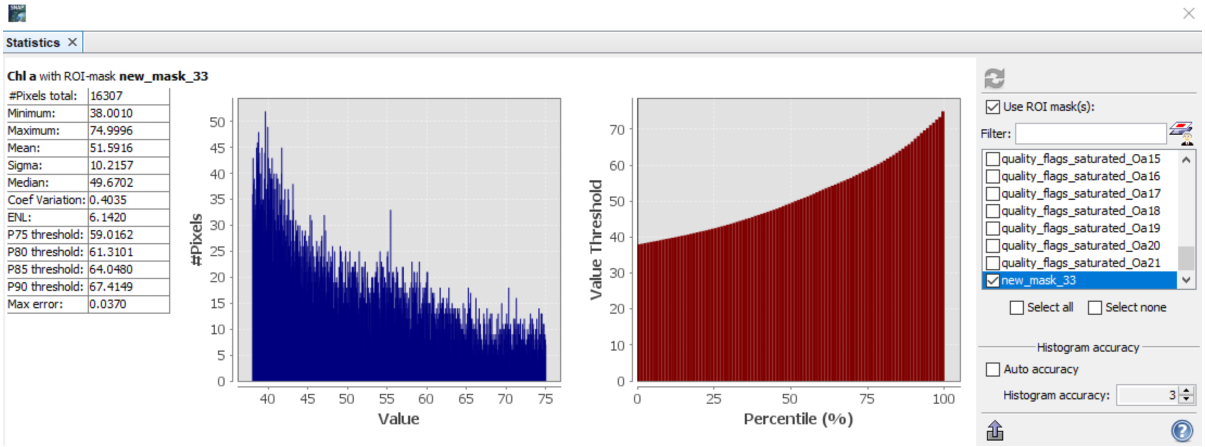


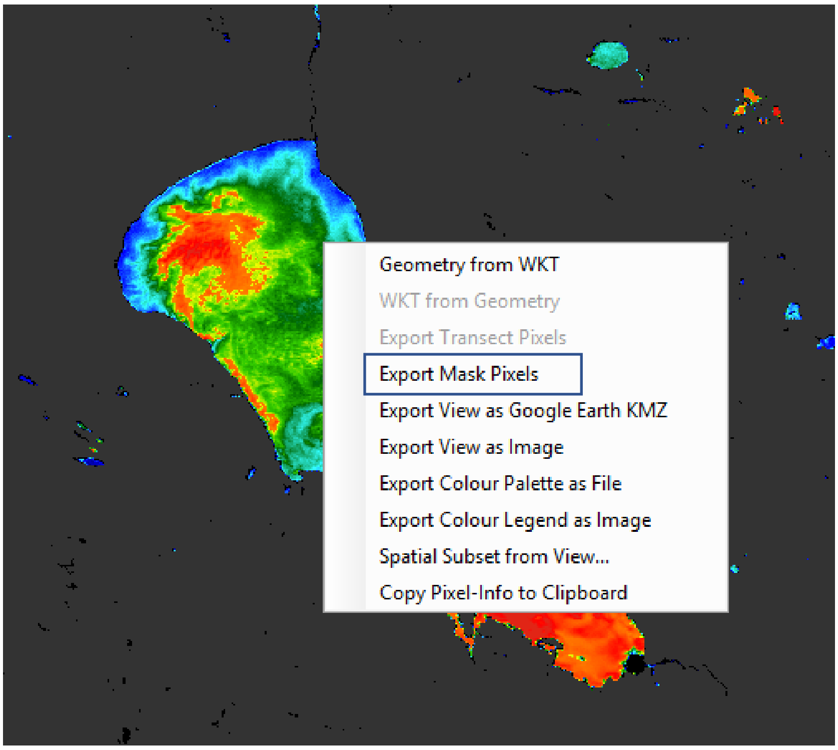
How to use Mask Manager? The Mask Manager Tab is on the right edge of the SNAP desktop or can be found from View-> Tool Windows.

Click on . **New Range Mask** appears. Add the values, click OK.



The created mask appears at the end of the list. You can change the **Name**, **Colour** and **Transparency** of the mask layer by clicking on. You can calculate **Statistics** (Analysis -> Statistics) for masked area or export the data (Click on the image and **Export Mask Pixels)**.



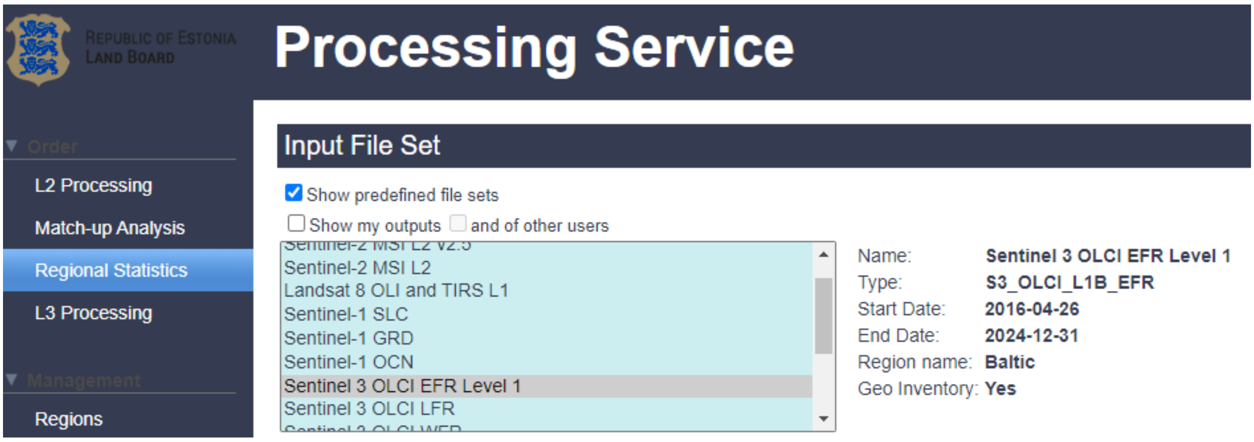


Optional exercise to practice spatial image processing and data analyses:

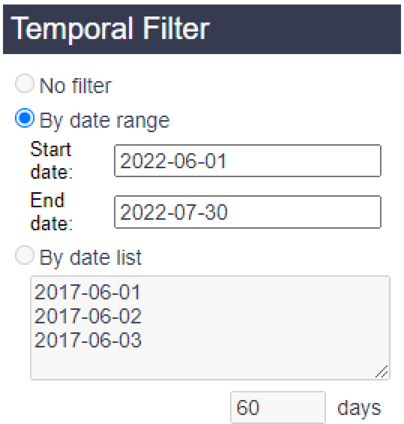
Do similar processing but with a spatial filter on the Pärnu Bay on the 13.06.2023 image. Use Table 6 to define threshold for different ecological status classes based on the Chl a.(e.g. Poor Status Chl a is defined as 9.2-13.6 µg/L). Create different subsets and masks for Peipsi and Pärnu Bay and compare the masked pixels by their surface area and statistics.

3.2.2. Chl a spatial variation in Pärnu Bay.

Regional statistics can be applied from the ESTHub portal over a specific region. Select **Regional Statistics**, choose S3/OLCI EFR Level 1.

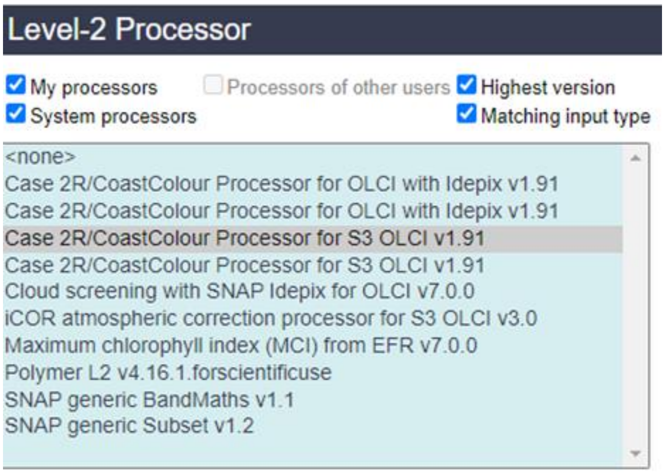


Temporal Filter can be set for 2 months during summer 2022.

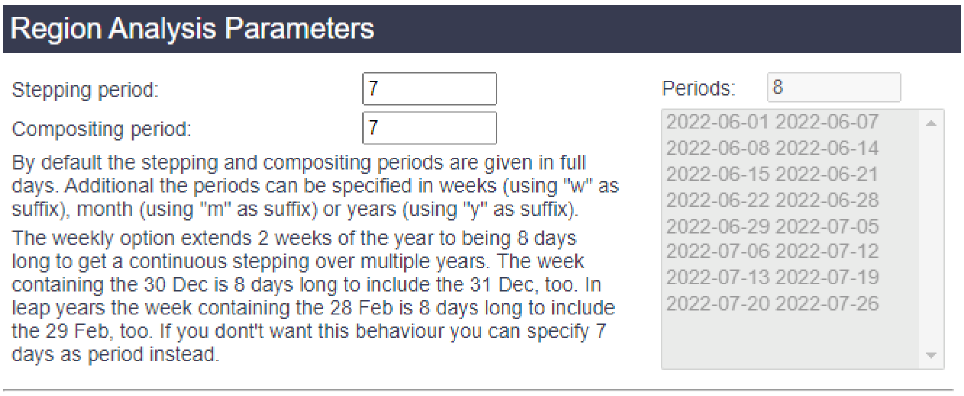


In the **Level-2 Processor**, select Case 2R/CoastColour Processor for S3 OLCI v1.91.

In **Level-2 Parameters**, change salinity to 5.

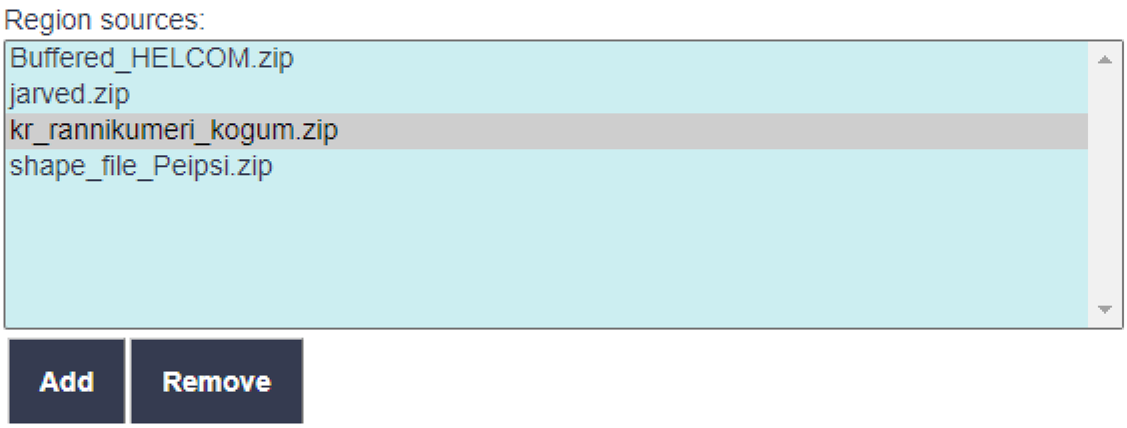


In the **<u>Region Analysis Parameters</u>**, choose 7 days for the stepping and compositing period.

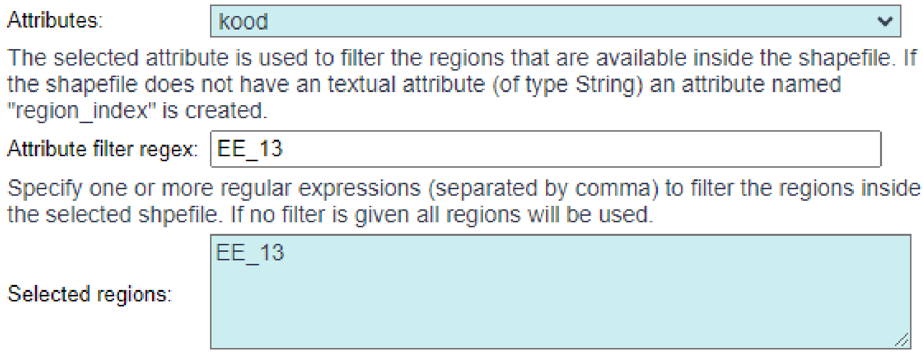


Upload your shape file kr_rannikumeri_kogum.zip (from the folder with additional files) in the **<u>Regional Analysis Parameters</u>** window and select it.

Note: Shapefiles have been modified with the application of a 1 km buffer zone from the land.



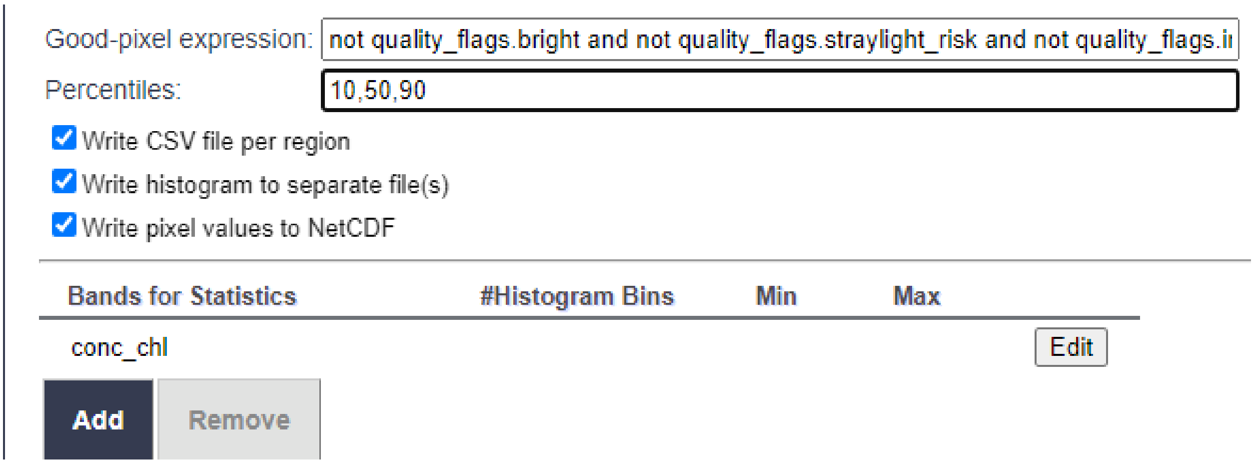
In the **Attributes filter regex** window, write EE_13; this retrieves information only about Pärnu Bay (Table 1).

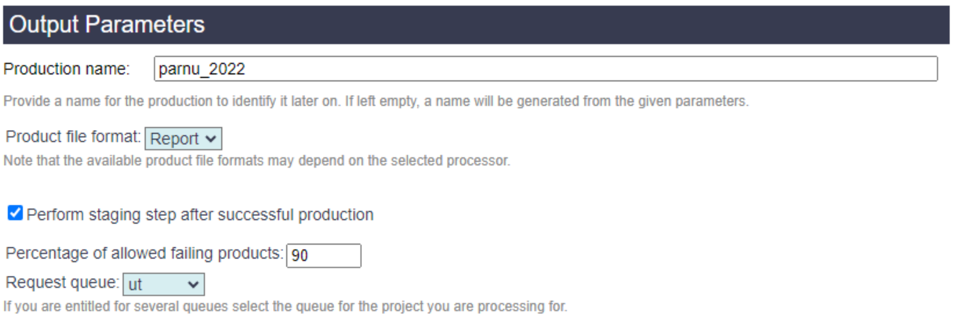


Good pixel expression: not quality_flags.bright and not quality_flags.straylight_risk and not quality_flags.invalid and not quality_flags.sun_glint_risk

Percentiles 10,50,90

Under Bands for Statistics, click on Add. A new window opens. Under Band name, write conc_chl, click OK.





Order Production.

An aggregated result over an area will be generated.

Load CSV to MS EXCEL and make a time series. Does it differ from the *in situ* and 1x1 pixel extraction of the point K5?

3.3. Assessment of the ecological status

The Baltic Sea is one of the areas most strongly affected by human activities in the world, and extensive international cooperation is carried out to preserve and improve its condition.
In order to protect the natural environment of the Baltic Sea, the Convention on the Protection of the Marine Environment of the Baltic Sea Region (HELCOM) was signed on April 9, 1992 between the countries surrounding the Baltic Sea and the European Economic Community (Mereseire allprogramm 2019). Monitoring is a well-established function in HELCOM - monitoring of physical, chemical and biological variables of the Baltic Sea **open area** started already in 1979 and monitoring of inputs of nutrients and hazardous substances was initiated in 1998 (https://helcom.fi/action-areas/monitoring-and-assessment/). Today, there are 12 agreed HELCOM monitoring programmes covering sources and inputs of human pressures and various variables reflecting the state of the environment. Four open marine areas surround Estonia (Figure 3).

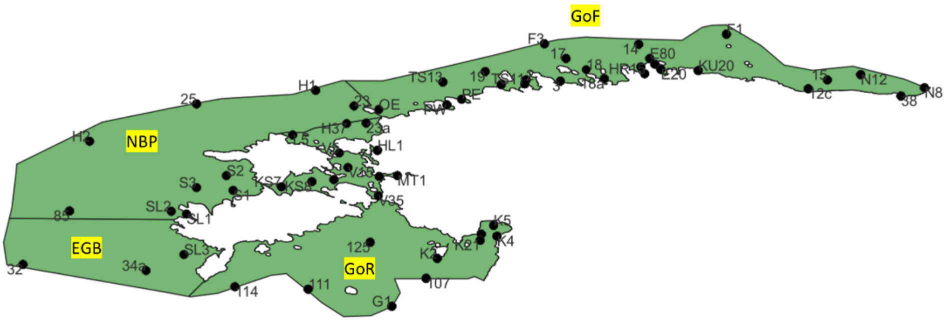


Figure 3. HELCOM areas surrounding Estonia (Gulf of Finland, Northern Baltic Proper, Eastern Gotland Basin, Gulf of Riga).

On June 17, 2008, the European Parliament and the Council adopted Directive 2008/56/EC, which establishes an action framework for the Community's marine environmental policy (**Marine Strategy Framework Directive**; MSFD). **This directive stated that the member states of the European Union are obliged to implement the necessary measures to achieve good environmental status of the marine environment**, whereas criteria and methodological standards on good environmental status of marine waters and specifications and standardized methods for monitoring and assessment were described in Commission Decision (EU) 2017/848.
Another important EU directive about water quality monitoring is the **Water Framework Directive** 2000/60/EC. This directive committed European Union member states to achieve good qualitative and quantitative status of all water bodies by 2015, which was later extended to 2027.

3.3.1. Lake Peipsi, WFD

The ecological status of the lakes > 50 ha is obligatory to monitor in the frames of WFD. For this assessment, the lakes in Estonia are divided into eight types according to their size, alkalinity, chloride content, stratification features and colour (Pinnavee…2009). L. Peipsi belongs to its specific type VII with surface area >1000 km^2, medium alkalinity (80–240 HCO_3^- mg/l, conductivity 165–

400 µS/cm), chloride content up to 25 mg/l), being unstratified and with light water (absorption coefficient 4 m^{-1} at 400 nm).

In situ sampling is performed in the frames of the national monitoring from **April to October.** This period is used to get an estimation of **Chl a** and total phytoplankton biomass together with physico-chemical quality elements (e.g. **transparency**). Estimations from the water samples are based on the arithmetic mean of integral samples. If cyanobacterial biomass share from the total phytoplankton biomass is included, its estimation is based on the time period from July-September.

The final status assessment needs many parameters to be estimated, which all cannot be derived from satellite products. However, we can still support the assessment according to Chl a and transparency based on the Copernicus data.

The ecological status according to Chl a and transparency can be estimated according to Tables 3 and 4 for Lake Peipsi. Note, the criteria are separately assessed for mesotrophic and more eutrophic parts of the lake. For WFD, the deviation of the natural conditions is assessed. Assessment is given in 5 classes: high, good, moderate, poor and bad.

Table 3. Thresholds for class borders for Chl a and transparency for naturally eutrophic lake-part Lämmijärv and Lake Pihkva. EQR is Ecological Quality Ratio between 0 and 1, and the natural level is 1.

Lämmijärv, L. Pihkva	**EQR=1**	**High**	**Good**	**Moderate**	**Poor**	**Bad**
Chl a, µg/l (May - October)	5.0	≤ 6	6.1-13.0	13.1-37.0	37.1-75	> 75.0
Transparency (m) (May-October)	2.5	≥ 2	1.9-1.5	1.4-1.0	0.9-0.7	< 0.6

Table 4. Thresholds for class borders for Chl a and transparency for mesotrophic lake-part L. Peipsi s.s.

Peipsi s.s.	**EQR=1**	**High**	**Good**	**Moderate**	**Poor**	**Bad**
Chl a, µg/l (May - October)	2.6	≤ 3.0	3.1-8.0	8.1-20.0	20.1-38.0	> 38.0
Transparency (m) (May-October)	4.4	≥ 3.5	3.4-2.5	2.4-1.5	1.4-1.0	< 0.9

3.3.2. Assessment of the status according to MSFD and WFD

Chl a and transparency in open marine areas (HELCOM sub-basins) can be evaluated according

to HELCOM regulations and established thresholds (HELCOM 2023: https://indicators.helcom.fi/indicator/chlorophyll/, https://indicators.helcom.fi/indicator/water-transparency/).

Assessing the status for MSFD is binary: **Meet/Fail**. For Estonian coastal areas, the threshold values for Chl a and transparency can be given, and these are in Table 5. If transparency is less than a threshold and Chl a concentration above the threshold, then the assessment result is Fail.

Long-term trends in the central and eastern parts of the Baltic Sea, where summer Chl a concentration is mainly related to phosphorus concentrations, the indicator shows no changes and fails to meet the criteria in all Estonian open sea areas (HELCOM 2018, 2023).

Table 5. Chl a and transparency thresholds according to MSFD for Estonian marine and coastal areas.

Code	Chl a threshold (µg/L)	Transparency threshold (m)
EE_1	3.7	3.6
EE_2	2.7	4.5
EE_3	2.7	4.5
EE_5	2.7	4.5
EE_6	2.7	4.5
EE_7	1.6	6.5
EE_8	2.4	4.9
EE_9	2.4	4.9
EE_10	1.6	6.5
EE_11	1.6	6.5
EE_13	4.5	3.2
EE_14	2.4	4.9
EE_16	2.4	4.9
EE_17	3	4.2
EE_18	3	4.2
EE_19	3	4.2
EGB	1.9	7.6
GOR	2.7	5
NBP	1.65	7.1
GOF (W)	1.9	5.9
GOF (E)	2.3	5.3

Based on the WFD, the ecological status class of the coastal water body according to phytoplankton is determined using the arithmetic mean of the values of the EQRs of two quality indicators - Chl a concentration and phytoplankton biomass, while the EQR values are obtained on the basis of the median value of the samples taken from June to September (Pinnavee…2009). However, if phytoplankton biomass data is absent, an assessment according to Chl a (Table 6).

Table 6. WFD class borders for Chl a (µg/L) in Estonian coastal areas.

Region	Coastal Type	High	Good	Moderate	Poor	Bad
GOF_SE	**1**	≤ 3	3.1-3.7	3.8-7.6	7.7-11.4	> 11.4
Pärnu Bay	**2**	≤3.6	3.7-4.5	4.6-9.1	9.2-13.6	> 13.6
GOF_W	**3**	≤2.2	2.3-2.7	2.8-5.4	5.5-8.2	> 8.2
Western_Islands_W_part	**4**	≤1.9	2.0-2.4	2.5-4.8	4.9-7.1	> 7.1
Moonsund area	**5**	≤1.9	2.0-2.4	2.5-4.8	4.9-7.1	> 7.1
GOR	**6**	≤2.4	2.5-3.0	3.1-6.2	6.3-9.3	> 9.3

Table 7. WFD class borders for transparency (m) in Estonian coastal areas.

Region	Type	High	Good	Moderate	Poor	Bad
GOF_SE	**1**	≥ 4.2	4.1-3.6	3.5-2.4	2.3-1.6	< 1.6
Pärnu Bay	**2**	≥ 3.7	3.6-3.2	3.1-2.0	1.9-1.5	< 1.5
GOF_W	**3**	≥ 5.3	5.2-4.5	4.4-2.8	2.7-2.1	< 2.1
Western_Islands_W_part	**4**	≥ 7.4	7.3-6.5	6.4-3.9	3.8-3.0	< 3.0
Moonsund area	**5**	≥ 5.7	5.6-4.9	4.8-3.1	3.0-2.3	< 2.3
GOR	**6**	≥ 4.9	4.8-4.2	4.1-2.6	2.5-2.0	< 2.0

and transparency (Table 7) can be made, and assessment criteria are different for the coastal water areas (6 types in the Estonian coastal area).

Give an assessment about the status in 2022, based on the satellite estimates on the Chl a.

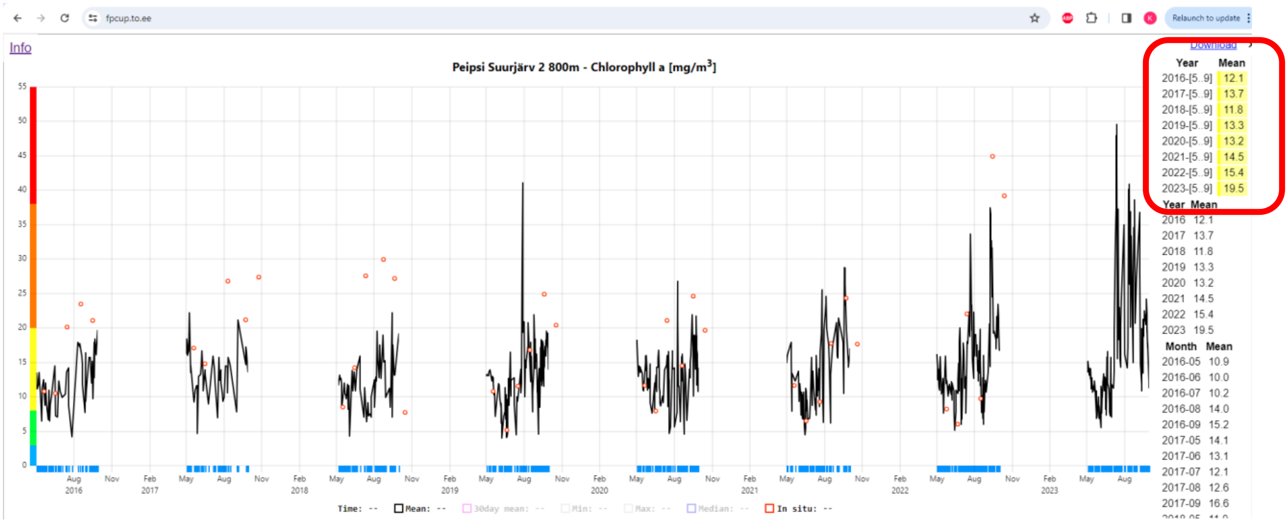
Use the extracted time series from the previous exercise – stations 12c (Narva Bay), K5 (Pärnu Bay) and GoF (Gulf of Finland) and compare the threshold value against averaged value over the time. Take the threshold for GoF (Table 5, code GOF (W)), 12c (Table 5, code EE_1) and K5 (Table 5, code EE_13)

Note the time period necessary for the assessment! For marine areas, you need an average over the months of **June-September.**

Does the Chl a concentration in the marine areas meet MSFD criteria (according to Chl a assessment)?

Find the assessment according to Chl a time series extracted for L. Peipsi (L. Peipsi s.s. P2 (58.78991 N, 27.19021 E) and Lämmijärv (point P16 58.234 N, 27.48669 E) for 2022. For L. Peipsi s.s. use Table 4 and for Lämmijärv, use Table 3. Derive the average value over the May-October period and assign the ecological status class.

You can compare the results from 2022 with previous years from the site fpcup.to.ee. There, the assessment is given according to the average for a specific monitoring point or spatial area.



Which lake part (Peipsi s.s., Lämmijärv, Pihkva) was in the best/worst status according to yearly estimates from remotely sensed Chl a? Do you see any trends in status classes over the years?

Optional exercises:

1. **These examples were given based on the Chl a product extracted from point measurement. As shown before, with Copernicus product we could derive the spatio-temporal averages over the whole waterbody. Do similar analyses but use Regional Statics and specific shapefiles for specific waterbodies. Derive the mean values over the required period and compare it either with the thresholds or assign an ecological status class according to WFD. Does the result change when you use spatial data instead of a point measurement?**
2. **Similarly to Chl a, you can also derive transparency from Copernicus data and assign an ecological status based on this product.**

4. Additional reading: Overview of the directives

4.1. Marine Strategy Framework Directive

On June 17, 2008, the European Parliament and the Council adopted Directive 2008/56/EC, which establishes an action framework for the Community's marine environmental policy (Marine Strategy Framework Directive; MSFD). This document was amended by the Commission Directive (EL) 2017/845. The MSFD is one of the most ambitious international marine protection legal frameworks, relying on the efforts of 23 coastal and 5 landlocked states – in coordination with non-EU countries – to apply an ecosystem-based management and to achieve good environmental status in 5,720,000 km^2 of sea surface area across four sea regions (Report, 2020). The member states of the European Union are obliged to implement the necessary measures to achieve good environmental status of the marine environment according to MSFD, whereas criteria and methodological standards on good environmental status of marine waters and specifications and standardized methods for monitoring and assessment were described in Commission Decision (EU) 2017/848.

The MSFD (Article 1(2)) obliges each Member State to develop and implement a marine strategy in its marine area based on an ecosystem-based approach, which aims to:
a) protect and preserve the marine environment, prevent its deterioration, or, if possible, restore marine ecosystems in areas where they have been damaged;
b) prevent and reduce discharges into the marine environment in order to gradually eliminate pollution to ensure that it does not significantly affect or threaten the diversity of marine life, marine ecosystems, human health or the legitimate uses of the sea.

Member States are required to follow a common approach, which involves reiterative six-year cycles assessing the current state of the marine environment (MSFD 2008) via

- initial assessment of marine waters, including an analysis of the current environmental status, the main impacts and pressures, as well as an economic, social and cost analysis of the deterioration of the marine environment
- determining good environmental status, implementation of monitoring programmes
- establishing environmental targets to guide progress towards achieving good environmental status
- establishing monitoring programmes for ongoing assessment and regular updating of targets,
- developing programmes of measures to achieve or maintain good environmental status

For this, a national marine strategy in accordance with the MSFD requirements was developed, consisting of a monitoring program and a program of measures for the Estonian marine waters.
Estonian marine monitoring program is covering the data gathering about 11 qualitative characteristics and human activities which affect the marine environment, based on the requirements stated by MSFD (2008/56/EC) (Keskkonnaministeerium 2022, Seletuskiri):

1) biological diversity (D1): presence of habitats and their quality, species abundance and distribution
2) non-native species (D2) and their potential influence on the marine ecosystem
3) commercial fish and other species (D3): status of economically important fish populations, their size and age distribution
4) food web (D4): abundance and variety of food web elements
5) eutrophication (D5) – the extent and effect of human-induced eutrophication
6) seabed integrity (D6): functioning and structure of sea bed ecosystems
7) hydrographic conditions (D7): changes and their extent
8) pollutant content (D8)
9) pollutants in the seafood (D9),

10) marine litter (D10) – micro and macro-size litter presence in water, coastal areas and sea bed
11) energy, including underwater noise (D11)

Qualitative descriptors of good environmental status according to the EU Marine Strategy Framework Directive are determined according to the Water Law § 71 and based upon criteria in appendices of RT I, 29.09.2020.
During later years, several working groups in sea conventions such as ICES, OSPAR and HELCOM are working towards harmonization of monitoring efforts in Europe to improve, amongst others, the MSFD. Monitoring is a well-established function in HELCOM. Monitoring of physical, chemical and biological variables of the Baltic Sea open area started already in 1979, and monitoring of inputs of nutrients and hazardous substances was initiated in 1998 (https://helcom.fi/action-areas/monitoring-and-assessment/). The basic document, the Baltic Sea ps://helcom.fi/action-areas/monitoring-and-assessment/). The basic document, the Baltic Sea Action Plan, was adopted by the HELCOM Contracting Parties (Germany, Denmark, Estonia, European Union, Finland, Lithuania, Latvia, Poland, Russia and Sweden) in 2007, and updated in 2021, is HELCOM's strategic programme of measures and actions for achieving good environmental status of the sea, ultimately leading to a Baltic Sea in a healthy state in the future. The basic document, the Baltic Sea Action Plan, was adopted by the HELCOM Contracting Parties (Germany, Denmark, Estonia, European Union, Finland, Lithuania, Latvia, Poland, Russia and Sweden) in 2007, and updated in 2021, is HELCOM's strategic programme of measures and actions for achieving good environmental status of the sea, ultimately leading to a Baltic Sea in a healthy state in the future.ties (Germany, Denmark, Estonia, European Union, Finland, Lithuania, Latvia, Poland, Russia and Sweden) in 2007 and updated in 2021, is HELCOM's strategic programme of measures and actions for achieving good environmental status of the sea, ultimately leading to a Baltic Sea in a healthy state in the future.

4.2. Water Framework Directive

Another important EU directive about water quality monitoring is the Water Framework Directive 2000/60/EC. This committed European Union member states to achieve good qualitative and quantitative status of all water bodies by 2015, which was later extended to 2027. The status estimation is given based on the criterions in Water Law (defining a good status), whereas the status assessment consists of 2 blocks – ecological status and chemical status (https://keskkonnaportaal.ee/et/teemad/vesi/meri). The chemical status is assessed in a 2-level scale – good (the content of priority pollutants is lower than the limit value established as an ecological quality standard); bad – the content of the priority substance is above the norm of the quality standard. Depending on the extent of human influence, the ecological state of surface water bodies (including the state of coastal water bodies) is assessed on a 5-level scale: from very good, in which there are no or negligible changes due to human activity, to bad due the extensive changes from natural reference conditions due to extensive human activity. In the long perspective, it is mandatory to improve the conditions to at least "Good" status of all water bodies (Figure 4). Reference status is defined as natural fluctuation of the parameters in a "natural reference "lake – a lake, where there is no human influence. Reference conditions are either derived from paleolimnological research, modelling approach, and expert judgement or from similar lakes in different countries with less human influence. The change of the paradigm is that an eutrophied lake is not a priori a lake in a bad status, but if it is situated in the nutrient-rich lowland and has been eutrophic since the beginning, it is in a good status. Chl a content is naturally highest in the shallow, alkaline lakes.

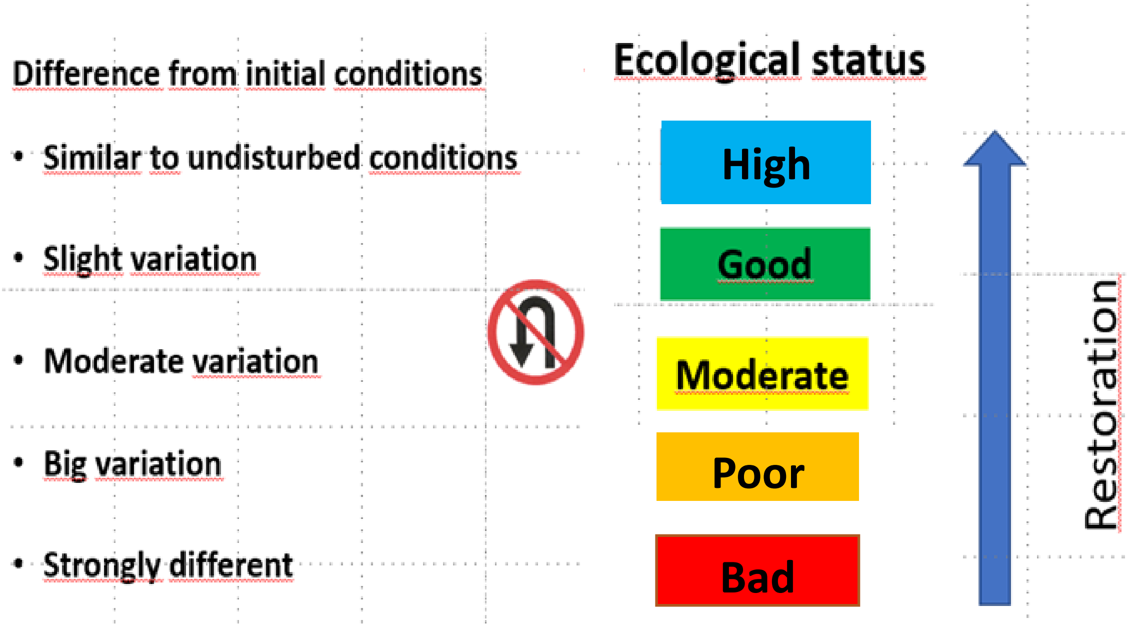


Figure 4. The logic behind the status assessment.

The following parameters are used for WFD type characterization in Estonia:
- Size (small < 10 km^{2}, large 100-300 km^{2}, very large >1000 km^{2})
- Stratification (present or not)
- Water colouration (light absorption coefficient (a.c.) at 400 nm < 4 m^{-1}, colour on Pt-Co scale <100°, dark: a.c. 400 nm ≥4 m^{-1}, colour on Pt-Co scale >100°)
- Chloride content (low (< 25 mg/l) or high (>25 mg/l))
- Water hardness (soft (HCO_3 < 80 mg/l); medium (80-240 mg/l); hard (> 240 mg/l))

In Estonia, for WFD assessment, lakes are divided into eight categories:
I -small, hard water, unstratified, low chloride content, water colour may be dark or light
II - small, medium hardness, low chloride content, unstratified, water colour may be dark or light
III - small, medium hardness, low chloride content, stratified, water colour may be dark or light
IV - small, soft, low chloride content, unstratified, dark
V - small, soft, low chloride content, unstratified, light
VI - Võrtsjärv - large, medium hardness, low chloride content, unstratified, light
VII - L. Peipsi - very large, medium hardness, low chloride content, unstratified, light
VIII - coastal lakes – high chloride content, close to the sea (within 5 km); other parameters are irrelevant

Hydro-morphological and chemical quality elements support biological quality elements.

A. Biological elements include:

- Phytoplankton community composition, abundance and biomass
- Community composition and abundance of macrophytes and mosses
- Community composition and abundance of benthos
- Community composition, abundance and age structure of fishes

B: Hydro-morphological elements

Hydrological regime

- Flow rate and dynamics
- Residence time
- Connection with ground water

Morphological conditions

- Variation in lake depth
- The structure and foundation of the lakebed
- The structure of the lake shore

C: Physico-chemical elements

- Transparency
- Temperature
- Oxygen content
- pH
- Nutrients – total nitrogen (totN) and total phosphorous (totP)
- Specific pollutants

In Estonia, there is now not a single water body in very good status due to the inclusion of specific chemical pollutants. Mainly, the amount of different heavy metals is problematic.

For phytoplankton assessment in lake types I-V and VII, four parameters are used (Chl a concentration, community composition assessment, Pielou evenness and phytoplankton compound quotient FKI). FKI takes into account the number of phytoplankton species preferring eutrophic conditions and the number of species preferring oligotrophic conditions.

$$FKI = \frac{Cyanophyta + Chlorococcales + Centrales + Euglenophyceae + Cryptophyta + 1}{Desmidiales + Chrysophyceae + 1}$$

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Additional files:

Shapefiles (Peipsi s.s., Lämmijärv, Pihkva; Buffered HELCOM – about HELCOM areas, with 1 km bufferzone around land, Buffered coastal – about coastal areas, with 1 km buffer zone around land to avoid shallow waters)

In situ data file: K5_12c.xls – *in situ* data for 2 locations, measured by Estonian Marine Institute.