



# Copernicus Marine Training Workshop

## QGIS tutorial for the MarineData4Coastal Monitoring 2024



PROGRAMME OF  
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Copernicus  
Marine Service

implemented by



**MERCATOR  
OCEAN**  
INTERNATIONAL

**MERCATOR OCEAN**  
INTERNATIONAL

2 avenue de l'Aérodrome de Montaudran, 31400 Toulouse, FRANCE

Tél : +33 5 61 39 38 02 - Fax : +33 5 61 39 38 99

Société civile de droit français au capital de 2 000 000 € - 522 911 577 RCS Toulouse - SIRET 522 911 577 00024

[marine.copernicus.eu](http://marine.copernicus.eu)  
[mercator-ocean.eu](http://mercator-ocean.eu)

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# 1. Introduction

## 1.1. Scope of the document

MarineData4CoastalMonitoring training event, promoted by Mercator Ocean International in the framework of the Copernicus Marine Service, aims at increasing user uptake and awareness of coastal environments in all regions of the world by sharing applications of the Copernicus Marine Service products in ecosystem monitoring studies.

Technically, here it is shown how to use QGIS for:

- Understanding Copernicus Marine data through mapping functions and
- Performing some spatial analysis to target the topics covered by this training, that are coral bleaching and eutrophication.

The technical material here described is complementary to the tutorial videos available on the [Copernicus Marine Service YouTube page](#).

**This document has been prepared by Dr. Stefania A. Ciliberti (NOW Systems, Madrid).**

## 1.2. Structure of this tutorial

This tutorial is organized in 2 parts:

- Section 2 gives an overview on coral bleaching, focusing on African coastal area of Kenya and Tanzania.
- Section 3 discusses eutrophication, showing how to use geospatial tools to analyze physical and biogeochemical conditions in the Western Mediterranean, taking the Ebro Delta as example.

Exercises here presented use some technical information as discussed in

**TD1: Copernicus Marine Service – Training Workshop | QGIS installation notes and plugin configuration, by Dr. Stefania A. Ciliberti (NOW Systems, Madrid).**

## 2. Coral bleaching: the Kenyan coral reef ecosystem

### 2.1. Introduction

Coral bleaching is a phenomenon where corals, under stress, expel the symbiotic algae (zooxanthellae) living in their tissues. Since these algae provide corals with food through photosynthesis and give them their color, their loss leads to bleaching. The primary causes of coral bleaching must be addressed to extreme weather events due to anthropogenic global warming, pollution and ocean acidification (Hughes et al. 2018).

The UN Environment Program (UNEP) promotes international cooperation to support the protection, sustainable management and restoration of coral reefs, and related ecosystems. As shown in Figure 1, coral reefs are distributed in tropical and subtropical oceans around the world, primarily between the Tropic of Cancer and the Tropic of Capricorn. These regions provide warm, shallow waters that are ideal for coral growth. Coral reefs are critically important for marine biodiversity, coastal protection, and local economies, particularly through tourism and fishing.

This training session is going to focus on discuss examples on how to use QGIS-based tools and Copernicus Marine products for monitoring Kenya-Tanzania's coastal region (Figure 2) with focus on Kenyan coral reef ecosystem, currently severely impacted by humanitarian and climate crisis due to rising temperatures.

The Eastern African coastal region is deeply influenced by the East African Coastal Current (EACC), supplied by the Northeast Madagascar Current (NEMC). The EACC is influenced by monsoonal wind system, with significant changes between the northeast and southwest monsoons. During the Northeast Monsoon (November to March), the EACC tends to be weaker, while during the Southwest Monsoon (June to September), the EACC strengths due to the prevailing winds. It transports warm water that feeds the coastal ecosystem, interacting with upwelling areas, exacerbating thermal stress during periods of high sea surface temperatures and so causing severe coral bleaching events.

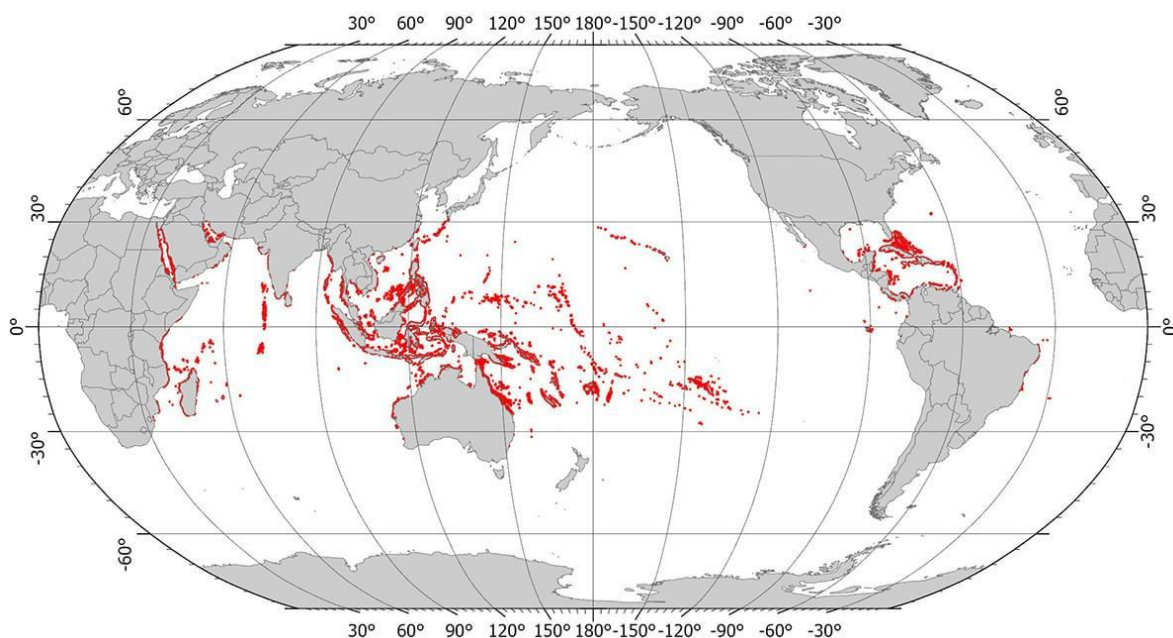


Figure 1. Distribution of coral reefs around the world (source: UNEP).

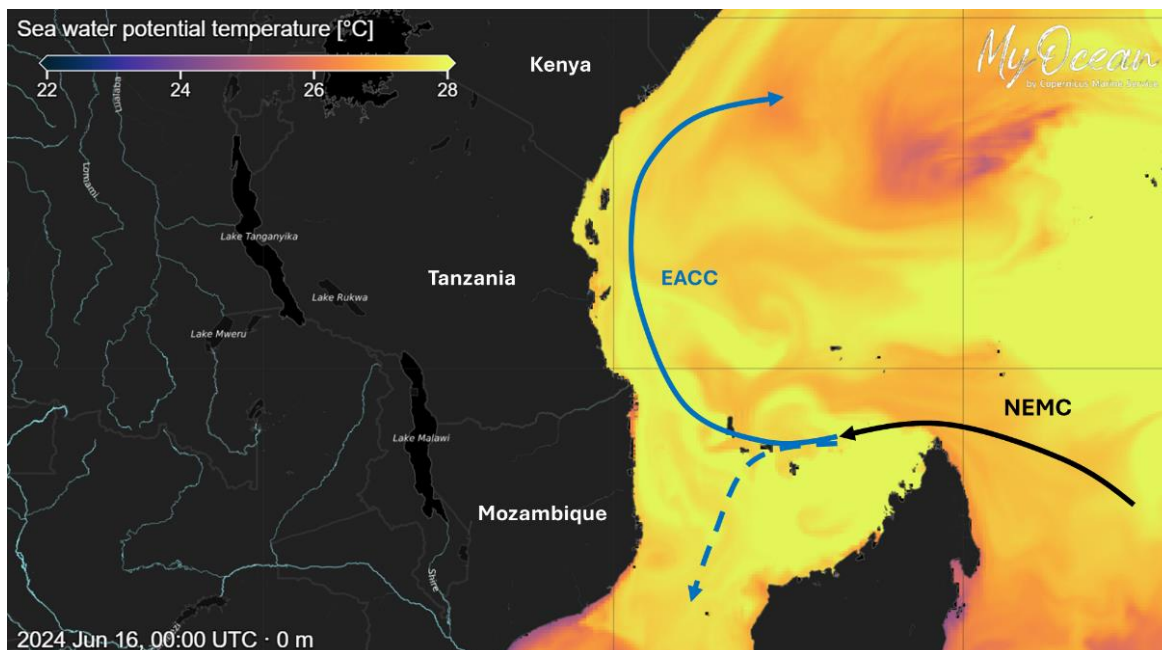


Figure 2. Kenya-Tanzania study area and main circulation features: the Northeast Madagascar (NEMC) and the East African Coastal Current (EACC; thick blue arrow) (reproduced from Schott et al., 2009). The map in background refers to sea surface temperature on 16/06/2024 as forecasted by the Global Ocean Physical Analysis and Forecasting System.

Coastal management plays an important role in definition of restoration plans for coral reefs and local biodiversity and monitoring water conditions can significantly help in the process. Guan et al. (2015) has proposed environmental tolerance limits for coral reefs for 6 EOVS: temperature, salinity, nitrate, phosphate, aragonite saturation state and light. The Authors found that the global, annually averaged tolerance limits for coral reefs are:

- For temperature: 21.7-29.6 °C.
- For salinity: 28.7-40.4 PSU.
- For nitrate: 4.51  $\mu\text{mol L}^{-1}$ .
- For phosphate: 0.63  $\mu\text{mol L}^{-1}$ .
- For aragonite saturation: 2.82.
- For the average minimum light intensity: 450  $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$ .

## 2.2. Scope of the QGIS application and input data

In this tutorial, we will learn how to use QGIS for assessing the physical and biogeochemical conditions in the Kenya-Tanzania region according to tolerance limits as given by Guan et al. (2015), using:

- Sea surface temperature from the Global Ocean Physics Analysis and Forecasting System.
- Phosphate concentrations from the Global Ocean Biogeochemical Analysis and Forecasting System.

Details on used Copernicus Marine products as downloaded from the Copernicus Marine Data Store are given in Table 1. The reference bounding box used in this exercise is: [15°S to 1.3°N; 35.45°W to 50°E].

Table 1. Copernicus Marine input data used in the demonstrative QGIS tutorial for the Kenya-Tanzania case study.

Product	Dataset	Variable and info	Reference
GLOBAL_ANALYSISFORECAST_PHY_001_024	cmems_mod_glo_phy-thetao_anfc_0.083deg_P1D-m	Temperature <i>Bulletin date:</i> 08/06/2024. <i>Timeseries:</i> from 08/06 (forecast day 1) to 17/06 (forecast day 10).	Le Galloudec et al. 2023
GLOBAL_ANALYSISFORECAST_BGC_001_028	cmems_mod_glo_bgc-nut_anfc_0.25deg_P1D-m	Phosphate: <i>Bulletin date:</i> 08/06/2024. <i>Timeseries:</i> from 08/06 (forecast day 4) to 17/06 (forecast day 10).	Lamouroux and Tonani, 2023

## 2.3. QGIS implementation

### 2.3.1. QGIS implementation

Before starting with the implementation of the proposed exercise, it is necessary to follow some preliminary steps as briefly reported here:

- Launch QGIS.
- Create a new project: **Project** → **New**.
- Save it in your local working folder (in this way, all QGIS temporary and working files are properly collected there, and you will easily manage them): **Project** → **Save Project As** (and complete).

Then, you are ready to start with the implementation of the exercise.

### 2.3.2. Loading input data

To load input data, consisting of NetCDF files related to products as listed in Table 1, use the CMEMS-NetCDF plugin, following instructions as in [TD1].

- Configure a basemap: from the icon bar, select **QuickMapService** → **Search QMS** → **Google Satellite**.
- Load the NetCDF files to continue the exercise: from the menu, select **Plugins** → **NetCDF2GIS** → **Import NetCDF Files** (alternatively, you may select the plugin icon from the main bar).
- From your local folder with data, select the NetCDF files according to [TD1].

After loading, 3 groups of layers are displayed:

- The Google Satellite basemap.
- thetao related to sea surface temperature, from 8 to 17 June 2024 (Figure 3).
- po4, related to phosphate concentration, from 8 to 14 June 2024 (Figure 4).

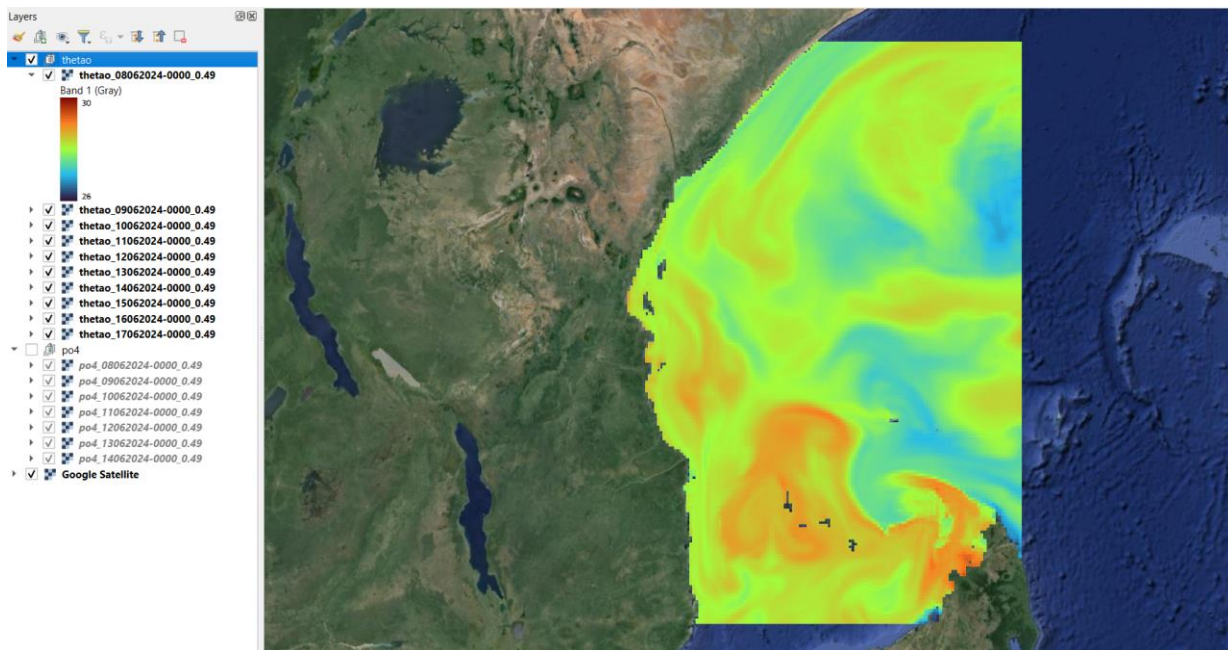


Figure 3. Sea surface temperature (in Celsius) from the Global Ocean Physical Analysis and Forecasting System on 08/06/2024.

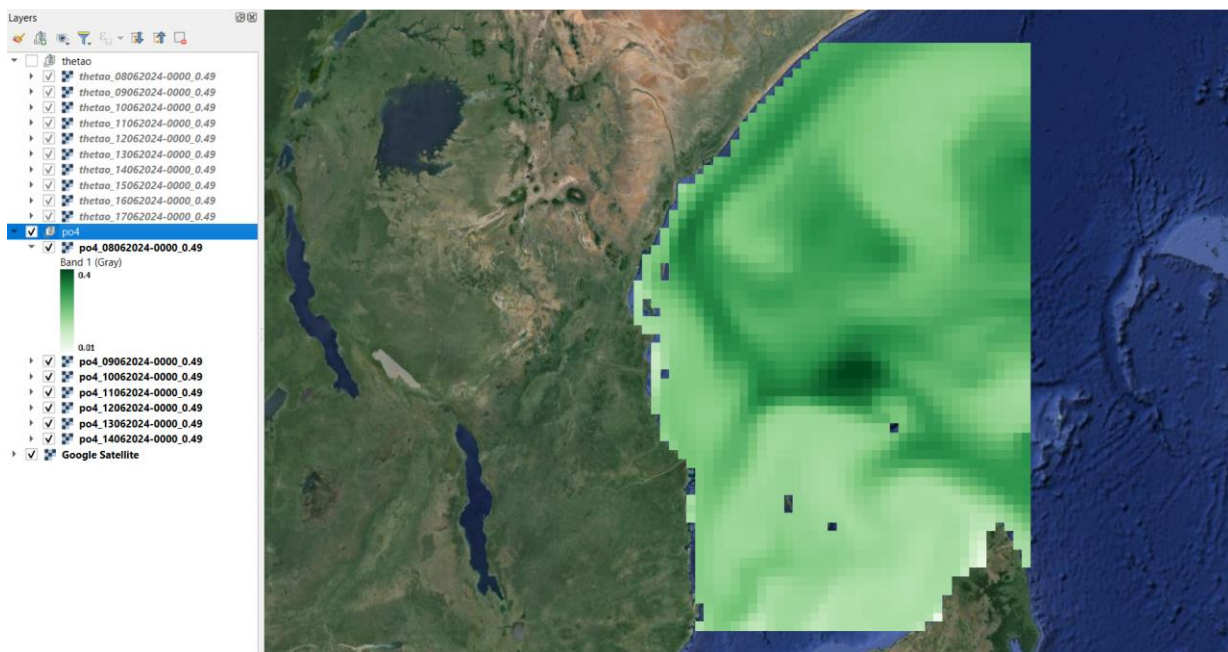


Figure 4. Concentration of phosphate in sea water (in mmol m-3) from the Global Ocean Biogeochemical Analysis and Forecasting System On 08/06/2024.

### 2.3.3. Analysis of the water conditions in the Kenya-Tanzania coastal area

The objective is to focus the geospatial analysis in the coastal area of the selected area of study, to characterize water conditions according to the method explained in Section 2.1.

It is necessary first to subset the region of interest and extract the 2 given layers accordingly.

- Definition of the subregion of interest, in the Kenya-Tanzania coastal area.

- **Layer** → **Create Layer** → **New Shapefile Layer**.
- Assign a name (for example, **ken-tan-region.shp**) and path where to save the new shapefile.
- Select **Geometry type: Polygon**.
- The created shapefile will be displayed in the Layers Board. Select it and from the icon bar select **Toggle Editing**. By activating it, the shapefile is now open for modification and new icons are activated.
- **Select Add Polygon** → **Digitize with Segment**. The polygon can be now drawn in your map.
- After digitizing the polygon, deactivate **Toogle Editing** function to save the result.

The result of this process is briefly represented in Figure 5.

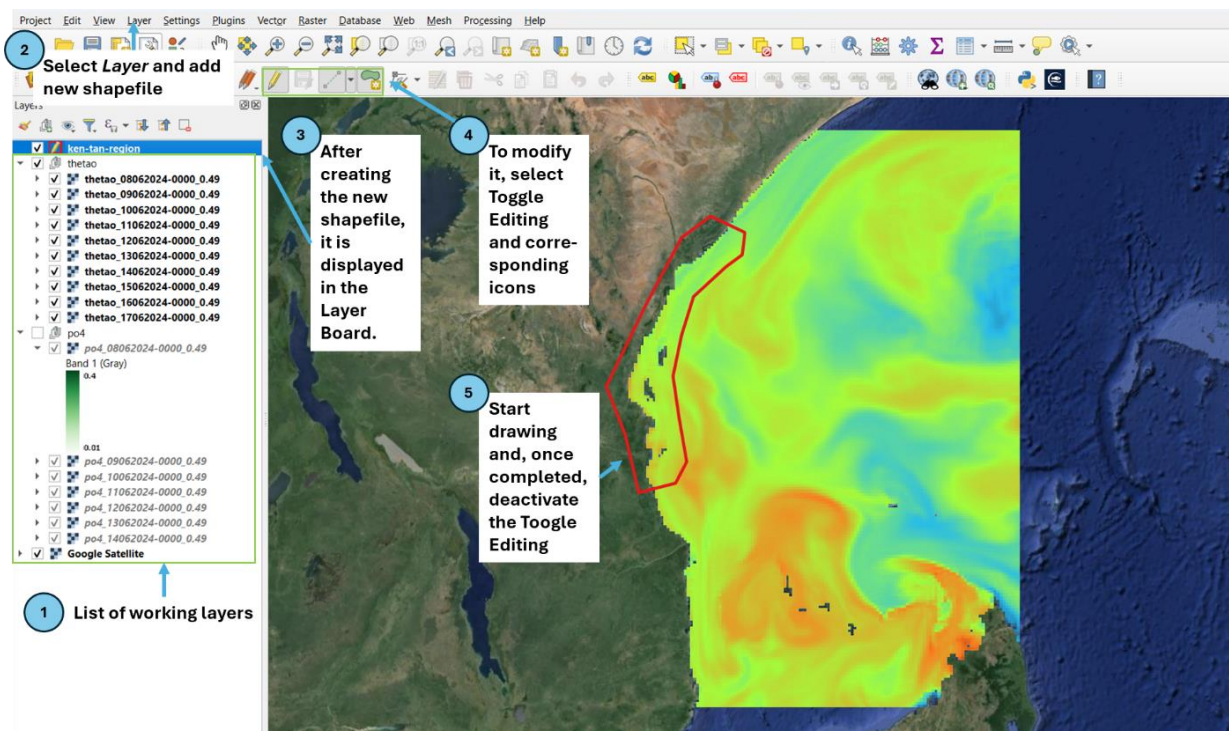


Figure 5. Main steps for defining the subregion of interest in the Kenya-Tanzania coastal area.

- Extraction of the physical and biogeochemical fields in the coastal region.
  - Extract the given fields over the subregion previously specified as **ken-taz-region.shp**: **Raster** → **Extraction** → **Clip Raster by Mask Layer**.
  - A window pops up. Since we are interested in processing all layers related to temperature and phosphate, we will run the process in batches. Select then **Run as Batch Process**.
  - It opens another window, where you must specify:
    - **Input layer**: in this case, from the available layer, select **thetao\_\*** and **po4\_\***.
    - **Mask layer**: by default, QGIS understand that **ken-taz-region** is the mask to use. To be able to apply it to all layers, **Autofill** → **Fill down**.
    - **Clipped (mask)**: here is the output of the process. It is built by specifying:

- Where to save the results.
- The tag to use for saving the new generated shapefile: for example, specify **clip\_** → **Save**.
- Automatically, **Autofill Settings** window appears: select Fill with parameters value & Input layer. In this way, the resulting file will be automatically generated by concatenating the string of the tag (**clip\_**) with the original filename of the layers (**thetao\_\*** and **po4\_\***).

The sequence of steps is simplified and represented in Figure 6.

- Run the batch process.
- After completed, the resulting new layers will be displayed on the map, as shown in Figure 7. You may customize the style of the map – for example, taking the input layers settings as reference and applying them to new clip ones.

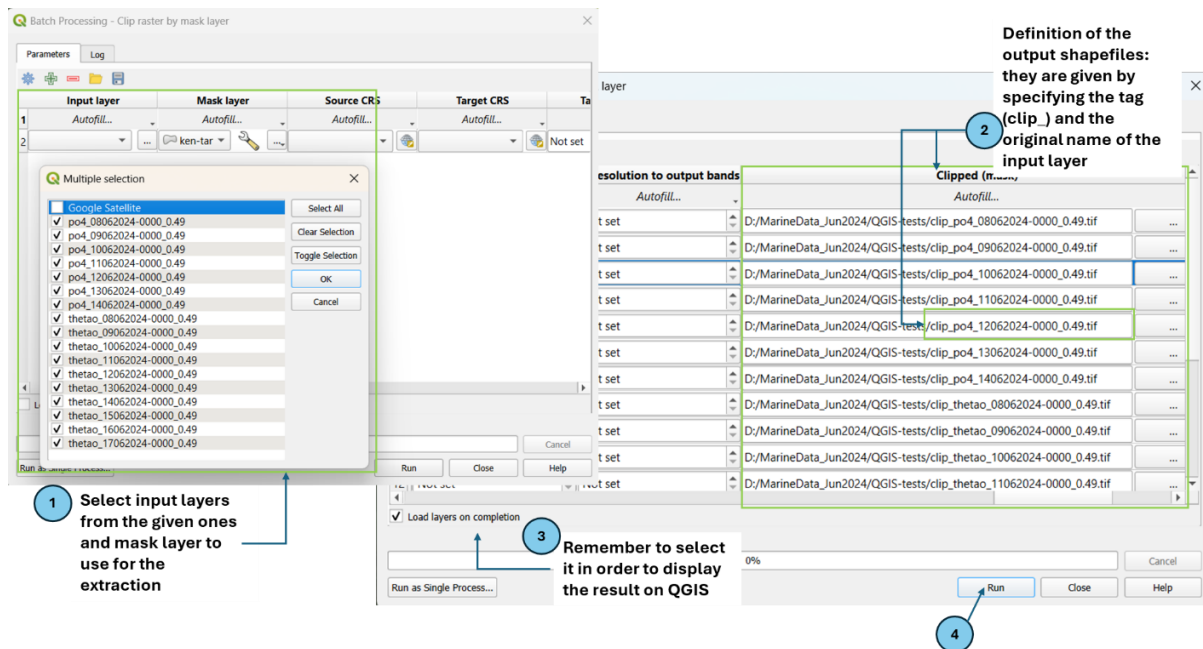


Figure 6. Main steps for executing geospatial extraction of physical fields in the given mask.

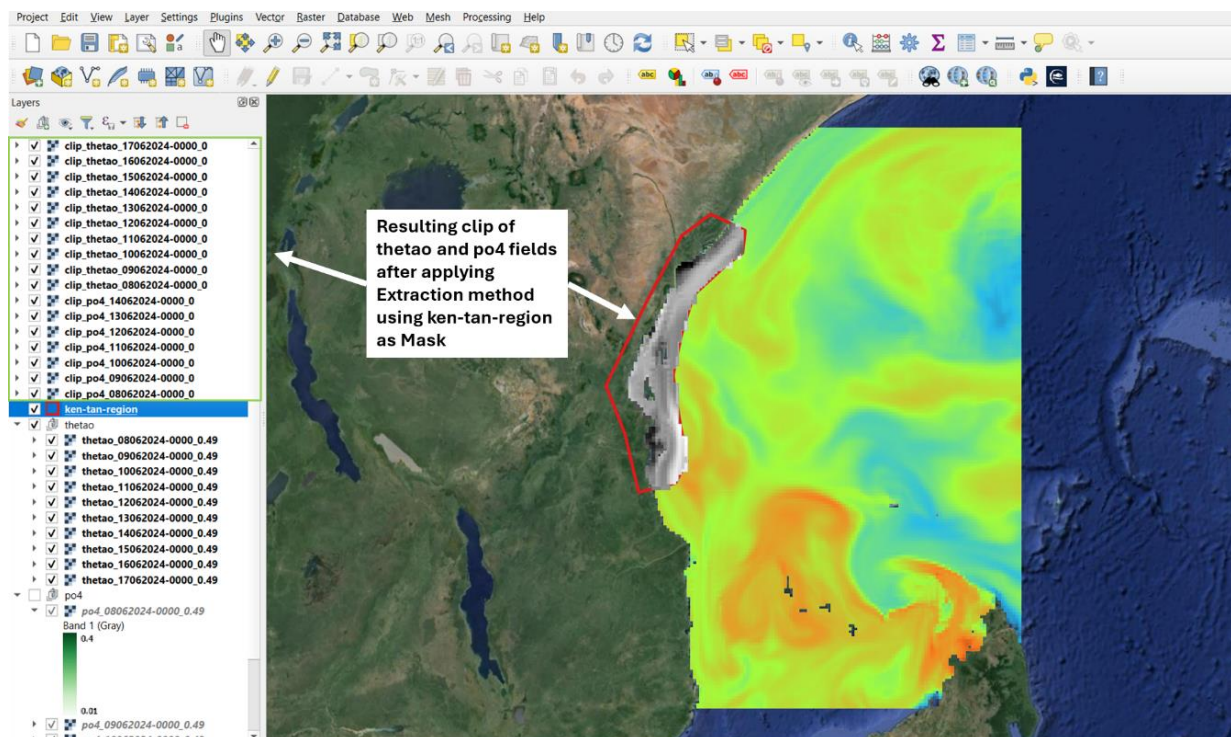


Figure 7. Temperature and phosphate layers extracted in the target region.

- Classification of temperature values according to Guan et al. (2015).
  - To apply environmental tolerance limits for coral reefs as theorized by Guan et al. (2015), it is necessary to apply Classification method provided by QGIS from Layer Properties accessible through Properties after selecting one layer as example.
  - In Symbology, you have the control of the main rendering settings for the selected layer. The application of the tolerance threshold is performed by specifying the following settings:
    - **Render Type:** select *Singleband pseudocolor*.
    - Impose **Min:** 21.7 and **Max:** 29.6.
    - **Min/Max Value Settings:** select *User defined*.
    - **Interpolation:** select *Discrete*.
    - Adjust the board **Value/Color/Label** to fit the limits as specified in Guan et al. (2015).

The resulting settings for Symbology are shown in Figure 8. Labels can be modified to include also text for communication purposes.

After defining, it is possible to apply the same settings to all temperature layers by copying/pasting the modified style. An example of temperature map after re-classification of values according to tolerance interval is given in Figure 9.

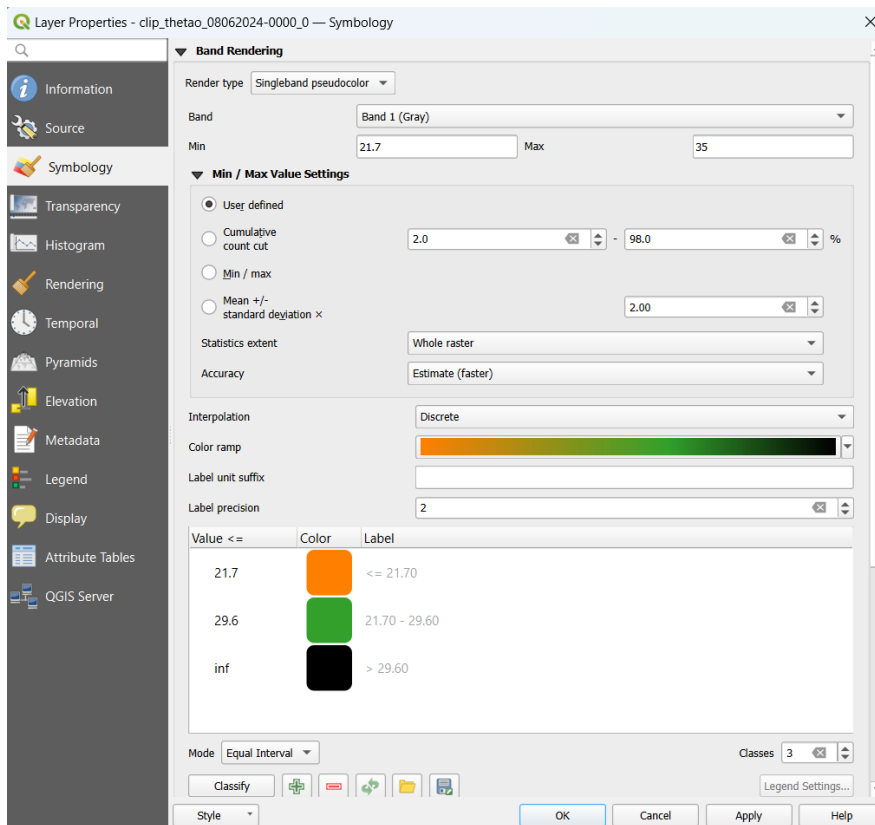


Figure 8. Customized symbology of temperature layers after imposing Guan et al. (2015) tolerance intervals.

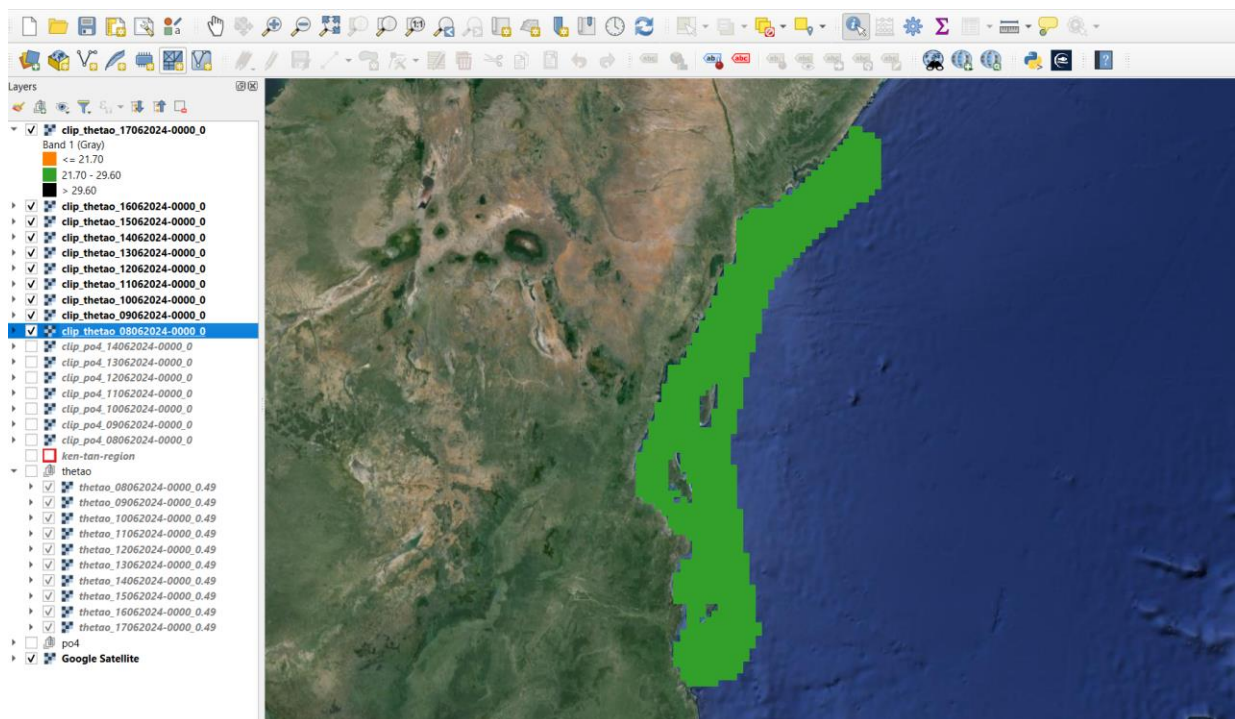


Figure 9. Characterization of the tolerance limits for temperature in the Kenya-Tanzania coastal region on 17/06/2024.

- Classification of phosphate values according to Guan et al. (2015).
  - Considering the concentration of phosphate in sea water in the given period, a similar analysis as performed before for temperature results in creation of a map that shows the area where the tolerance interval is still valid. Figure 10 shows the resulting final map that shows the tolerated limits in phosphate concentration in the study area.

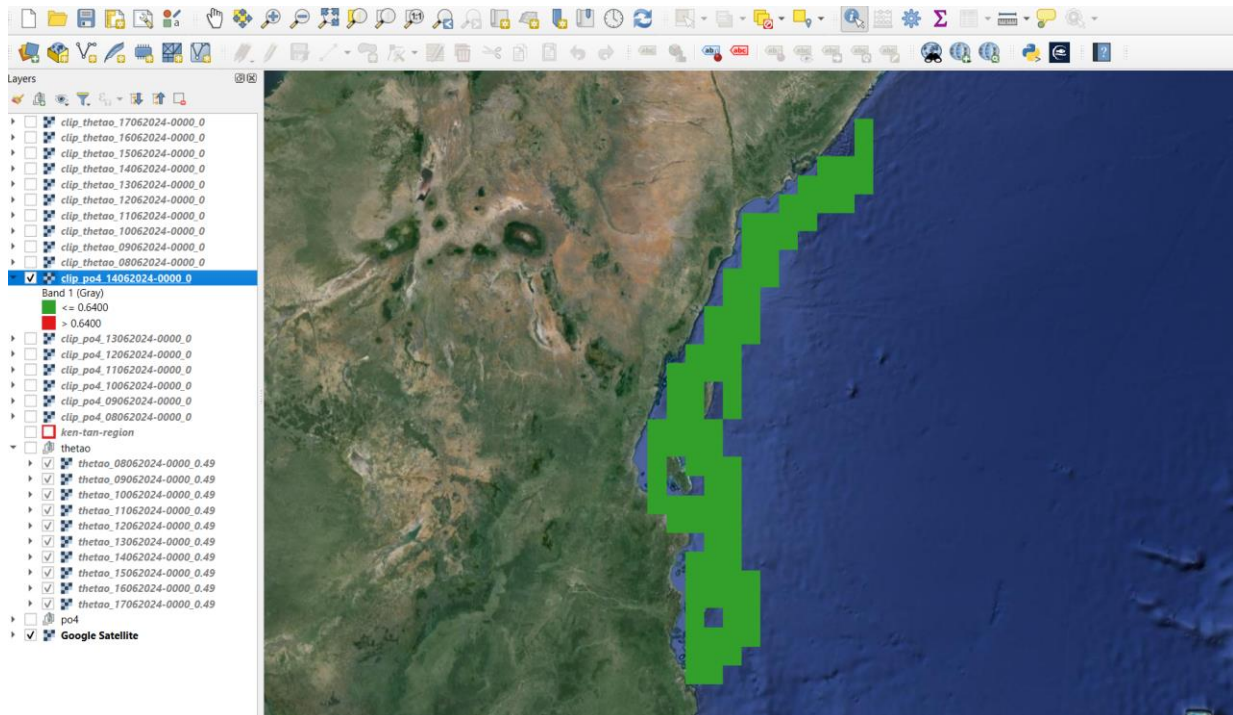


Figure 10. Characterization of the tolerance limits for temperature in the Kenya-Tanzania coastal region on 14/06/2024.

## 3. Eutrophication: the Ebro Delta ecosystem

### 3.1. Introduction

Anthropogenic activities are nowadays the main sources of stress with undesirable ecological effects in coastal ecosystems. Increased concentrations of nitrogen (N) and phosphorous (P) that reach coastal waters through rivers are the primary cause of eutrophication (Malone and Newton, 2020): it causes changes in the structure and functioning of marine ecosystems and reduction in biodiversity, with high impacts on fishery, aquaculture, tourism and other coastal activities.

The European Environment Agency provided a reference document that evaluates the causes, state and development of eutrophication in European coastal waters, identifying areas where monitoring is needed to improve assessment. Breitburg et al. (2018) analyzed the combined effects of eutrophication and deoxygenation in the global coastal ocean: the increase of nutrients from rivers accelerates the proliferation of algal blooms, which initially increase the production of oxygen. But when dying, the produced bacteria from the decomposition phase are responsible for deoxygenation, with huge and uncontrolled impact on food webs and biodiversity. Figure 11 shows the worldwide coastal areas affected by eutrophication and deoxygenation from Breitburg et al. (2018): the North Sea and Baltic Sea are particularly and seriously affected by eutrophication, as well as several hotspots can be found in the Mediterranean and Black Sea.

Among the parameters measured by satellites, ocean color provides the most useful information for the monitoring of eutrophication, and it is a key indicator of ocean health.

This training session is going to focus on discussing examples on how to use QGIS-based tools and Copernicus Marine products for assessing average concentrations of chlorophyll-and oxygen in delta ecosystems: as references, we will consider the Ebro Delta (Mediterranean Sea).

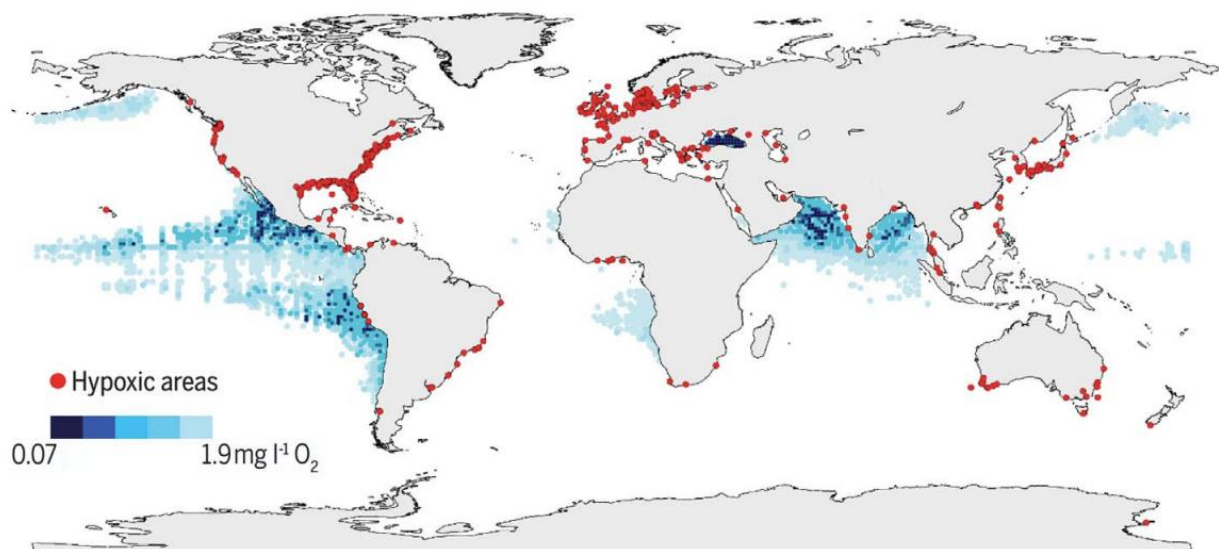


Figure 11. Overview of the hypoxic areas (red dots) and ocean regions with minimum oxygen concentration at 300 m depth (blue areas). Source: Breitburg et al. (2018).

The Ebro Delta is a natural protected area and the largest wetland areas in the Western Mediterranean, extensively used for agricultural purposes and for carrying out shellfish aquaculture (Fernandez-Tejedor et al., 2022). The area is supplied by nutrients, rich in nitrogen and phosphorus, provided by intensive agriculture activities, and by urban and industrial wastewater. They are the main drivers for eutrophication processes in the area, that can cause quality degradation in aquatic habitat due to harmful algal blooms (HABs). From an oceanographic point of view, the

Northeast Spanish coastline is characterized by the Ligurian-Provencal Current flowing from the North and bringing warm and saline waters (Margirier et al., 2020), and the Balearic Front (Figure 12).

Monitoring of the coastal water quality in areas where eutrophication and consequently HABs is fundamental to prevent contamination of farms and loss of biodiversity.

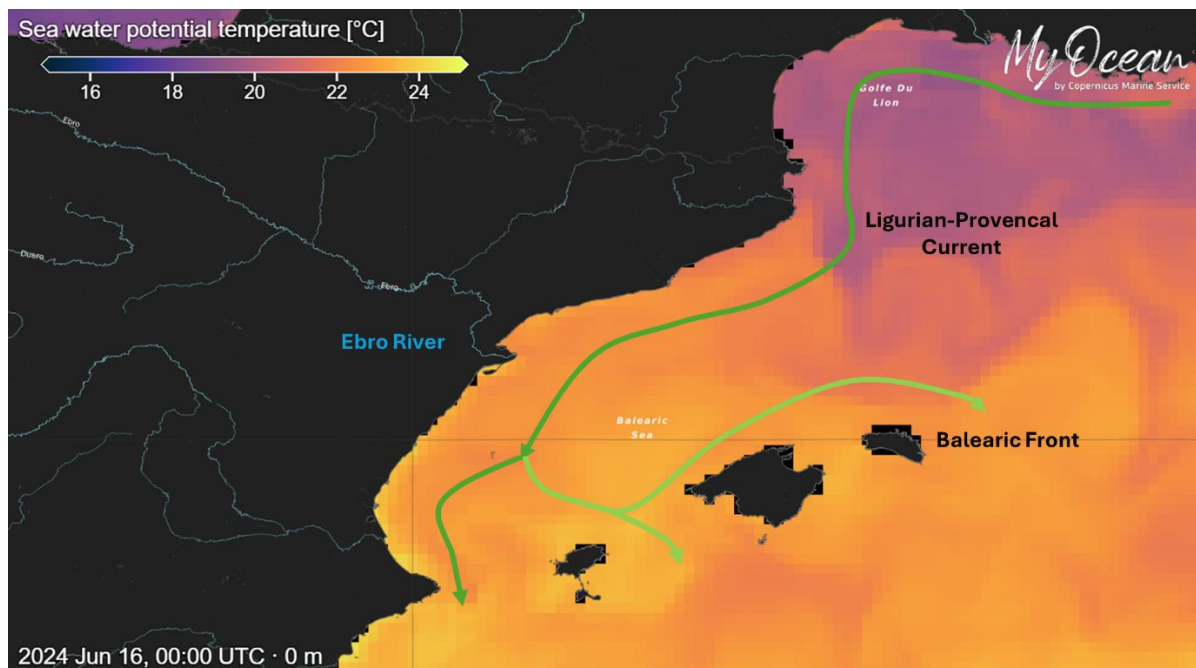


Figure 12. Localization of the Ebro River and its delta in the NE Spanish coastal zone. Schematic representation of the main circulation patterns characterizing the Western Mediterranean Sea: the Ligurian-Provencal Current and the Balearic Front. More details about Western Mediterranean Circulation is Pinardi et al., (2007). The map in background refers to sea surface temperature on 16/06/2024 as forecasted by the Global Ocean Physical Analysis and Forecasting System.

### 3.2. Scope of the QGIS application and input data

In this tutorial, we will learn how to use of geospatial analysis with QGIS for quantifying average concentrations of chlorophyll-a and for assessing the physical state of the Ebro Delta and its coastal region, using:

- Chlorophyll concentration from satellite observations.
- Sea surface salinity from 2 physical modelling systems: the Iberia-Biscay-Ireland Analysis and Forecasting System at 1/36° horizontal resolution and the Mediterranean Analysis and Forecasting System at 1/24° horizontal resolution.

Details on used Copernicus Marine products, as downloaded from the Copernicus Marine Data Store, are available in Table 2. The reference bounding box used in this exercise is: **[40.2°N to 41.55°N; 0.15°E to 1.2°E]**.

Table 2. Copernicus Marine input data used in the demonstrative QGIS tutorial for the Ebro Delta case study.

Product	Dataset	Variable and info	Reference
OCEANCOLOUR_MED_BGC_L4_MY_009_144	cmems_obs-oc_med_bgc-plankton_my_l4-olci-300m_P1M	Chlorophyll Monthly fields for Jun-Jul-Aug 2023	Colella et al., 2023
MEDSEA_ANALYSISFORECAST_PHY_006_013	cmems_mod_med_phy-sal_anfc_4.2km_P1D-m	Salinity Monthly mean fields for Jun-Jul-Aug 2023	Clementi et al., 2021
IBI_ANALYSISFORECAST_PHY_005_001	cmems_mod_ibi_phy_anfc_0.027deg-3D_P1D-m	Salinity Monthly mean fields for Jun-Jul-Aug 2023	Amo-Baladron et al., 2023

### 3.3. QGIS implementation

#### 3.3.1. Preliminary steps

Before starting with the implementation of this exercise, it is necessary to create a new QGIS project, as already described in Section 2.3.1.

#### 3.3.2. Loading input data

To load NetCDF files as accessed and downloaded from the Copernicus Marine Data Store, listed in Table 2, use the CMEMS NetCDF plugin, following instructions as in [TD1].

- Configure a basemap: from the icon bar, select **QuickMapService** → **Search QMS** → **Google Satellite\_**. This basemap visualizes also labels.
- Load the NetCDF files to continue the exercise: from the menu, select **Plugins** → **NetCDF2GIS** → **Import NetCDF Files** (alternatively, you may select the plugin icon from the main bar).
- From your local folder with data, select the NetCDF files according to [TD1].

After loading, 4 groups of layers are displayed:

- The Google Satellite basemap with labels.
- **CHL**, related to satellite chlorophyll for June, July and August 2023, from satellite observations at 300 m resolution (Figure 13).
- **so\_ibi**, related to sea surface salinity as provided by the Iberia-Biscay-Ireland Analysis and Forecasting System, for June, July and August 2023 (Figure 14).
- **so\_med**, related to sea surface salinity as provided by the Mediterranean Analysis and Forecasting System, for June, July and August 2023 (Figure 15).



Figure 13. Chlorophyll concentration (in  $\text{mg m}^{-3}$ ) from the Ocean Colour satellite product available in the Mediterranean Sea at 300 m resolution. Displayed map is for Jun 2023.

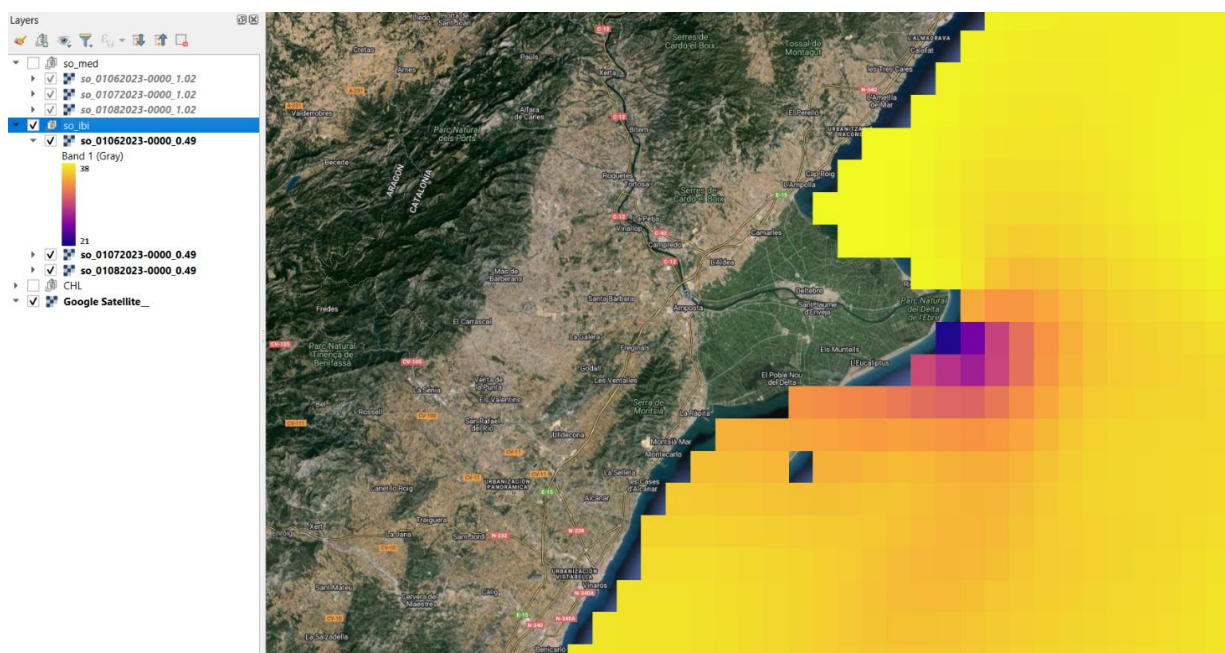


Figure 14. Sea surface salinity (in PSU) from the Iberia-Biscay-Ireland Analysis and Forecasting System, at 1/36 horizontal resolution. Displayed map is for Jun 2023.

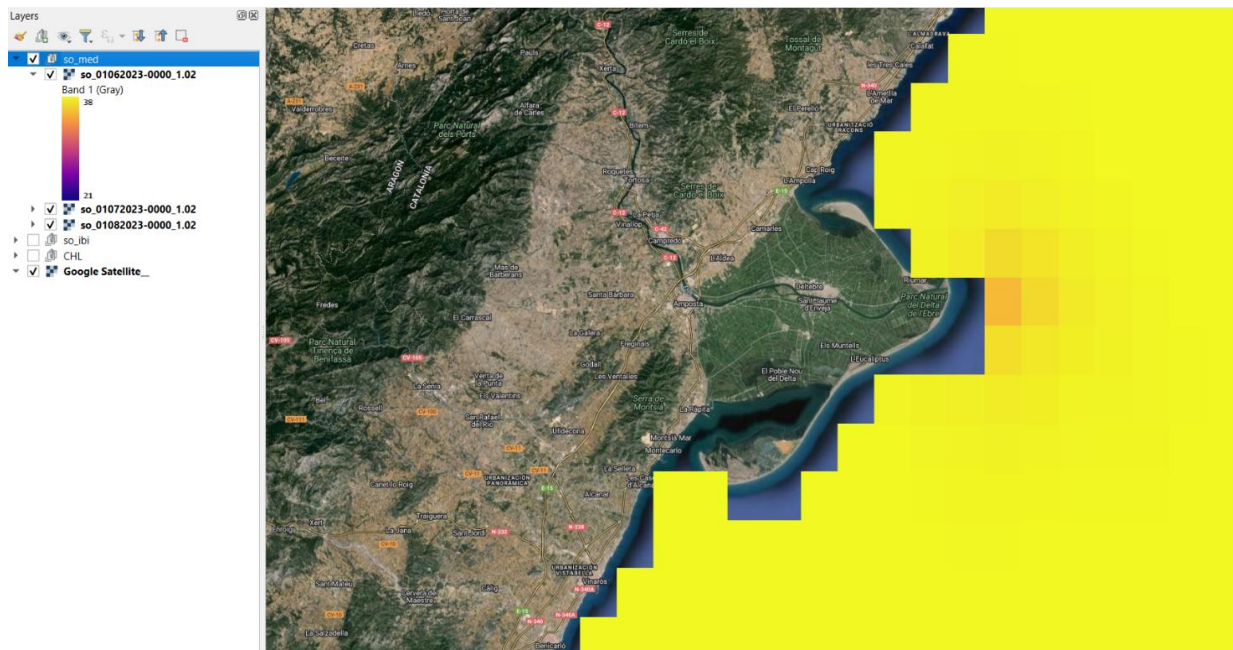


Figure 15. Sea surface salinity (in PSU) from the Mediterranean Analysis and Forecasting System, at 1/24 horizontal resolution. Displayed map is for Jun 2023.

### 3.3.3. Characterization of chlorophyll concentration in the Ebro Delta and its coastal area

The scope of this section is to show how to use QGIS for assessing the chlorophyll concentration in the Ebro Delta coastal region, to support monitoring of marine health.

- Definition of the reference locations in Fangar Bay (located in the Northern part of the delta) and in Alfacs Bay (located in the Southern part of the delta).
  - **Layer → Create Layer → New Shapefile Layer.**
  - Assign a name (for example, **ebro-stations.shp**) and path where to save the new shapefile.
  - Select **Geometry type: Point.**
  - The created shapefile will be displayed in the Layer Board. Select it, and from the icon bar select **Toggle Editing**. By activating it, the shapefile is now open for modification and new icons are activated.
  - Select **Add Point Feature** and start to digitize the stations in the Ebro's bays.
  - After the digitalization is completed, deactivate **Toogle Editing** function to save the result.

The result is shown in Figure 16. Steps to achieve the result are like the ones already introduced in Section 2.3.3.

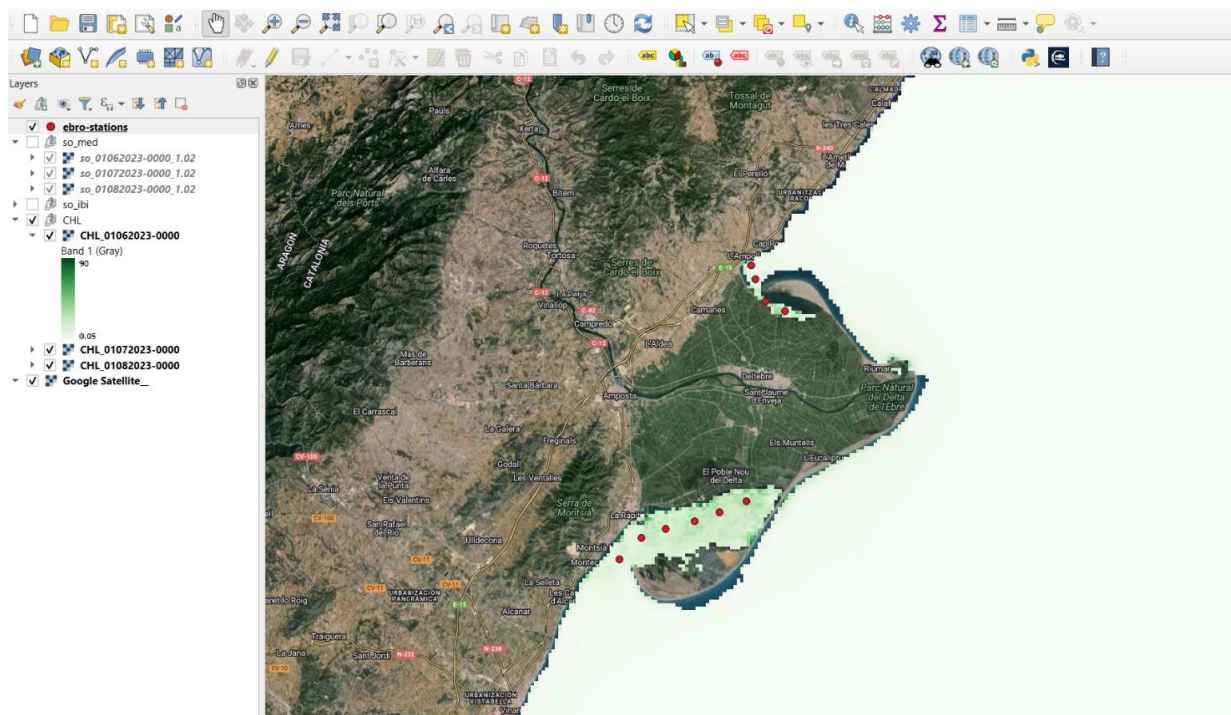


Figure 16. Digitalization of the reference monitoring stations (red dots) in the Fangar and Alfacs Bays.

- Extraction of chlorophyll data in the digitized stations.
  - **Processing** → **Toolbox**. It opens a list of functions that can be used for manipulating and processing raster values. Search for Sample raster values.
  - Once selected, a new window is opened. To speed up the processing, having 3 reference timestamps (i.e., June, July and August 2023 data), it is recommended to run this step in batch. So, select **Run as Batch Process**.
  - It opens another window, where you must specify:
    - **Input layer**: in this case, it is the shapefile containing the digitized stations.
    - **Raster layer**: here, you make a selection considering the function **Select from open layer**. The layers to select are the ones with tag **CHL\_\***.
    - **Sampled**: here you must define the name (tag) and location where to save the result. For example, specify **points\_** as tag of the output shapefiles and allow QGIS to autocomplete the filename by concatenating the tag itself with the original filename of the raster layer. The sequence of steps is simplified and represented in Figure 6.
    - Run the batch process.
    - After completed, the resulting new layer will be displayed on the map, as shown in Figure 18.
  - The values of chlorophyll at station location can be displayed by selecting **Open Attribute Table** from one of the produced new layers. It consists of a table with ID points and chlorophyll value. An example is given in Figure 19. Tables can be exported and further processed to get monthly values for future analysis.

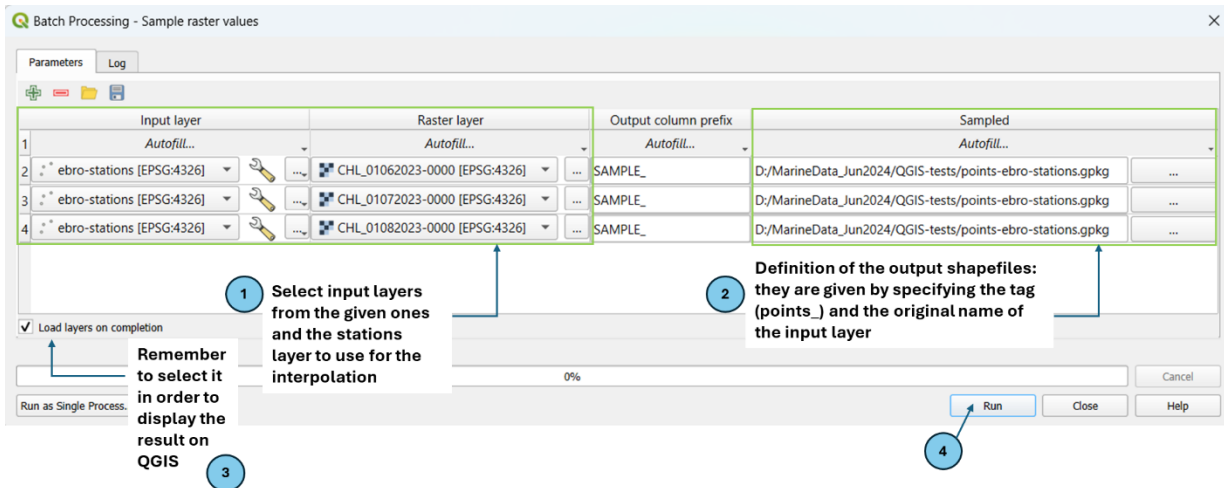


Figure 17. Main steps for executing geospatial interpolation of chlorophyll fields in the given stations.

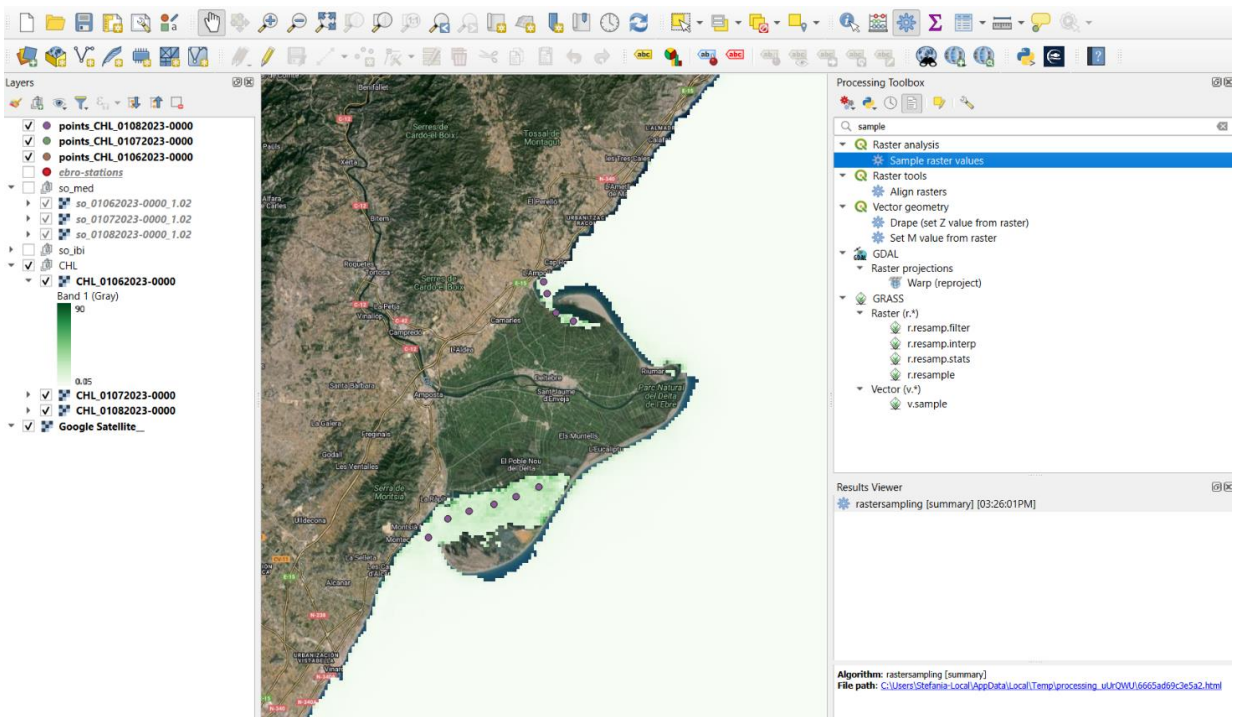
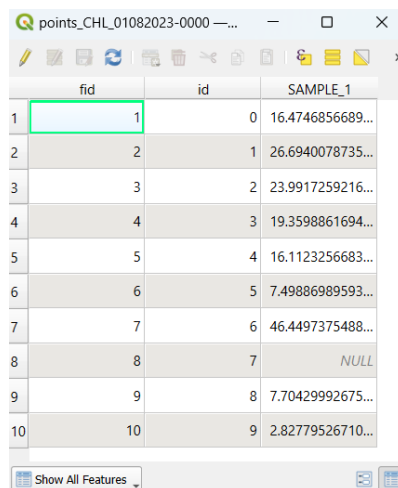


Figure 18. Chlorophyll concentration for June, July and August 2023 calculated on selected stations in the Fangar and Alpacas Bays. On the right: the panel containing some functions, including the Sample Raster Value used in this section.



	fid	id	SAMPLE_1
1	1	0	16.4746856689...
2	2	1	26.6940078735...
3	3	2	23.9917259216...
4	4	3	19.3598861694...
5	5	4	16.1123256683...
6	6	5	7.49886989593...
7	7	6	46.4497375488...
8	8	7	NULL
9	9	8	7.70429992675...
10	10	9	2.82779526710...

Figure 19. Example of resulting table containing chlorophyll values as extracted in the selected points in August 2023.

- Calculation of Summer averaged chlorophyll concentration and analysis of water quality at given stations.
  - **Raster** → **Raster Calculator**. It opens a window – a calculator – where you may type the formula to compute the mean of the 3 chlorophyll raster fields.
  - Similarly to the previous point, it is now possible to extract the averaged values of chlorophyll at given stations by using the function Sample raster values. The resulting layer is called, for example, **JJA-points**.
  - The final map can be further customized by clustering the computed averaged chlorophyll values in groups. This can be done by selecting the corresponding Properties of the **JJA-points** shapefile. You must specify the following settings from **Symbology**:
    - Select **Graduated**.
    - **Value:** **SAMPLE\_1** corresponding to chlorophyll values previously computed.
    - **Method:** **Color**
    - **Mode:** **Equal Interval**.
    - **Classes:** **5**.

Automatically, the Classes will be displayed. Settings as specified for this exercise are shown in Figure 21. A refreshed map with points colored according to specified classes is shown in Figure 22.

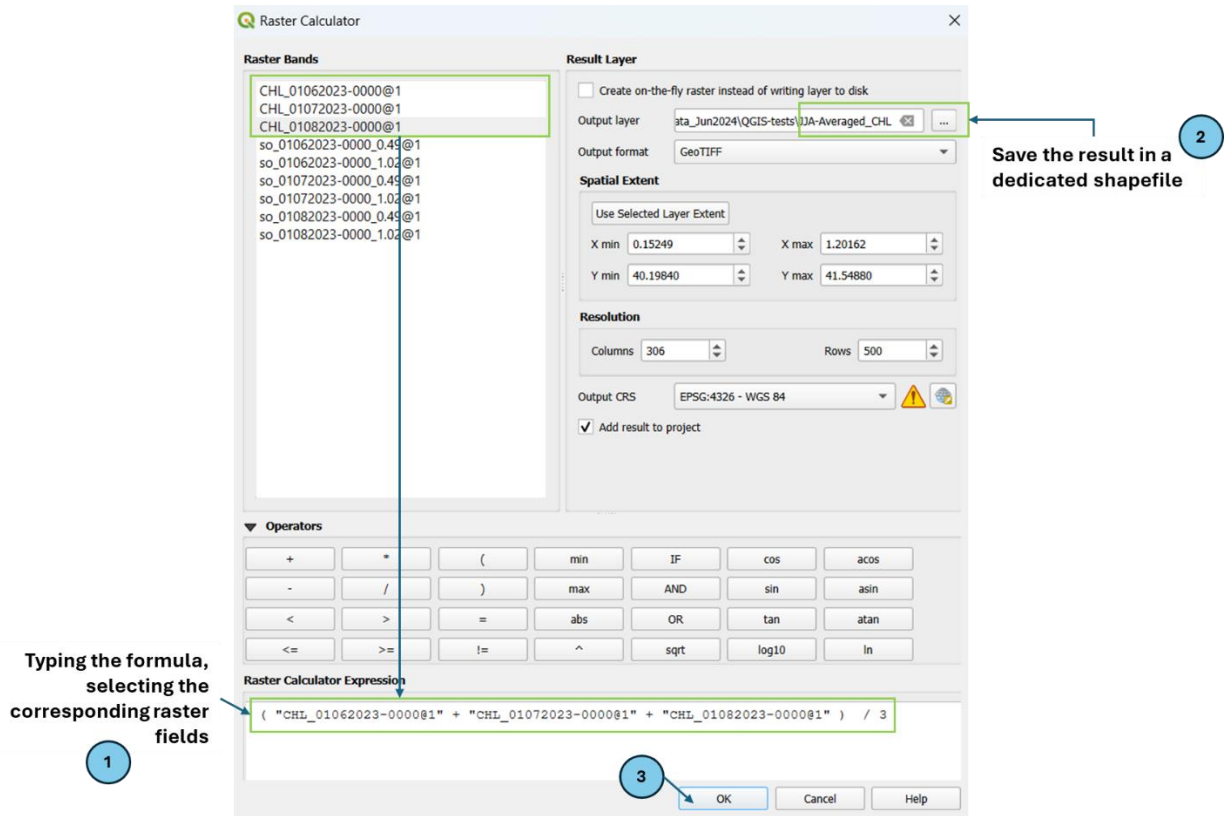


Figure 20. Setup of formula for computing Summer averaged chlorophyll concentration using Raster Calculator.

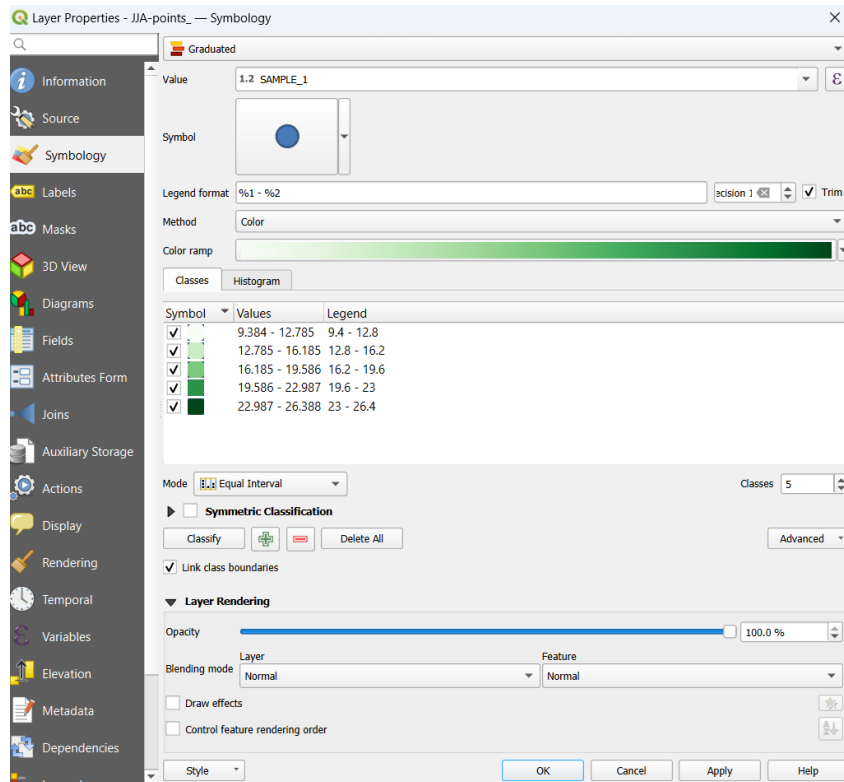


Figure 21. Setup of Symbology settings for JJA-points layer.

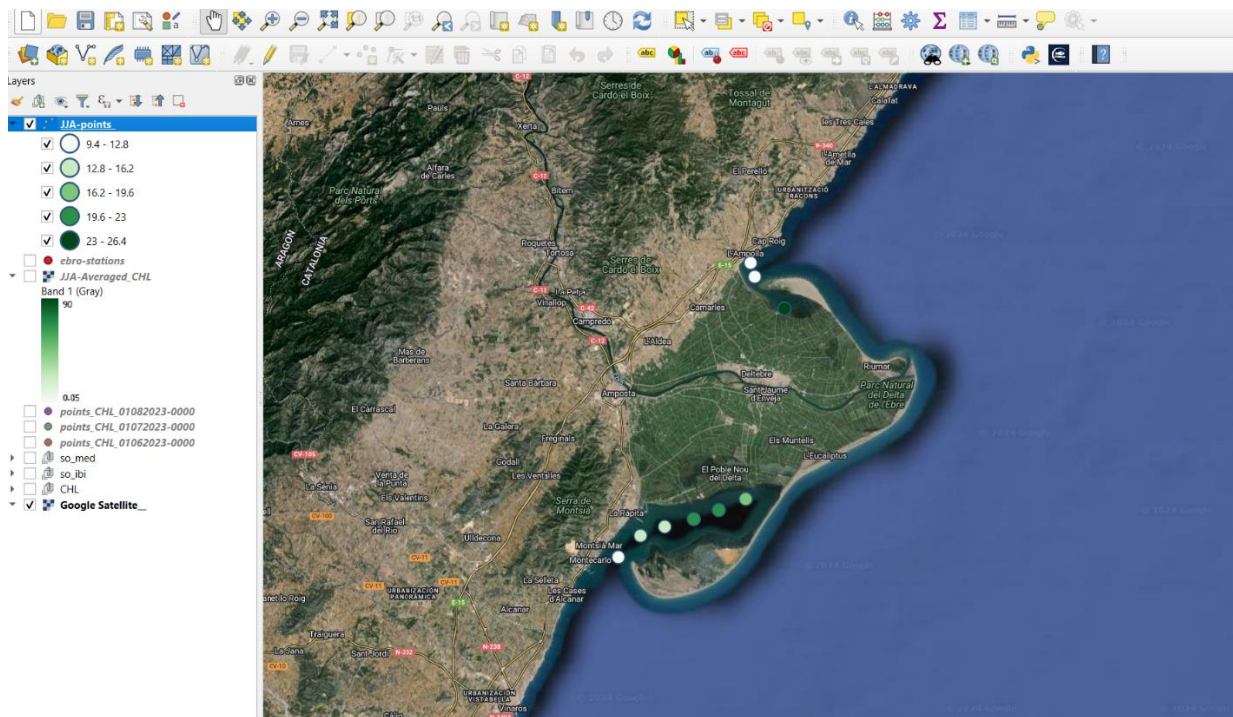


Figure 22. Averaged chlorophyll concentration in JJA 2023 at stations location.

### 3.3.4. Assessment of sea surface salinity from multi-model sources

The scope of this section is to show how to use QGIS for evaluating sea surface salinity in the Ebro Delta coastal region.

- Extraction of sea surface salinity data in reference sections.
  - To easily extract and compare sea surface salinity values over given sections, you may use the **Profile Tool** plugin. This tool is extremely powerful for the visualization of sequence of values in digitized sections. An example of how to use it is shown in Figure 23.

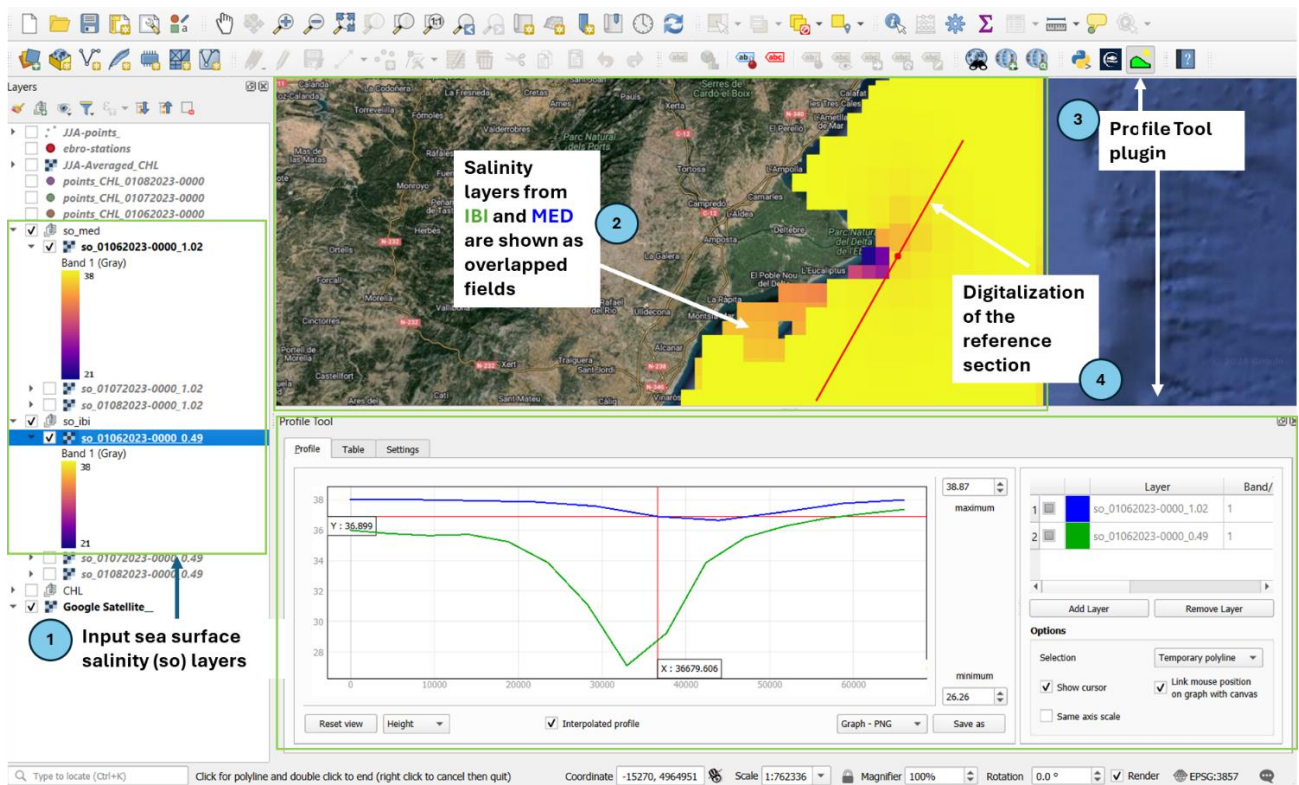


Figure 23. Example on how to use the Profile Tool for extracting sea surface salinity values from the IBI and MED model products in Jun 2023.

## 4. Additional information and conclusions

This report focused on presenting the way we can use the Blue and Green Ocean products provided by the Copernicus Marine Service in QGIS for monitoring coastal areas, and particularly key variables that are relevant for characterizing coral bleaching in the Eastern southern Africa coastal region and eutrophication in the Western Mediterranean.

These technical notes complemented the training session (i.e. digital material and live presentation) given during the MarineData4CoastalMonitoring Event, organized by Mercator Ocean International for the Copernicus Marine Service on 21-22/06/2024.

**Please, visit the dedicated User Learning Service promoted by the Copernicus Marine Service to access the e-learning material and discover other interesting exercises.**

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**Other Useful links:**

- Copernicus Marine Service: <https://marine.copernicus.eu/>
- Copernicus Marine E-Learning Material: <https://marine.copernicus.eu/services/user-learning-services/tutorials>
- Copernicus Marine QGIS plugin installation: <https://marine.copernicus.eu/services/user-learning-services/qgis-plugin-cmems-netcdf>
- Copernicus Marine Toolbox: <https://help.marine.copernicus.eu/en/collections/4060068-copernicus-marine-toolbox>
- Copernicus Marine YouTube Channel: <https://www.youtube.com/@copernicusmarineservice1453>
- Copernicus Webinar - MarineData4Coastal Monitoring 2024: <https://events.marine.copernicus.eu/marinedata4-coastal-monitoring-2024>
- CF Conventions: <https://cfconventions.org/>
- NetCDF: <https://www.unidata.ucar.edu/software/netcdf/>

