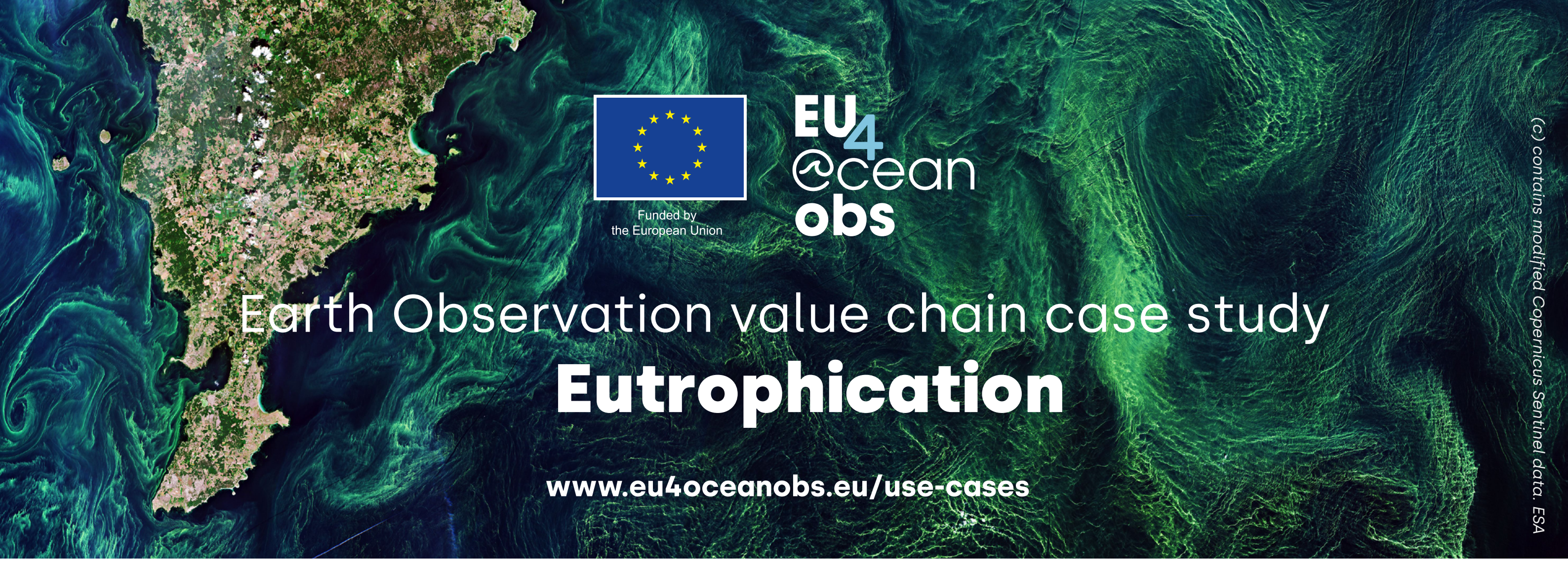

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EU4Oceanobs

Earth Observation value chain case study
Eutrophication

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For coastal waters, too many nutrients can be a bad thing. Marine algae and plants thrive on nutrients such as nitrogen and phosphorus, so when an excess of nutrients enters the water, algae and plants grow in huge numbers. When they die, they decompose. This process sucks up oxygen that supports other marine life and releasing carbon dioxide and toxins. The impacts of these eutrophication events on marine life and the human communities that depend on them can be substantial. Since the 20th century, rapid population growth, industrialisation, and intensive agriculture have been increasing the number of eutrophication events.

This case study presents how Earth Observation can help detect, monitor, and forecast eutrophication status and risks. Highlighting European Union (EU) programmes, services, and tools, including free and open access data and information, we show how different Earth observations support eutrophication assessments, help determine potential impacts and be used to develop effective mitigation and adaptation plans, and create strategies to prevent further eutrophication events.

Description & impact

Marine eutrophication is the excessive input of nutrients, particularly nitrogen and phosphorus, into coastal waters. It is characterised by the significant and rapid growth of phytoplankton and other algae, like seaweeds, causing dysfunction within the ecosystem. Dysfunctions include harmful algal blooms - blooms of phytoplankton that can produce toxins that are hazardous to people and marine life.

A distinction should be made between natural eutrophication, which corresponds to an increase in the production of organic matter linked to the evolution of an aquatic ecosystem, which extends over several thousand or million years, and anthropogenic (human-driven) eutrophication, which occurs over short time scales (from one hour to one year).

Anthropogenic eutrophication is mainly attributed to phosphorus (contained in the phosphates of laundry detergents, in fertilisers, and industrial runoff, for example) and nitrogen (contained in ammonium and nitrates found in fertilisers, aquaculture, and industries). Today, agricultural, domestic, or industrial discharges into watercourses drive many eutrophication events.

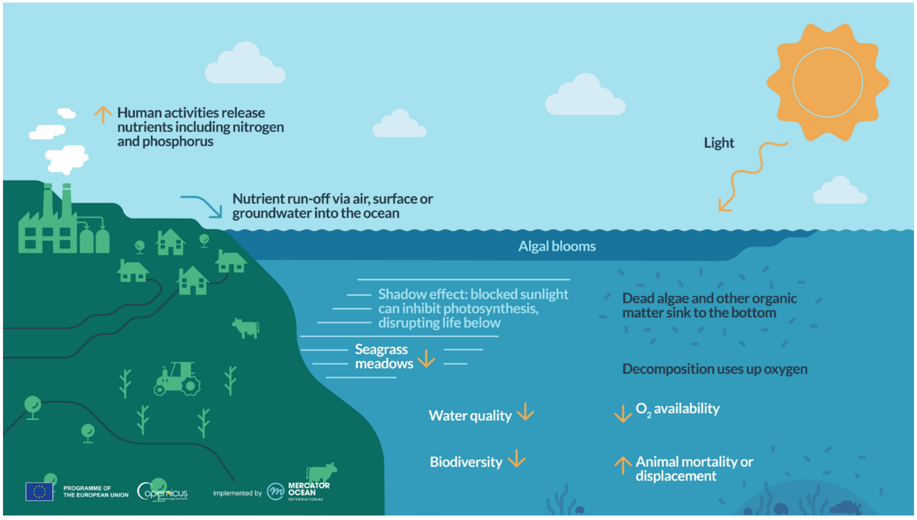


Figure 1: Eutrophication explained. (c) Copernicus Marine Service

Situated next to the land, coastal waters are the first to be affected by anthropogenic eutrophication. Despite their relatively small surface area, coastal waters serve as important areas for marine life and host multiple social and economic activities, such as aquaculture, fishing, and tourism.

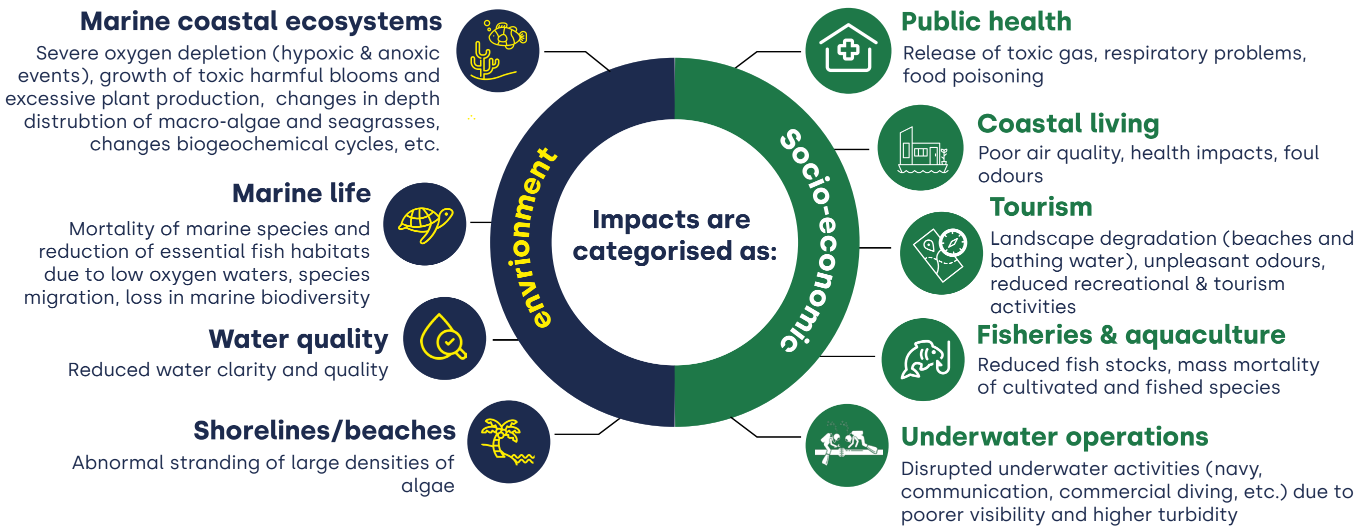


Figure 2: The impacts of eutrophication on the marine environment and socio-economy

EU Policy and Directives on Eutrophication

Approximately 50 years ago, European law introduced eutrophication as a criterion for assessing the good ecological status of coastal and offshore water bodies. Concerns surrounding eutrophication also resulted in political action in Europe, which then translated into programmes that are now implemented by regional conventions:

- OSPAR: the Oslo-Paris Convention for the Protection of the Northeast Atlantic (1972)
- HELCOM: the Helsinki Convention for the Protection of the Baltic Sea (1974)
- MEDPOL: the Programme for the Assessment and Control of Marine Pollution in the Mediterranean (1975). MEDPOL is the implementation of the Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention)
- BSIMAP: the Black Sea Integrated Monitoring and Assessment Programme (1992)

These initiatives have initiated several legislative instruments, such as the Urban Wastewater Treatment Directive and Nitrates Directive, as well as more comprehensive legislation:

- WFD: the Water Framework Directive, which addresses all surface waters and groundwater (2000)
- MSFD: the EU Marine Strategy Framework Directive, which established a framework for marine environmental policy up to the 200 nautical mile limit of the European exclusive economic zone (2008)

Criteria for measuring and evaluating eutrophication can differ between the policies and directives. For example, the MSFD evaluates eutrophication based on eight criteria: nutrients and chlorophyll-a concentration (a measurement of the amount of phytoplankton present in the water), occurrence of toxic algae, transparency, dissolved oxygen concentration, and abundance of opportunistic macroalgae, macrophyte communities in benthic habitats, and benthic macrofauna.

Earth observation data and derived serves to address challenges of marine eutrophication

Detection, monitoring and forecasting of eutrophication

Since the 1980s, phytoplankton measurement networks have been set up in various countries (e.g., **France**, **Ireland**, **USA**) to monitor phytoplankton composition, chlorophyll-a, dissolved oxygen, turbidity and nutrient concentrations with instruments at fixed points and different depths. Related variables such as temperature, acidity (pH), and salinity are also frequently measured. These networks usually focus on waters close to the coast, though they are occasionally supplemented by offshore fixed buoys and ship monitoring campaigns. Although collecting high-quality in-situ measurements of chlorophyll-a, nutrients, and dissolved oxygen in the sea is currently the best way to monitor eutrophication, collecting them is expensive in terms of personnel and equipment. As a result, measurement networks are limited in spatial and temporal coverage and not well developed in many countries.

Like plants on land, marine plants and algae like phytoplankton use chlorophyll-a and other pigments to photosynthesise – the process that allows plants to use carbon dioxide and sunlight to make energy. Chlorophyll in plants and algae absorbs the red and blue light of the sun and reflects green light, which satellites equipped with ocean colour sensors can detect from space. These Earth observations provide crucial data on phytoplankton abundance.

Thanks to the **EU's Copernicus Earth Observation programme**, and other international space programmes (e.g. US), it is possible to monitor the global ocean for chlorophyll-a and other important variables such as dissolved oxygen, daily and in near real-time. Daily global ocean colour satellite data has been available across the globe since 1998, with the launch of SeaWiFS (Sea-viewing Wide Field-of-View Sensor) by NASA. This unique database includes estimates of chlorophyll-a concentrations, allowing us to follow the changes and trends in eutrophication events and improve our understanding of eutrophication triggers. Although SeaWiFS ceased operation in 2010, several other ocean colour sensors on board satellites that cover the mid-latitudes (between 30 to 60 degrees) daily are now in operation:

- **Ocean and Land Colour Instrument (OLCI)** onboard the Copernicus Sentinel-3 (A & B) satellite (European Space Agency - ESA), with a spatial resolution of ~1km and 300m.
- **Moderate Resolution Imaging Spectroradiometer (MODIS)** onboard the Aqua & Terra satellite (NASA) with a spatial resolution of ~1.2km. MODIS will cease operations in 2024.
- **Visible Infrared Imaging Radiometer Suite (VIIRS)** onboard the Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 satellites (NASA/NOAA), with a spatial resolution of ~750m.

Identifying specific plankton that cause harmful algal blooms from satellites is only possible for a few groups. These included *Karenia*, which emits a red colour, and *Lepidodinium*, which emits a green colour. For others, we rely on their phenology and the appearance of high chlorophyll-a to characterise the bloom. Model systems that combine satellite ocean colour, wind, and ocean current data can also monitor harmful algal blooms.

For opportunistic seaweed (macroalgae) like sea lettuce, which can form huge mats called green tides, the Sentinel-2 (A & B) from the Copernicus programme, which has a repeatability of two to three days at mid-latitudes, is equipped with optical sensors that can assess the coverage the algae on coastlines. The abundance of opportunistic macroalgae on the sea floor in shallow coastal waters can also be assessed by high or very-high-resolution satellite imagery, as well as by aircraft or drone surveys.

Earth Observation data can also be used in ocean models. Models can provide useful information on the entire water column and make short-term predictions (a few days). Thanks to the **Copernicus Marine Service**, there are **global models** with a resolution of about 25 kilometres and **regional models** in European Seas with resolutions ranging from two or three kilometres to 10 kilometres that can estimate and forecast nutrients and dissolved oxygen concentration – both useful variables to measure for eutrophication assessments.

Local models are available at higher resolutions, but their spatial coverage is more limited. Regional and local models such as **ASIMUTH** and **PRIMROSE** have been developed to monitor and predict the occurrence of harmful algal blooms. Ocean models are not yet used for eutrophication assessments for water directives. However, studies are looking at integrating them into future assessments.

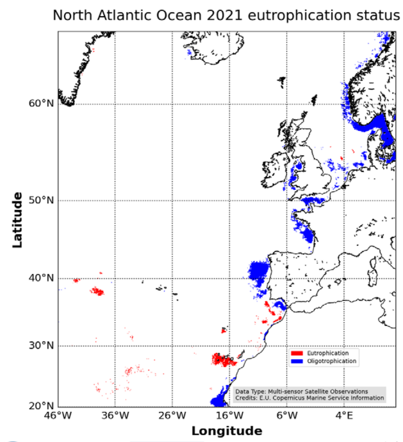


Figure 3: North Atlantic Ocean 2021 eutrophication indicator map, based on Copernicus Marine product OCEANCOLOUR_ATL_BGC_L3_MY_009_113 and with respect to the 1998-2017 P90/P10 climatologies. Eutrophication flags are shown in red and oligotrophication flags shown in blue.

Access to eutrophication data and information

The EU contributes to various monitoring and forecasting platforms, services, and tools that provide access to data and information about eutrophication. These tools, services, and data and information portals are essential for decision-making in various key sectors such as aquaculture, fisheries, and tourism, as well as for international, national, and local authorities involved in monitoring and managing the quality of the coastal and offshore waters.

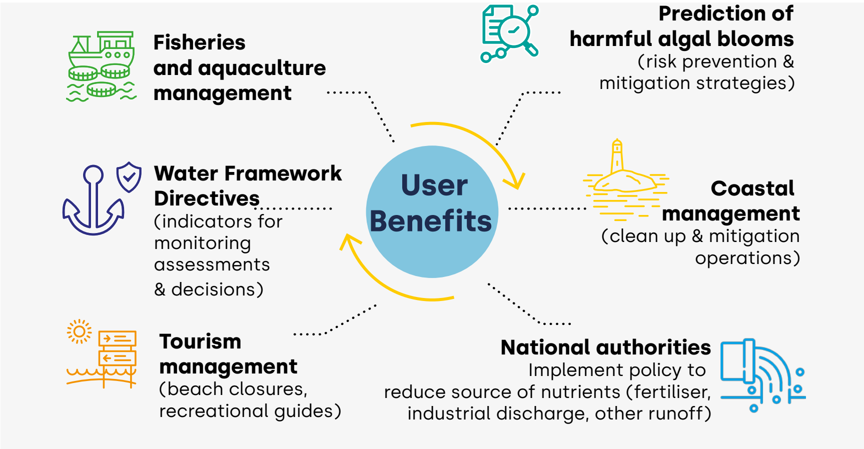


Figure 4: Users benefits and decision point from access to eutrophication monitoring and forecasting tools , services and information

The EU supports various programmes, initiatives and projects providing monitoring and forecasting services and access to data and information on Eutrophication worldwide. Some are listed below:

The **EU's Copernicus Marine Service** (copernicus.marine.eu): provides free and open access to in situ, satellite and modelled data on variables useful for monitoring and assessing eutrophication status, including oxygen levels, chlorophyll-a concentration, and nitrogen concentration. Its **Ocean Colour Thematic Assembly Centre** provides free and open access to satellite ocean colour high level data at spatial resolution of 4 km for the global ocean, 1 km for European seas and 300 m for coastal regions. Copernicus Marine also provides an eutrophication indicator, that is used by **Eurostat** and helps track progress towards reaching the United Nations 2030 Agenda for sustainable development, including water quality improvements.

The **European Marine Observation and Data Network (EMODnet)** (emodnet.ec.europa.eu): hosts data on multiple variables relevant to eutrophication collected across Europe. EMODnet Chemistry's data infrastructure stores more than 600,000 datasets and CDI metadata for eutrophication, including chlorophyll-a, oxygen, and dissolved inorganic nitrogen concentrations.

The **GEO Blue Planet Initiative** (www.geoblueplanet.org): jointly supported by the EU, USA, and the Republic of Korea, has a working group dedicated to eutrophication and with the Environmental Systems Research Institute (ESRI) hosts the **Eutrophication Information Hub**. The Hub allows monitoring for "SDG indicator 14.1.1: Coastal Eutrophication." It presents chlorophyll-a as an indicator of eutrophication and explains how to estimate its concentration by remote sensing. It describes the methodology, processing and application development to propose an indicator to support eutrophication assessments. An interactive tool shows the maps of the available dataset of chlorophyll-a data.

The **TELECHLOR project** (proj-telechlor): aimed to provide satellite products to WFD/MSFD stakeholders for French metropolitan waters with water quality metrics for the eutrophication descriptor based on the chlorophyll-a parameter. It provides chlorophyll-a satellite data for eutrophication assessment in OSPAR region IV, the French WFD and MSFD. (Ended in 2021)

Water Information System for Europe - Marine: provides access to information and data on the state of Europe's seas, the pressures affecting them like **eutrophication**, and the actions being taken to protect and conserve the marine environment.

The **S-3 EUROHAB - Sentinel products for detecting EUtROphication and Harmful Algal Bloom events** (**EUROHAB project**) uses the latest satellite technology to improve the way water quality and harmful algal blooms are monitored in the English Channel and will assess the socio-economic implications of harmful algal blooms. (Ended in 2022)

The **Joint Monitoring Programme of the Eutrophication of the North Sea with Satellite data (JMP-EUNOSAT project)** (www.deltares.nl/en/expertise/projects/jmp-eunosat): developed a new method for monitoring and assessment of eutrophication in the North Sea with satellite data in the framework of OSPAR. Provides chlorophyll-a satellite data for eutrophication assessments in OSPAR regions I, II and III. (Ended in 2019)

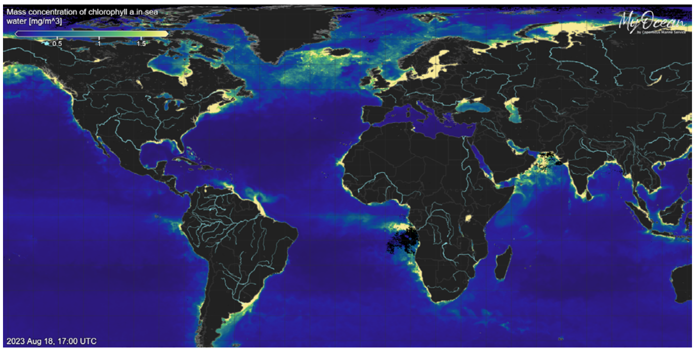
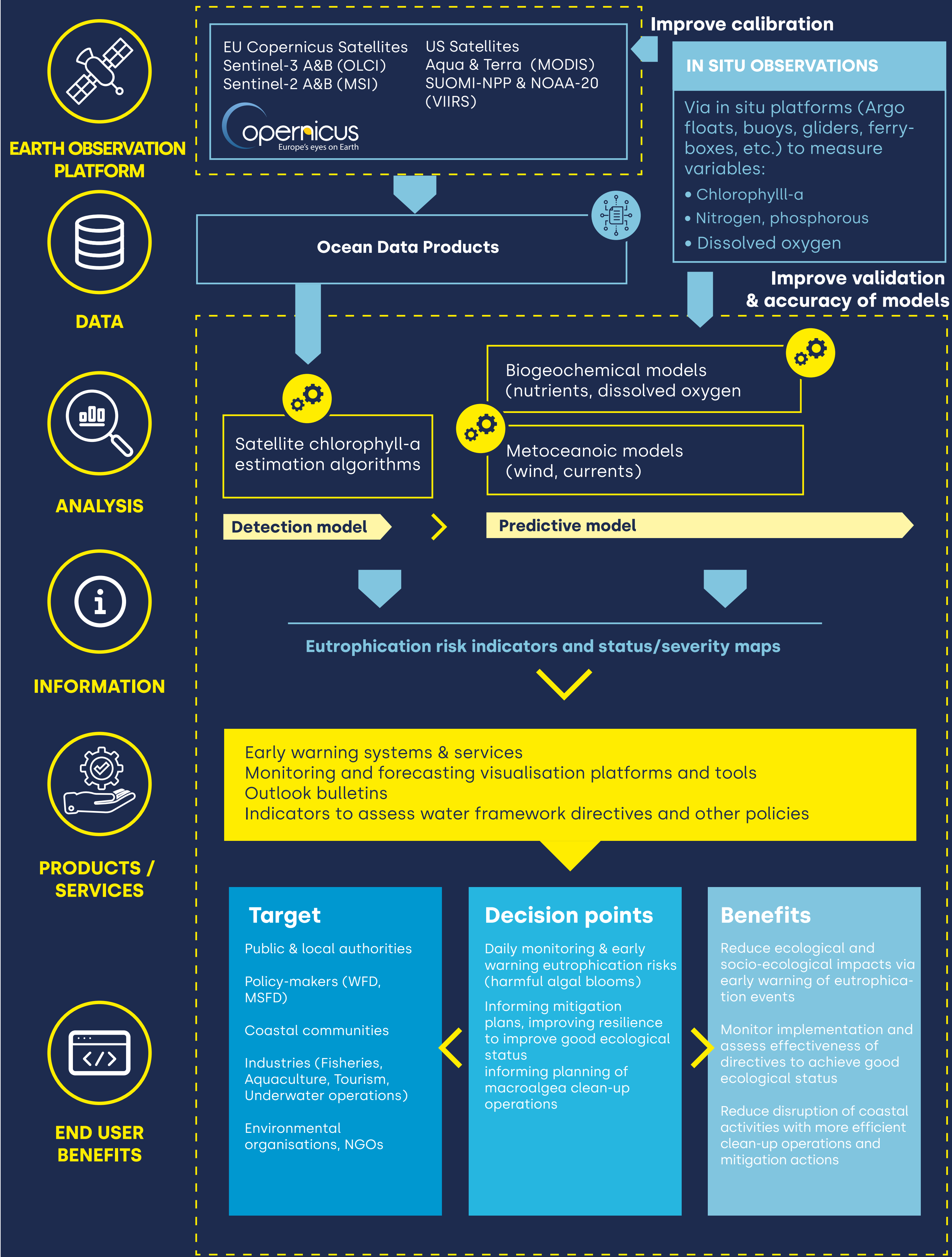


Figure 5: The map shows monthly mean mass concentration of chlorophyll-a in sea water, which reflects the abundance of phytoplankton—some microscopic, plant-like organisms that live freely suspended in the sunlit zone of water. On the map, it can be seen that the phytoplankton concentrations are commonly higher along the coastal regions than offshore marine water. Such elevated levels may be caused by an excess of nutrients from human activities, leading to eutrophication.
Credit: Copernicus Marine Service.

Figure 6: Earth observation value chain for monitoring and forecasting eutrophication



Gaps in monitoring and forecasting Sargassum inundations and spread

Currently, using in situ measurement of chlorophyll-a, nutrients, and dissolved oxygen in the sea is the best way to estimate eutrophication. However, collecting these measurements is costly and requires equipment and infrastructure. As a result, efforts to collect these measurements are not well developed in many coastal countries, leaving many areas and regions with insufficient information to monitor eutrophication. However, over the last 25 years, Earth Observation, satellite imagery, and ocean models have provided free and open access to data crucial for monitoring and predicting eutrophication events.

Despite these advancements, there are still gaps in the capacity of monitoring and forecasting eutrophication:

Because of the complexity of certain coastal waters, satellite algorithms for chlorophyll-a estimation still need to be improved in certain areas. For example, in areas where water is very turbid (murky), it can be harder for the satellite sensors to measure chlorophyll-a concentrations.

Ocean models have insufficient spatial resolution to show the level of detail needed. Furthermore, rivers bring nutrients from the land into the sea. However, we currently don't have sufficient information on the amount of nutrients rivers are transporting. This lack of data impacts the ability of models to predict nutrient and oxygen levels in the coastal area accurately. These and other problems currently prevent models from being reliable monitoring and prediction systems. It is not yet possible to identify most harmful phytoplankton groups with satellite sensors, and modelling them is not yet perfected.

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