GROWTH AND INNOVATION IN OCEAN ECONOMY

GAPS AND PRIORITIES IN SEA BASIN OBSERVATION AND DATA

D7.3.5 MedSea Checkpoint Challenge 6 (Marine Environment): Description of Targeted Products, the methodology and the expert evaluation of fitness for purpose

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Glossary

OCEANS-CAT – OCEANS Catalonia International SL (ES)
OOCS – Operational Observatory of the Catalan Sea
CZCS – Coastal Zone Colour Scanner
SeaWiFS – Sea-viewing Wide Field-of-view Sensor
MODIS – Moderate Resolution Imaging Spectroradiometer
MERIS – MEdium Resolution Imaging Spectrometer
SMOS – Soil Moisture and Ocean Salinity
TRIX – Trophic Index
DIN – Dissolved Inorganic Nitrogen
TP – Total Phosphorous
TN – Total Nitrogen
DO – Dissolved Oxygen

Executive Summary

This report provides an overview of the targeted products of WP 7 –Challenge 6 – Marine Environment and describes the methodology we used to produce them. It also attempts to answer some primary “adequacy” questions.

After some necessary inputs and modifications to the initial list of challenge products, the final output contains four Targeted Products:

- **MEDSEA_CH6_Product_1**: Maps of seasonal Chlorophyll (UNITS: mg/m^3) from L4 satellite ocean color data FOR THE PAST 10 YEARS (1998-2009).
- **MEDSEA_CH6_Product_2**: Map of Chlorophyll trends (UNITS: mg/m^3/year) from L4 satellite ocean color data FOR THE PAST 10 YEARS (1998-2009).
- **MEDSEA_CH6_Product_3**: Maps of 5-year “eutrophication algorithm/indicator” TRIX from in situ data FOR THE PAST 20 YEARS (1993-2012).
- **MEDSEA_CH6_Product_4**: Maps of trends of “eutrophication algorithm/indicator” TRIX from in situ data FOR THE PAST 20 YEARS (1993- 2012).

General scope of the Targeted Products

Chlorophyll-a is often used as a proxy for phytoplankton biomass and as an easily available indicator of eutrophication phenomena. However, because eutrophication is the result of a combination of excess inorganic and/or organic nutrients, it cannot be assessed only on the basis of observed chlorophyll-a, regardless of whether it is measured in situ or computed through measurements of ocean colour from satellite observations.

Most eutrophication assessment methods recognize that chlorophyll-a is the end-product of primary production enhanced by the availability of abnormally high levels of nutrients. The existence of river outflows and other outfalls in coastal areas gives rise to plumes of high-nutrient water at the surface, which promotes primary production because of enhanced chlorophyll-a levels. However, there are other forms of oxygen-consuming organic matter not related to phytoplankton that contribute to eutrophication without ever producing chlorophyll-a.

Eutrophication assessment is based on a combination of various in situ parameters, including chlorophyll-a levels, but also inorganic nutrient concentrations and often dissolved oxygen (DO). In situ measurements of eutrophication-related parameters include inorganic and organic nutrients (nitrogen and phosphorus), chlorophyll-a, DO and oxygen-consuming organic matter such as BOD5 or COD.

A number of eutrophication algorithms and indicators are in use, among which the trophic index (TRIX) is the most popular (EEA 2001). The EEA has set up an indicator based on in-situ chlorophyll-a trends to monitor eutrophication in European seas, referred to as CSI023. For a complete overview of the indicator, please refer to the website http://www.eea.europa.eu/data-and-maps/indicators/chlorophyll-in-transitional-coastal-and/chlorophyll-in-transitional-coastal-and-3.

The easy availability, synoptic view, high sampling frequency and spatial resolution of remotely sensed data make it the first-choice approach for eutrophication assessment in the Mediterranean Sea and other oceanic and coastal areas of Europe.

The first ocean colour sensor, the Coastal Zone Colour Scanner (CZCS), was in operation between 1980 and 1986, and was followed by other sensors on board various Earth-scanning satellites (MOS, OCTS) and SeaWiFS. Ocean-colour satellite products are now available from SeaWiFS, MERIS-Envisat and MODIS-AQUA sensors. The Sentinel-3 GMES satellite also has an ocean-colour sensor ensuring continuous monitoring for the 2015-2030 period.

Ocean colour-derived chlorophyll-a measurement has recently been used to assess eutrophication after obtaining careful ground truth calibrations. A study that supplemented the in situ derived EEA index CSI023 with ocean colour derived observations (CSI023+) expanded the assessment to previously unassessed zones (*Coppini et al., 2013*). Nevertheless, there are still large zones for which it is difficult to assess eutrophication from ocean colour observations alone due to the lack of in situ observations (Colella et al., 2016).

Targeted Products catalogue for this Challenge

Name of Targeted product	Short description	Format
MEDSEA_CH6_Product_1: Maps of seasonal Chlorophyll (UNITS: mg/m^3) from L4 satellite ocean color data FOR THE PAST 10 YEARS (1998-2009)	Maps of Chlorophyll concentration seasonal climatologies (i.e., Winter, Spring, Summer and Fall) over the Mediterranean Sea for the 1998-2009 period.	png
MEDSEA_CH6_Product_2: Map of Chlorophyll trends (UNITS: $mg/m^3/year$) from L4 satellite ocean color data FOR THE PAST 10 YEARS (1998-2009)	Map of chlorophyll concentration trend over the Mediterranean Sea for the 1998-2009 period, expressed as a percentage of variation with respect to the climatological field.	png
MEDSEA_CH6_Product_3: Maps of seasonal “eutrophication algorithm/indicator” TRIX from in situ data and FOR THE PAST 20 YEARS (1993-2012).	Maps of 5-year average TRIX indices calculated from Mediterranean Sea surface data for the 2008-2012, 1998-2002 and 1993-1997 periods.	pdf
MEDSEA_CH6_Product_4: Mapsof trends of “eutrophication algorithm/indicator” TRIX from in situ data and FOR THE PAST 20 YEARS (1993-2012).	Maps showing differences between most recent 5-year average TRIX estimate (2008-2012) and TRIX from the earlier 1998-2002 and 1993-1997 periods.	pdf

Description of Characteristics and Data sources used by Targeted products

MEDSEA_CH6_Product_1

Nb	Characteristic name (P02)	Environmental Matrix	Data source (URL)
	Chlorophyll pigment concentrations in the water column	Marine water	http://marine.copernicus.eu/

MEDSEA_CH6_Product_2

Nb	Characteristic name (P02)	Environmental Matrix	Data source (URL)
	Chlorophyll pigment concentrations in the water column	Marine water	http://marine.copernicus.eu/

MEDSEA_CH6_Product_3

Nb	Characteristic name (P02)	Environmental Matrix	Data source (URL)
	Temperature of the water column	Marine water	http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html http://isramar.ocean.org.il/perseus_data/ http://odv.awi.de/en/data/ocean/medatlasii/
	Nitrate concentration parameters in the water column	Marine water	http://www.emodnet.eu/ http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html http://isramar.ocean.org.il/perseus_data/ http://odv.awi.de/en/data/ocean/medatlasii/
	Dissolved oxygen parameters in the water column	Marine water	http://www.emodnet.eu/ http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html http://isramar.ocean.org.il/perseus_data/ http://odv.awi.de/en/data/ocean/medatlasii/
	Salinity of the water column	Marine water	http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html http://isramar.ocean.org.il/perseus_data/ http://odv.awi.de/en/data/ocean/medatlasii/
	Phosphate concentration parameters in the water column	Marine water	http://www.emodnet.eu/ http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html http://isramar.ocean.org.il/perseus_data/ http://odv.awi.de/en/data/ocean/medatlasii/
	Chlorophyll pigment concentration in the water column	Marine water	http://marine.copernicus.eu/

MEDSEA_CH6_Product_4

Nb	Characteristic name (P02)	Environmental Matrix	Data source (URL)
	Temperature of the water column	Marine water	http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html http://isramar.ocean.org.il/perseus_data/ http://odv.awi.de/en/data/ocean/medatlasii/
	Nitrate concentration parameters in the water column	Marine water	http://www.emodnet.eu/ http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html http://isramar.ocean.org.il/perseus_data/ http://odv.awi.de/en/data/ocean/medatlasii/
	Dissolved oxygen parameters in the water column	Marine water	http://www.emodnet.eu/ http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html http://isramar.ocean.org.il/perseus_data/ http://odv.awi.de/en/data/ocean/medatlasii/
	Salinity of the water column	Marine water	http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html http://isramar.ocean.org.il/perseus_data/

			http://odv.awi.de/en/data/ocean/medatlasii/
	Phosphate concentration parameters in the water column	Marine water	http://www.emodnet.eu/ http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html http://isramar.ocean.org.il/perseus_data/ http://odv.awi.de/en/data/ocean/medatlasii/
	Chlorophyll pigment concentration in the water column	Marine water	http://marine.copernicus.eu/

Description of methodology to produce the Targeted Products

MEDSEA_CH6_Product_1 and _2

The maps of seasonal climatology (MEDSEA_CH6_Product_1) and trends (MEDSEA_CH6_Product_2) for chlorophyll-a concentration were calculated from the Mediterranean Sea Surface Chlorophyll Concentration from Multi Satellite Observations Reprocessed (OCEANCOLOUR_MED_CHL_L4_REP_OBSERVATIONS_009_078). For this L4 satellite product, the daily surface chlorophyll concentrations without data voids were computed by applying the interpolation procedure to the CHL L3 REP products, derived from the MedOC4 algorithm (*Volpe et al., 2007*) to the ESA-CCI remote sensing reflectance spectra. These spectra were obtained by merging the SeaWiFS, MODIS-Aqua and MERIS sensors.

Chl seasonal means and trends need to be detected from long time series that are able to capture biomass changes in coastal waters due to anthropic pressures. Indeed, the analysis of short time series can lead to the interpretation of spatial patterns produced by random processes as a change in Chl concentration driven by actual chemical or physical processes (*Wunsch, 1999; Rudnick and Davis, 2003*). Moreover, coastal eutrophication is an inter-seasonal process that strongly depends on anthropic activities and continuous river inputs. In the Mediterranean Sea, river runoffs are at their maximum during autumn and winter and their minimum during summer (*Gasith and Resh, 1999*). To accurately assess biomass variations from Chl trends, year-round inputs need to be considered because the summer Chl dataset may hide crucial processes such as fall and winter runoffs. Finally, OC satellite products are derived from algorithms that often need to be regionalized. Global ocean retrieval algorithms overestimate Chl concentrations in the Mediterranean Sea because of the peculiar optical proprieties of this basin; that is, the abundance of additional yellow substances not strictly related to the biomass (*Volpe et al., 2007* and reference therein).

Removing seasonality is fundamental for any method of trend detection (*Gregg et al., 2005; Behrenfeld et al., 2006; Vantrepotte and Mélin, 2009; Henson et al., 2010; Vantrepotte and Mélin, 2011; Beaulieu et al., 2013; Brown et al., 2014; Gregg and Rousseaux, 2014*). However, some approaches (i.e., considering the annual cycle as the seasonal cycle) assume that the annual cycle is not affected by inter-annual variations and thus they damp the long-term signals within the seasonal variability (*Pezzulli et al., 2005*). Several studies (e.g., *Vantrepotte and Mélin, 2009, 2011; Loisel et al., 2014*) have applied the X-11 decomposition procedure to investigate the temporal variation of OC biogeochemical products. This approach allows variations in the annual cycle by decomposing the original time series into seasonal, irregular and trend-cycle terms.

Based on these considerations, we use a Mediterranean chlorophyll satellite product and combine the Mann-Kendall test and Sen's method to a de-seasonalied monthly time series obtained using the X-11 technique. We fully explore this de-compositional method by considering the contribution of each component to the variance in Chl. The use of such a non-parametric test is particularly suitable for non-normally distributed data and for datasets that contain missing data (*Vantrepotte and Mélin, 2011*).

For a more detailed description of MEDSEA_CH6_Product_1 and MEDSEA_CH6_Product_2, please see *Colella, S., Falcini, F., Rinaldi, E., Sammartino, M., & Santoleri, R. (2016). Mediterranean Ocean Colour Chlorophyll Trends. PloS one, 11(6), e015575.*

MEDSEA_CH6_Product_3 and _4

Eutrophication is the enrichment of an ecosystem with chemical nutrients, typically compounds containing nitrogen, phosphorus, or both. It is a well-documented process (e.g. *Vollenweider, 1992; Vollenweider et al., 1988*) in which the enrichment of water by nutrients causes an undesirable increase in autotrophic organisms such as phytoplankton and bacteria that compromise the equilibrium of the ecosystem. For example, the reduction of light penetration prevents seagrass species from growing. The depletion of DO due to oxidation of excess organic matter may be stressful, and even fatal, for aerobic organisms such as invertebrates and fish. Eutrophication is a water pollution problem recognized by European directives (e.g. EEA, 2001; EC, 2009; UNEP-MAP, 2003).

Estimating phytoplankton biomass, usually by assessing the chlorophyll content in the phytoplankton cells, may help to quantify the effects of nutrient enrichment but is insufficient to evaluate all stages of nutrient-supported biomass growth.

Eutrophication in marine ecosystems can be assessed using various components involved in the eutrophication process, apart from phytoplankton biomass, such as DO and nutrient concentrations. The trophic index (TRIX) was developed to integrate chlorophyll, oxygen saturation, total nitrogen and total phosphorus to provide a measure of the trophic level (*Vollenweider et al., 1998*).

The TRIX was adopted in the MEDPOL Programme, and is defined by a linear combination of the logarithms of four state variables: chlorophyll-a, oxygen as the absolute percentage deviation from saturation, mineral nitrogen and total phosphorus (*Vollenweider et al., 1998*). The general TRIX equation provided by *Fiori et al. (2016)* is

$$TRIX = (Log[CHL*(100-\%DOSAT)*DIN*TP] + 1.5]) / 1.2$$

where CHL represents the chlorophyll concentration (µg/l), %DOSAT represents the percentage of DO departure from saturation, DIN is the dissolved inorganic nitrogen (DIN) in µg/l and TP represents the total phosphorous (µg/l). The coefficients 1.5 and 1.2 are scale coefficients that fix the index scale from 0 to 10 TRIX units.

The index has been successfully tested in a number of coastal and open sea areas of the Mediterranean Sea such as the Adriatic and Tyrrhenian Seas (*Fiori et al., 2016; Giovanardi and Vollenweider, 2004*).

TRIX is suitable for characterising trophic conditions in coastal and open sea waters. Scores range from 0 to 10, with scores closer to zero indicating lower eutrophication. The interpretation of TRIX values can be affected by a number of factors. For example, correlations between variables such as nutrients and phytoplankton biomass may lead to the under or overestimation of trophic status (*Primpas and Karydis, 2009*). Scaling parameters may change for time series data shorter than 10 years (Fiori et al., 2016). The index values may change according to the variables used for calculation. For example, the use of phosphate (P) instead of TP and the use of DIN instead of TN may lower the TRIX value by about 0.4 log units (*Vollenweider et al., 1998*).

The time evolution of seasonal TRIX may provide an indication of the eutrophication trend. At middle and high latitudes, TRIX values are affected by seasonality: summer stratified waters may show relatively low TRIX values that indicate a lower trophic level than in winter, but are unconnected to eutrophication problems. For the Operational Observatory of the Catalan Sea (OOCS, www2.ceab.csic.es/oceans/, unpublished data), a fixed station located in an oligotrophic area at the head of the Blanes submarine canyon (NW Mediterranean), the yearly average TRIX for surface waters for the 2012 to 2014 period, using nitrate (N) instead of DIN and P instead of TP, was 3.5±0.5 SD, although the average values for summer and winter were 4.0 ± 0.5 SD and 3.3 ± 0.3 SD. Figure 1 shows the depth and seasonal variable TRIX estimates for the OOCS station.

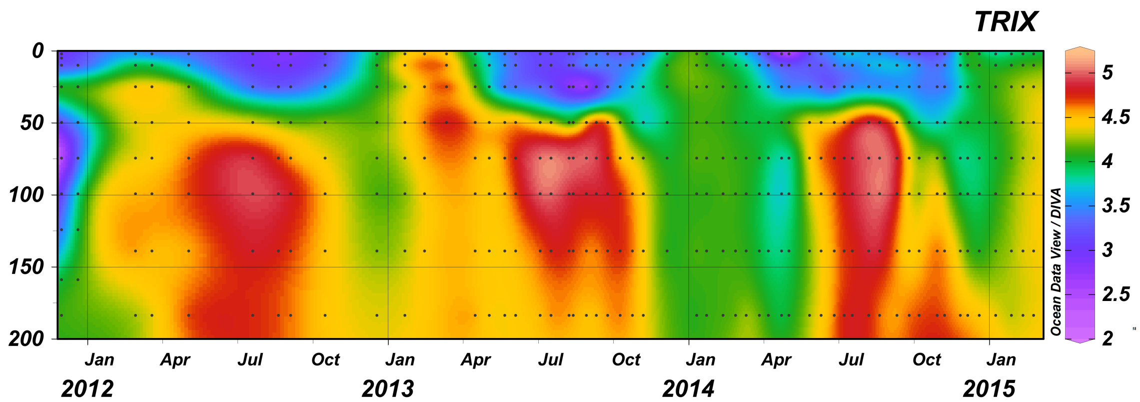

Figure 1 Depth and seasonal TRIX estimates for the OOCS station.

Databases used

TRIX maps (MEDSEA_CH6_Product_3) and trends (MEDSEA_CH6_Product_4) were produced from a single merged dataset that included all of the above-mentioned sea surface variables, created from data retrieved from four on-line public website sources:

- World Ocean Database from NOAA/NODC: http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html
- MedAtlas II 2013: http://odv.awi.de/en/data/ocean/medatlasii/
- EMODNET: http://www.emodnet.eu/
- ISRAMAR data base: http://isramar.ocean.org.il/perseus_data/

Data processing

For targeted products MEDSEA_CH6_Product_3 and MEDSEA_CH6_Product_4, we used sea surface data from public datasets to calculate the TRIX values. Because the available datasets mostly contained N and P instead of DIN and TP, the TRIX values were calculated using the original equation above, but using the available parameters instead of the original parameters, as follows:

$$TRIX = (Log[CHL*(100-\%DOSAT)*N*P] + 1.5]) / 1.2$$

The departure of DO from the saturation [%] was estimated from DO [ml/l], sea surface temperature [°C] and sea surface salinity data available from public datasets. First, oxygen saturation was calculated following the equation by *Garcia and Gordon (1992),* and then the percentage deviations from saturation were estimated.

The available in-situ sea surface chlorophyll data (µg/l) showed large areas with missing values and the available data were dispersed over small areas of the Mediterranean Sea. To overcome this problem, yearly averages of multi-satellite observations of sea surface chlorophylls (as described in Targeted product MEDSEA_CH6_product_1 and _2) covering the entire Mediterranean Sea were used instead.

The poor temporal and spatial coverage of the information available from public datasets for the last decade prevented the reconstruction of seasonal time series of TRIX. Instead, we provided 5-year average TRIX values for the 2008-2012, 1998-2002 and 1993-1997 periods.

Using the variables in the original equation, *Giovanardi and Vollenweider (2004)* found that TRIX values greater than 6 log units indicated highly productive waters with eventual anoxia events, whereas values lower than 4 indicated scarcely productive coastal waters. Values lower than 3 were found in open sea areas.

The TRIX estimates provided in the present work, calculated with modified variables (N instead of NP and P instead of TP), were expected to be slightly lower, i.e., 0.4 log units, than the estimates provided by the original variables (*Vollenweider et al., 1998*). First, nitrogen is just a portion of DIN (that is, the total sum of nitrogen contained in nitrate, nitrite and ammonium), although nitrate is the most abundant nitrogen form of the three DIN components; and second, phosphate is a variable fraction of TP. We assume that the present TRIX estimates can only be compared with other TRIX estimates using the modified parameters in the original TRIX equation, which to the best of our knowledge are not yet available in the literature.

To render TRIX estimates for Mediterranean Sea areas, isosurface contours of surface field data for each of the variables (required to estimate TRIX) were adjusted using ODV software (http://odv.awi.de/). Spatial data interpolation using DIVA gridding (http://ec.oceanbrowser.net/emodnet/diva.html) was carried out for every variable for the 2008-2012, 1998-2002 and 1993-1997 periods. The georeferenced and extrapolated results for each variable were exported to a single file for further TRIX calculation (MEDSEA_CH6_product_3), following the above equation.

Finally, differences in TRIX values among the periods were calculated, i.e., TRIX 2008-2012 minus TRIX 1998-2002, and TRIX 2008-2012 minus TRIX 1998-2002, to produce MEDSEA_CH6_product_4. Finally, the TRIX estimates for the three 5-year periods and the TRIX differences among the periods were plotted using ODV. Outliers were eliminated from the gridded data and restricted to the ranges provided in the Table 1.

	Chlorophyll [mg/l]	Dissolved Oxygen [ml/l]	Temperature [° C]	Salinity [psu]	Nitrate [mg/l]	Phosphate [mg/l]	Average TRIX	TRIX difference
1993-1997								[2008-2012] – [1993-1997]
Mean	0.22	5.39	18.59	37.37	8.17	1.67	2.78	-0.11
Standard deviation	0.21	0.99	2.37	1.31	5.39	1.02	0.92	1.39
Minimum	0.03	3.00	12.85	30.03	0.04	0.23	0.09	-2.95
Maximum	1.13	9.99	26.23	39.43	29.94	6.55	5.85	6.09
1998-2002								[2008-2012] – [1998-2002]
Mean	0.27	5.21	18.57	37.41	9.54	2.74	2.33	0.26
Standard deviation	0.53	0.64	2.54	1.52	7.44	1.71	1.02	1.32
Minimum	0.03	3.12	10.01	30.07	0.14	0.81	0.05	-4.97
Maximum	7.45	9.98	27.15	39.43	29.99	9.98	5.78	6.04
2008-2012								
Mean	0.21	5.30	20.24	38.12	11.44	2.04	2.59	
Standard deviation	0.45	0.18	3.15	0.88	9.05	1.51	1.41	
Minimum	0.01	4.93	13.44	34.49	0.11	0.32	0.01	
Maximum	9.48	6.27	27.28	39.62	30.00	9.99	7.43	

Table 1. Basic statistics of gridded data and TRIX estimates over 13977 grid points.

The present TRIX estimates can be considered as a proxy of average eutrophic conditions over 5-year periods. The TRIX difference between periods suggests magnitudes of the eutrophic conditions change over time. Nonetheless, the present results should be viewed with caution, as the weighted seasonal contributions of the individual variables for the 5-year pooled data are not provided and the TRIX estimates were produced over gridded (extrapolated) values.

Expert evaluation of Targeted Product quality

The objective is to provide an expert evaluation of the "fitness for purpose and use" for each Targeted Product. The coordinator asked the challenges teams to answer to the following points:

1. Assign an overall product quality score with respect to scope (fitness for purpose) and explain why according to the scale in Table 2.
2. Explain what is (are) the most important characteristic(s) for the Targeted Product quality (if all characteristics are important please say so);
3. Explain what is (are) the quality element(s) (see Annex 1) of the most important characteristic(s) that affects the Targeted Product quality;
4. Explain the limitations on the quality of Targeted products due to the input data set used;
5. Explain which characteristics "fails the most" to meet the scope of the Targeted Product;

SCORE	MEANING
1	EXCELLENT → it meets completely the scope of the Targeted Product
2	VERY GOOD → it meets more than 70% of the scope of the Targeted Product
3	GOOD → it meets less than 50% of the scope of the Targeted Product
4	SUFFICIENT → it does not really meet the scope but it is a starting point
5	INADEQUATE → it does not really fulfil the scope, not usable

Table 2. Targeted Products quality scores and their meaning.

MEDSEA_CH6_Product_1

1) The overall product quality score with respect to scope is **very good** (2). The synopticity of satellite-based data allows for the complete retrieval of chlorophyll concentration seasonal maps. Moreover, the ESA-CCI L4 product is very suitable for mapping chlorophyll patterns both offshore and along the coast without any voids. However, we used the chlorophyll concentration as a proxy of phytoplankton biomass. This strong assumption may have led to some under or overestimation of phytoplankton concentrations.
2) For this product, the most important characteristic is the chlorophyll-a concentration.
3) The usability of satellite-based chlorophyll concentrations may be an issue for users who are unfamiliar with satellite data analysis. The targeted product was produced after some scripting that i) read the satellite data and ii) calculated climatological averages.
4) The Copernicus Marine Environment Monitoring Service was the most important dataset that we could find and it fully satisfied the necessary requirements to build this targeted product.
5) Overall, due to the synopticity of satellite-based data, the Copernicus Marine Environment Monitoring Service provided the best characteristics to build our targeted product.

MEDSEA_CH6_Product_2

1) The overall product quality score with respect to scope is **very good** (2). The synopticity of satellite-based data allows for the complete retrieval of chlorophyll concentration seasonal maps. Moreover, the ESA-CCI L4 product is very suitable for mapping chlorophyll patterns both offshore and along the coast without any voids. However, we used the chlorophyll concentration as a proxy of phytoplankton biomass. This strong assumption may have led

to some under or overestimation of undesirable modifications of phytoplankton concentrations (i.e., eutrophication).

2) The most important characteristic for this product is the chlorophyll-a concentration.
3) The usability of satellite-based chlorophyll concentration data could be an issue for users who are unfamiliar with satellite data analysis. The targeted product was produced after some scripting to i) read the satellite data; ii) de-seasonalized the chlorophyll time series by means of the X-11 technique (see Description of methodology to produce the Targeted Products); and iii) applied the non-parametric Mann-Kendall test and Sen's method (see Description of methodology to produce the Targeted Products).
4) The Copernicus Marine Environment Monitoring Service was the most important dataset we could find and it fully satisfied the necessary requirements to build this targeted product.
5) Overall, due to the synopticity of satellite-based data, the Copernicus Marine Environment Monitoring Service provided the best characteristics to build our targeted product.

MEDSEA_CH6_Product_3

1) The overall product quality score with respect to scope is **sufficient** (4). Historical data on the Mediterranean Sea surface properties, obtained from public databases, only allowed us to estimate an average 5-year TRIX map for the second half of the last decade (assuming the decade range to be between 2003 and 2012) and two other averaged 5-year TRIX maps for the earlier decade between 1993 and 2002 for comparison. The TRIX was used to assess the eutrophication level of the Mediterranean Sea, following *Fiori et al. (2016)*. However, as some of the variables required for the original TRIX were not available in the datasets, they were replaced by available and closely related variables. Thus, nitrogen contained in nitrate was used instead of DIN, and phosphorous in phosphates was used instead of TP. The replacement of variables in the equation may have produced lower TRIX values within the expected range scale between 0 and 10. However, the difference between the present results and the expected results using the original variables should be minor as the final TRIX scale is similar to that provided by Fiori et al. (2016) and *Giovanardi and Vollenweider (2004)*. Nevertheless, the present TRIX values and those calculated following the original nutrient variables should be compared with caution. Inevitably, there were some missing historical data for the six variables required for calculating TRIX, chlorophylls, DIN, TP, DO, water temperature and salinity (the last three variables are required to calculate the DO concentration saturation), covering all of the targeted years and covering all Mediterranean Sea areas. The satellite sea surface chlorophyll data were the most complete in terms of geographical and temporal coverage. Satellite sea surface temperature data were available for similar periods as for chlorophylls, although they were not used in the present work. At present, the time evolution of yearly TRIX estimates can be provided for fixed monitoring stations (i.e. not areas) such as the OOCS (http://www2.ceab.csic.es/oceans/), collecting time series data of closely related variables required to calculate TRIX.
2) All of the above-mentioned characteristics were required to calculate the TRIX and thus they are all important. As explained above, eutrophication levels in a water body are dependent on a number of variables that need to be included in the TRIX equation.
3) The satisfactory temporal and spatial coverage of the water characteristics is the most important quality element affecting the targeted products. Assessment of the time variability of the eutrophic conditions of the marine ecosystem using the TRIX requires representative

data covering the whole study area, for every season and for a number of consecutive years, but such data are not available from public datasets.

4) The limited spatial and temporal extent of the data available from publicly available databases is the most important limitation on the quality of TRIX estimates. The present TRIX estimates could be improved by the use of additional data from different sources (research institutions, observation systems, etc.) that are not available to the public or are subject to negotiation. Future TRIX construction could also use validated numerical modelling products covering the whole Mediterranean area for a number of consecutive years.
5) DO, water salinity and nutrients (DIN and TP) were the variables with the greatest temporal and spatial limitations. DO data are generally obtained using sensors attached to moored and profiler CTDs. Comparison of DO values obtained from CTD and chemical methods (e.g. the Winkler method) at the OOCS station (http://www2.ceab.csic.es/oceans/) suggests that CTD sensors tend to underestimate DO values, which may have affected the TRIX estimates. Regarding nutrients at sea, DIN and TP values are generally scarcer in the datasets than nitrate+nitrite and phosphate values with lower magnitudes (i.e. concentrations). In the present study, the use of nitrate+nitrite instead of DIN and the use of phosphate instead of TP may also have affected the TRIX estimates. Finally, the increased temporal and spatial coverage of surface salinity data from the recently launched SMOS and AQUARIUS satellites, despite providing very low resolution values for the Mediterranean Sea, should improve future TRIX calculations.

MEDSEA_CH6_Product_4

1) The overall product quality score with respect to scope is **sufficient (4)**. TRIX trends were calculated as the difference between the TRIX map for the 2008-2012 period and the TRIX map for the 1993-1997 and 1998-2002 periods. Data for 2003 - 2007 were very scarce, preventing the construction of the TRIX map to compare against the map for 2008-2012.
2) All of the above-mentioned characteristics were required to calculate TRIX trends; therefore, they are all important. As explained above, eutrophication levels in a water body are dependent on a number of variables (i.e., not a single variable) included in the TRIX equation.
3) The satisfactory temporal and spatial coverage of the water variables (characteristics) are the most important quality elements affecting the targeted products. Representative data for each season for a number of years covering the whole study area are required to provide more accurate trends.
4) The limited temporal and spatial coverage of the data available from public databases is the most important limitation on the quality of TRIX trends. The present TRIX trends may benefit from the use of additional data from different sources (research institutions, observation systems, etc.) that are not available to the public or subject to negotiation.
5) DO, water salinity and nutrients (DIN and TP) are the variables (characteristics) with the most limited temporal and spatial coverage. DO data are generally obtained with sensors attached to moored and profiler CTDs. A comparison of DO values obtained by CTD with those obtained by chemical methods (e.g. Winkler method) at the OOCS station (http://www2.ceab.csic.es/oceans/) suggests that CTD sensors tend to underestimate DO values. This may have affected the TRIX estimates. Regarding nutrients at sea, DIN and TP values were generally scarcer in the datasets than nitrate+nitrite and phosphate values with lower magnitudes (i.e. concentrations). In the present study, the use of nitrate+nitrite instead of DIN and the use of phosphate instead of TP may also have affected the TRIX estimates.

Finally, the increased temporal and spatial coverage of surface salinity data from the recently launched SMOS and AQUARIUS satellites, despite providing very low resolution values for the Mediterranean Sea, should improve future TRIX calculations.

Expert evaluation of gaps

Targeted Products MEDSEA_CH6_product_1 and _2 are based on the assumption that the assumed chlorophyll concentration is a proxy of phytoplankton biomass. This strong assumption may lead to some under or overestimation of eutrophication, particularly in coastal environments. Targeted Products MEDSEA_CH6_product_3 and _4 are based on a relatively high number of characteristics (six characteristics in total), most of which were obtained from public databases with limited geographical and temporal coverage. This meant that it was not possible to assess the evolution of eutrophication with a temporal resolution higher than 5-year periods and even prevented the assessment of periods with very scarce representation (as was the case for the 2003 to 2007 period). The limited data also prevents any improvement in the current spatial resolution. Consequently, the limited data availability may lead to under or overestimation of eutrophication in open sea and coastal environments.

TP	CH6
1	2
2	2
3	4
4	4

Table 3 Summary of the quality scores associated with each Targeted Product according to the experts' evaluations and the evaluation scheme presented in Table 2.

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Annex 1

From the MedSea Literature Survey we have extracted the following definitions:

Characteristic

In this document, a "characteristic" is a distinguishing feature which refers:

1. either to a variable derived from the observation, the measurement or the numerical model output of a phenomenon or of an object property in the environment
2. or to the geographical representation of an object on a map (ie a layer such as a protected area, a coastline or wrecks) by a set of vectors (polygon, curve, point) or a raster (a spatial data model that defines space as an array of equally sized cells such as a grid or an image).

Environmental matrices

This concept is introduced to avoid ambiguities when using a characteristic name such as "temperature". The environment matrix is the environment to which a characteristic is related and we define them to be:

1. Air,
2. Marine Waters,
3. Fresh Waters,
4. Biota/Biology,
5. Seabed,
6. Human activities.

Quality principles

- ✓ *Spatial extent*
  Box or geographic region bounding the datasets
- ✓ *Spatial resolution* :
  Size of the smallest object that can be resolved on the ground. In a raster dataset, the resolution is limited by the cell size.
- ✓ *Spatial Accuracy*
  Requested closeness of coordinate values to values accepted as or being true e.g. on the base of instrumentation used
- ✓ *Time extent*
  Time interval represented by the dataset or by the collection.
- ✓ *Time resolution*
  Size of the smallest interval of time that can be resolved.
- ✓ *Time Accuracy*
  Requested closeness of temporal values to values accepted as or being true.
- ✓ *Usability*
  The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use.
- ✓ *Completeness*
  Degree of absence of data in a dataset
- ✓ *Logical Consistency*
  Degree of adherence to format required
- ✓ *Thematic Accuracy*
  Requested closeness of characteristic values to values accepted as or being true (the so called attribute of a data entity eg "wave height"). It includes the correctness of the classification of features or of their associations...