Ecological Objective 5 (EO5): Eutrophication

EO5: Common Indicator 13. Key nutrients concentration in water column

GENERAL

Reporter:	UNEP/MAP/MED POL
Geographical scale of the assessment:	Regional, Mediterranean Sea
Contributing countries:	Albania, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Montenegro, Morocco, Slovenia, Spain, Tunisia, Turkey
Mid-Term Strategy (MTS) Core Theme	1-Land and Sea Based Pollution
Ecological Objective	EO5. Human-induced eutrophication is prevented, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algal blooms and oxygen deficiency in bottom waters
IMAP Common Indicator	CI13. Key nutrients concentration in water column (EO5**)**
Indicator Assessment Factsheet Code	EO5CI13

RATIONALE/METHODS

Background

Eutrophication is a process driven by enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, leading to: increased growth, primary production and biomass of algae; changes in the balance of nutrients causing changes to the balance of organisms; and water quality degradation (IMAP, 2017). Seawaters depending on nutrient loading and phytoplankton growth are classified according to their level of eutrophication. Low nutrient/ phytoplankton levels characterize oligotrophic areas, water enriched in nutrients is characterized as mesotrophic, whereas water rich in nutrients and algal biomass is characterized as eutrophic. The Mediterranean is one of the most oligotrophic seas in the world and most of its biological productivity takes place in the euphotic zone (UNEP, 1989, UNEP/MAP, 2012). The development of nutrient/phytoplankton concentration scales has been a difficult task for marine scientists because of the seasonal fluctuations of nutrient and phytoplankton concentrations, phytoplankton patchiness and small-scale eutrophication phenomena. Although long-term scientific research (UNEP/FAO/WHO1996; Krom *et al.*, 2010) has shown that the main body of the Mediterranean Sea is in good condition, there are coastal areas, especially in enclosed gulfs near big cities in estuarine areas and near ports, where marine eutrophication is a serious threat. In the Mediterranean Sea, the Barcelona Convention adopted in 1976 was the first legally-binding instrument for its environmental protection and included a number of protocols, such as the pollution land-based sources (LBS) Protocol. Since 2000, other international and national policies, such as the European Water Framework Directive (WFD) and the European Marine Strategy Framework (MSFD) are developing programmes, which sums to its environmental protection at sub regional levels and collaborate with UNEP/MAP. At the 19th Ordinary Meeting in 2016 of the Contracting Parties to the Barcelona Convention (Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean and its Protocols) adopted the Integrated Monitoring and Assessment Programme (IMAP) of the Mediterranean Coast and Sea and Related Assessment Criteria, which includes the targets to achieve the Good Environmental Status (UNEP/MAP, 2016). The initial targets of Good Environmental Status (GES) for IMAP Common

Indicator 13 are reflecting the scope of the current MED POL Programme and the availability of suitable agreed assessment criteria.

In the Mediterranean area eutrophication is caused by both regional sources such as urban effluents, industrial discharges, and aquaculture activities as well as transboundary components such as agricultural runoffs, riverine outflows, and airborne nutrient deposition. The variables related to eutrophication are influenced by water circulation, but it is only recently that the general circulation pattern has been connected to regional sources of pollution including eutrophication (UNEP/MAP, 2003).

The highly populated coastal zone in the Mediterranean and the riverine input from a draining area of 1.5 10^6 km^2 (Ludwig *et al.*, 2009) induce eutrophic trends in coastal areas. The offshore waters of the Mediterranean have been characterized as extremely oligotrophic with a clear gradient toward east (Turley, 1999). The gradient is illustrated on figure 1 from data collected during the Meteor M84/3 cruise (Tanhua *et al.* 2013).

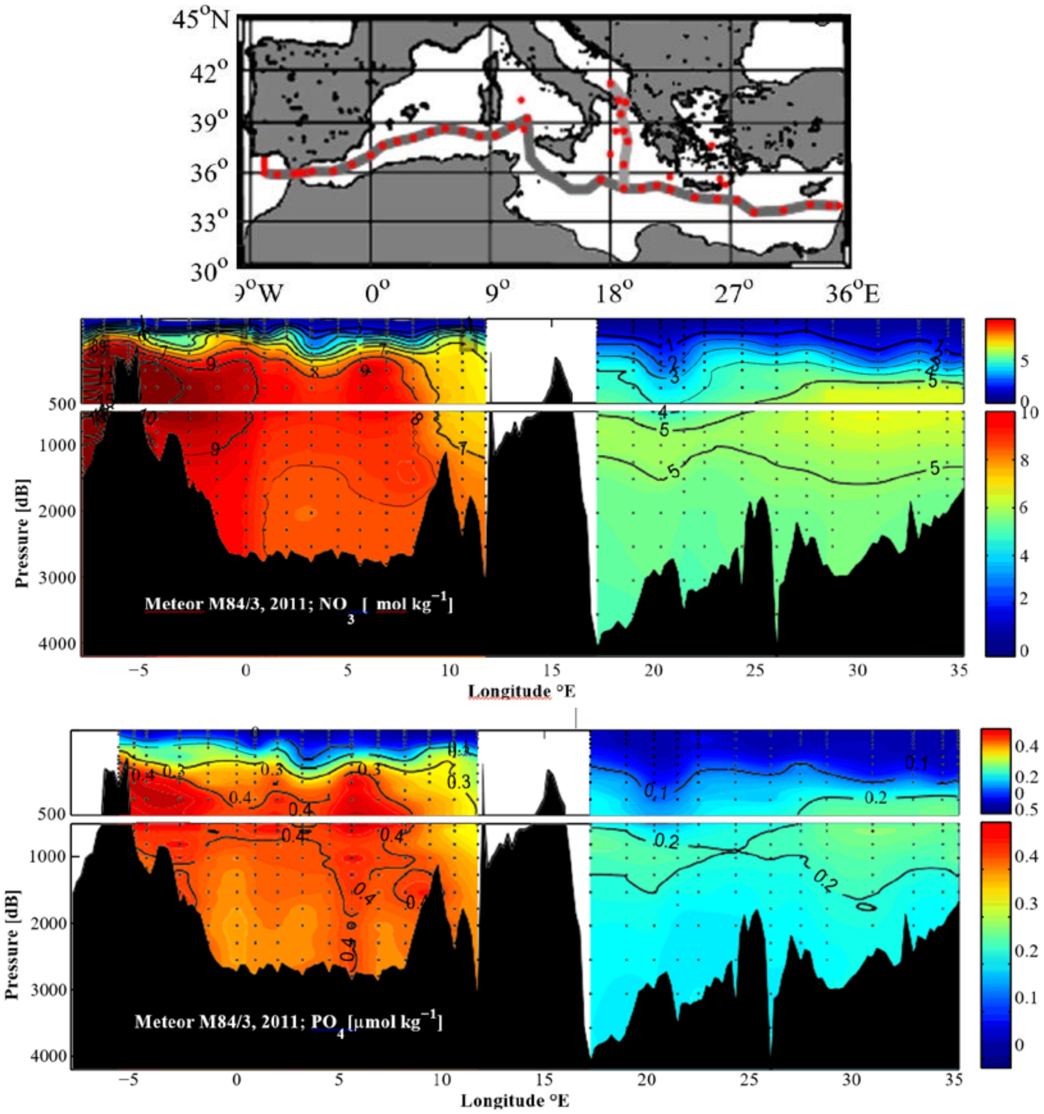

Figure 1. Distribution of nitrate (NO_3) and phosphate (PO_4) concentrations along a profile from off the coast of Lebanon to the Strait of Gibraltar during spring 2011. Data were collected during the Meteor 84/3 cruise. Reproduced from: Tanhua *et al.*, 2013.

Assessment methods

At the moment only some of the Mediterranean countries have developed a boundary approach for the assessment of eutrophication and no general assessment criteria have been agreed for the Mediterranean area for the key nutrient concentrations in the water column. This assessment effort was based only on the presentation of the geographical variability of some key nutrients (DIN – dissolved inorganic nitrogen and TP- total phosphorous; μmol L^{-1}).

For the presentation of the data Box and Whiskerplots are used. Information contained in the plot are Hspreads (interquartile range - the absolute value of the difference between the values of the two hinges) and fences that define outside and far outside values:
Lower inner fence = lower hinge - (1.5 • (Hspread))
Upper inner fence = upper hinge + (1.5 • (Hspread))
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The whiskers show the range of observed values that fall within the inner fences. Because the whiskers do not necessarily extend all the way to the inner fences, values between the inner and outer fences are plotted with asterisks. Values beyond the outer fences are plotted with empty circles.

UNEP/MAP's Pollution Programme (MEDPOL) has a monitoring programme since 1999, based on the contribution of data from Mediterranean countries, including nutrients.

In this assessment, aware that for most of the northern Mediterranean countries data are available also in other databases (such as EEA, EIONET, EMODnet), only datasets obtained from the MED POL Database for nutrients were used. Data availability by country were as follows:
Albania (2005-2006), Bosnia and Herzegovina (2006-2008) Croatia (2009, 2011-2014), Cyprus (1999-2015), Egypt (2009, 2010), France (2009, 2010), Greece (2004-2006), Israel (2001-2012), Montenegro (2008-2012, 2014-2015), Morocco (2006,2007), Slovenia (1999-2013, 2015), Tunisia (2002-2013), Turkey (2005-2009, 2011, 2013)

RESULTS

Results and Status, including trends

The trophic status of the Mediterranean Sea is controlled by the highly populated coastal zone and the riverine input from a draining area of 1.5 million km^2 (Ludwig *et al.* 2009) that induce eutrophic trends in coastal areas. The blue offshore waters of the Mediterranean have been characterized as extremely oligotrophic with an increasing tendency for oligotrophy eastwards (Turley 1999). Eutrophication and oligotrophy in the Mediterranean is illustrated as chlorophyll *a* distribution in remote sensing imagery (Figure 1). It is observed that the Eastern Mediterranean Sea (EMS) is still the most oligotrophic area of the whole Mediterranean basin. This is due to the low nutrient content of EMS; the maximum concentrations recorded for nitrate were about 6 μmol L^{-1}, for phosphate 0.25 μmol L^{-1}, and for silicate 10–12 μmol L^{-1}, with the nitrate to phosphate ratio (N/P) >20 and in deep waters about 28:1, the EMS has been characterized as the largest phosphorus-limited body of water in the global ocean.

The coastal area of the southeastern part of the Mediterranean shows clearly eutrophic trends. Although the River Nile is the major water resource in the area, its freshwater fluxes are becoming limited because of the Aswan Dam and increasing trends in anthropogenic water use in the lower Nile. Eutrophic conditions in the area are mainly induced by the sewage effluents of Cairo and Alexandria. The Northern Aegean shows mesotrophic to eutrophic trends. This can be explained by the river inputs from northern Greece and the water inflow from the nutrient rich Black Sea.

The nutrient regime and primary productivity in the Western Mediterranean Sea (WMS) are relatively higher compared to the EMS. There is limited nutrient supply through the Strait of Gibraltar due to different nutrient concentrations between the Atlantic and Mediterranean waters. The surface water entering from the Atlantic carries nutrients directly available for photosynthesis (EEA 1999) but at low concentrations. The phosphorus (phosphate) concentrations in the inflowing waters ranges from 0.05 to 0.20 μmol L^{-1}, the nitrogen (nitrate) concentrations being about 1–4 μmol L^{-1}, and the silicon (silicate) concentration is about 1.2 μmol L^{-1} (Coste *et al.* 1988). The nutrients of the surface layer are reduced as they propagate eastwards due to mixing with poor basin water and nutrient use by phytoplankton. However, the primary productivity of the main WMS, away from the coastal areas and influenced by rivers and urban agglomerations, is still higher than the primary productivity in the EMS.

The main coastal areas in the Mediterranean which are historically known to be influenced by natural and anthropogenic inputs of nutrients are the Gulf of Lions, the Gulf of Gabès, the Adriatic, Northern Aegean and the SE Mediterranean (Nile–Levantine). A recent work on nutrient and phytoplankton distribution along a large-scale longitudinal east–west transect (3 188 km) of the Mediterranean Sea extended over nine stations was published by Ignatiades *et al.* (2009). The results confirmed the oligotrophic character of the area and the nutrient and chlorophyll gradient characterized by decreasing concentrations from Gibraltar to the sea of Levantine. Phosphate maxima ranged from 0.05 to 0.26 μmol L^{-1}, nitrate from 4.04 to 1.87 μmol L^{-1}, chlorophyll *a* (chl*a*) from 0.96 to 0.39 μg L^{-1}.

The results of assessment and status of the key nutrients concentration in the water column are presented on Figs 3-5 showing a rather limited figure of the Mediterranean region. The main reason is the data availability and quality. On the Figure 2 are clearly visible that for the great part of the region data are missing. The implementation of water type criteria for the purpose of IMAP are also limited. Even a rather weak criteria (10 samples in 10 years in surface layer - <= 10 m) were adopted the data availability for assessment were low.

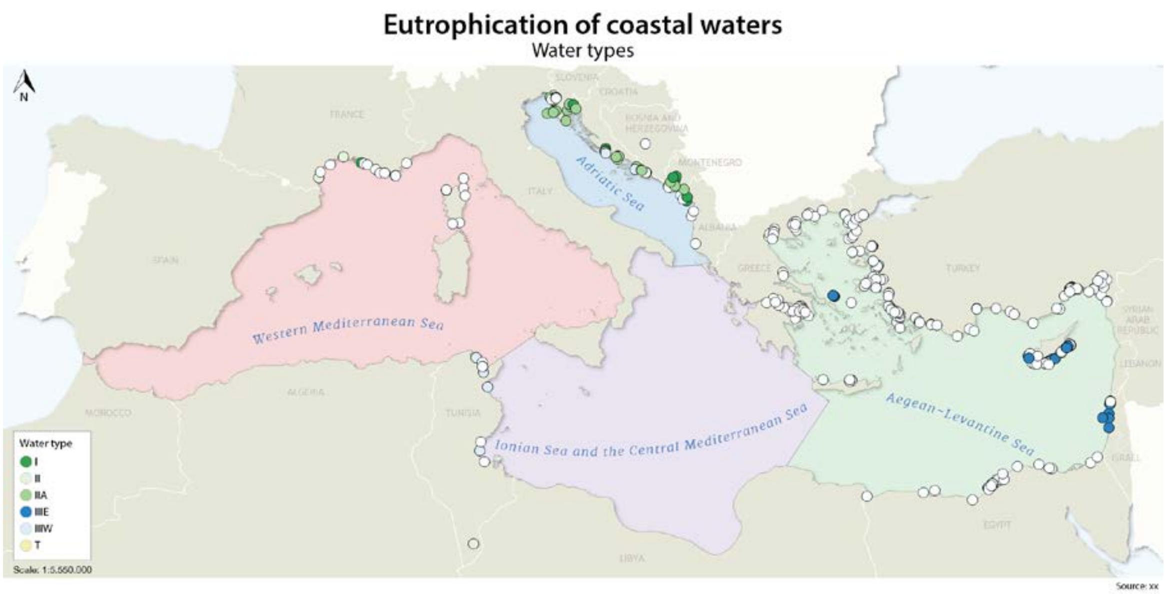

Figure 2. Stations in the Mediterranean region for which nutrient concentrations were sampled. Also are shown the water types (applicable for phytoplankton; IMAP, 2017) were minimal statistical requirements were satisfied (10 samples in the last 10 years and in the surface layer, <= 10 m)

Figure 2 presents the stations in the Mediterranean region for which nutrient concentrations were sampled used for the assessment. On Figures 3-5 data for the Adriatic and Aegean-Levantine sub regions for dissolved inorganic nitrogen (DIN) and total phosphorus (TP) were presented. DIN and TP concentration show a characteristic variability for both coastal sea (Adriatic and Aegean-Levantine Sea) indicating that no hotspot is present for DIN and TP.

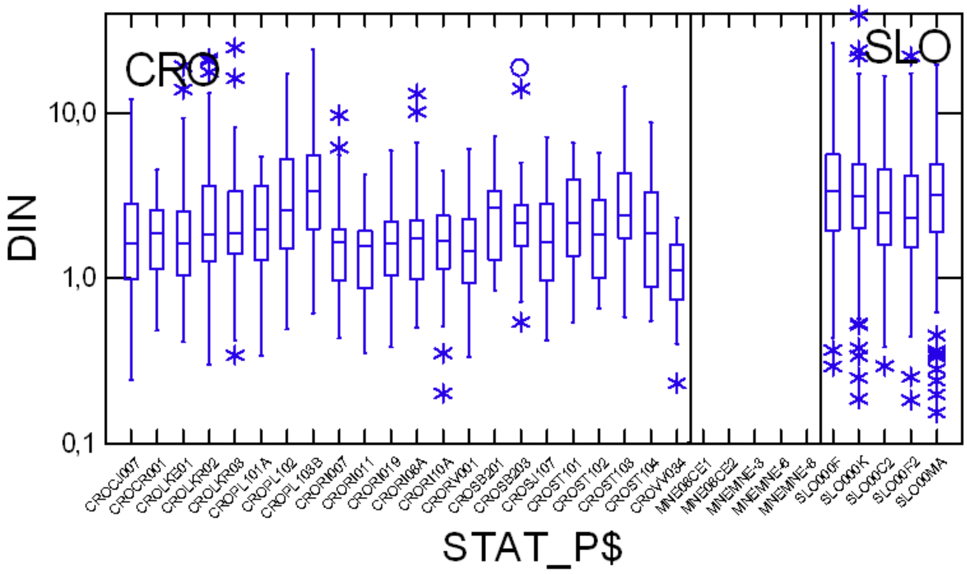

Figure 3. Box and whisker plot for dissolved inorganic nitrogen (DIN) concentration (µmol L^{-1}) in the Adriatic Sea sub region (water type IIA) for Croatia (CRO) and Slovenia (SLO)

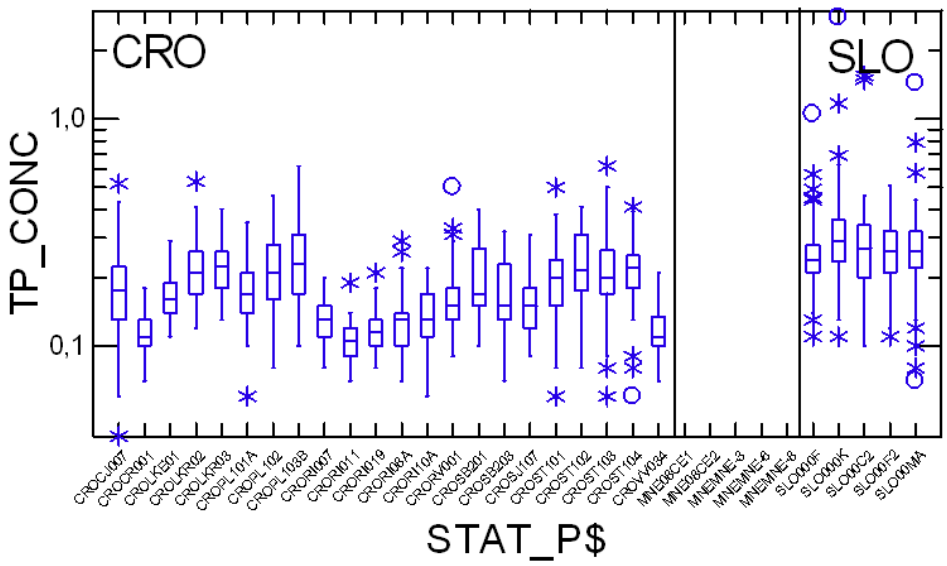

Figure 4. Box and whisker plot for Total Phosphorous (TP) concentration (µmol L^{-1}) in the Adriatic Sea sub region (water type IIA) for Croatia (CRO) and Slovenia (SLO)

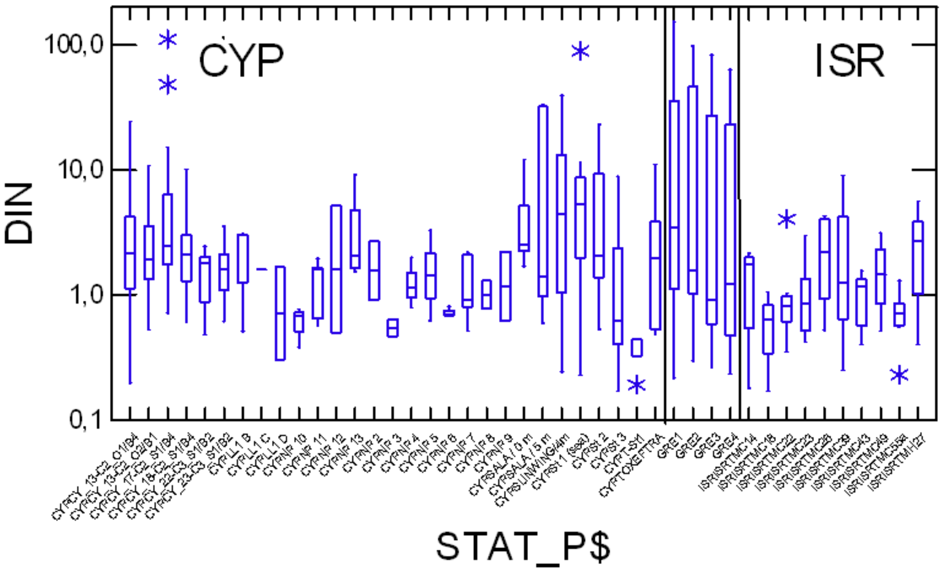

Figure 5. Box and whisker plot for dissolved inorganic nitrogen (DIN) concentration (µmol L^{-1}) in in the Aegean-Levantine Sea subregion (water type IIIE) for Cyprus (CYP) and Israel (ISR).

The available data shows that in areas where assessment is possible the key nutrient concentrations are in ranges characteristic for coastal areas and in line with the main processes undergoing in the interested area. The result also confirms the validity of this indicator in assessing eutrophication.

CONCLUSIONS

The available data show that in areas were assessment is possible the key nutrient concentrations are in ranges characteristic for coastal areas and in line with the main processes undergoing in the interested area. The result also confirm the validity of this indicator as support in assessing eutrophication. Coastal Water type assessment criteria for reference condition and boundaries for key nutrients in the water column have to be built and harmonised through the Mediterranean region, which will greatly help the implementation of a clear sampling strategy with a simplified approach in monitoring design and data handling for the future implementation of IMAP.

Whilst data was available through the MEDPOL database, and substantial data is also available through EEA, EMODnet-Chemistry (http://www.emodnet-chemistry.eu/) and other sources, priority should be given to ensure Mediterranean countries regularly report quality assured data nutrient data to UNEP/MAP in line with IMAP, and ensure common reporting. Potential integration of data-sets in the future could be considered with EMODnet-Chemistry.

Key messages

- assessment is possible and key nutrient concentrations are in ranges characteristic for coastal areas and in line with the main processes undergoing in the interested area,
- criteria for reference condition and boundaries for key nutrients in the water column have to be built and harmonised through the Mediterranean region.

Knowledge gaps

At the eutrophication hot spots in the Mediterranean Sea a comprehensive key nutrient concentrations in the water column trend analysis would be beneficial. Significant trends need to be detected from long time series that are able to capture nutrient concentrations changes in coastal waters as the analysis of short time series can erroneously lead to interpret some spatial patterns produced by random processes nutrients concentration trends. For that reason, data availability should be improved.

A possible approach is to use data stored in other databases were some of the Mediterranean countries regularly contribute.

Criteria for reference condition and boundaries for key nutrients in the water column have to be built and harmonised through the Mediterranean region. Data availability have to be improved. A possible approach is to use data stored in other databases were some of the Mediterranean countries regularly contribute.

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Ecological Objective 5 (EO5): Eutrophication

EO5: Common Indicator 14. Chlorophyll-a concentration in water column

GENERAL

Reporter:	UNEP/MAP/MED POL
Geographical scale of the assessment:	Regional, Mediterranean Sea
Contributing countries:	Albania, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Montenegro, Morocco, Slovenia, Spain, Tunisia, Turkey
Mid-Term Strategy (MTS) Core Theme	1-Land and Sea Based Pollution
Ecological Objective	EO5. Human-induced eutrophication is prevented, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algal blooms and oxygen deficiency in bottom waters
IMAP Common Indicator	CI14. Chlorophyll-a concentration in water column (EO5**)**
Indicator Assessment Factsheet Code	EO5CI14

RATIONALE/METHODS

Background

Eutrophication is a process driven by enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, leading to: increased growth, primary production and biomass of algae; changes in the balance of nutrients causing changes to the balance of organisms; and water quality degradation (IMAP, 2017). Seawaters depending on nutrient loading and phytoplankton growth are classified according to their level of eutrophication. Low nutrient/ phytoplankton levels characterize oligotrophic areas, water enriched in nutrients is characterized as mesotrophic, whereas water rich in nutrients and algal biomass is characterized as eutrophic. The Mediterranean is one of the most oligotrophic seas in the world and most of its biological productivity takes place in the euphotic zone (UNEP, 1989, UNEP/MAP, 2012). The development of nutrient/phytoplankton concentration scales has been a difficult task for marine scientists because of the seasonal fluctuations of nutrient and phytoplankton concentrations, phytoplankton patchiness and small-scale eutrophication phenomena. Although long-term scientific research (UNEP/FAO/WHO1996; Krom *et al.*, 2010) has shown that the main body of the Mediterranean Sea is in good condition, there are coastal areas, especially in enclosed gulfs near big cities in estuarine areas and near ports, where marine eutrophication is a serious threat.

In the Mediterranean Sea, the Barcelona Convention adopted in 1976 was the first legally binding instrument for its environmental protection and included a number of protocols, such as the pollution land-based sources (LBS) Protocol. Since 2000, other international and national policies, such as the European Water Framework Directive (WFD) and the European Marine Strategy Framework (MSFD) are developing programmes, which sums to its environmental protection at sub regional levels and collaborate with UNEP/MAP. At the 19th Ordinary Meeting in 2016 of the Contracting Parties to the Barcelona Convention (Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean and its Protocols) adopted the Integrated Monitoring and Assessment Programme (IMAP) of the Mediterranean Coast and Sea and Related Assessment Criteria, which includes the targets to achieve the Good Environmental Status (UNEP/MAP, 2016). The initial targets of GES for IMAP Common Indicator 14 are reflecting the scope of the current MED POL Programme and the availability of suitable agreed assessment criteria.

In the Mediterranean area, eutrophication is caused by both regional sources such as urban effluents, industrial discharges, and aquaculture activities as well as transboundary components such as agricultural runoffs, riverine outflows, and airborne nutrient deposition. The variables related to eutrophication are influenced by water circulation and to regional sources of pollution including eutrophication (UNEP, 2003).

The highly populated coastal zone in the Mediterranean and the riverine input from a draining area of 1.5 10^6 km^2 (Ludwig *et al.*, 2009) induce eutrophic trends in coastal areas. The offshore waters of the Mediterranean have been characterized as extremely oligotrophic with a clear gradient toward east (Turley, 1999). Eutrophication and oligotrophy in the Mediterranean is illustrated as chlorophyll *a* distribution in remote sensing imagery (Figure 1).

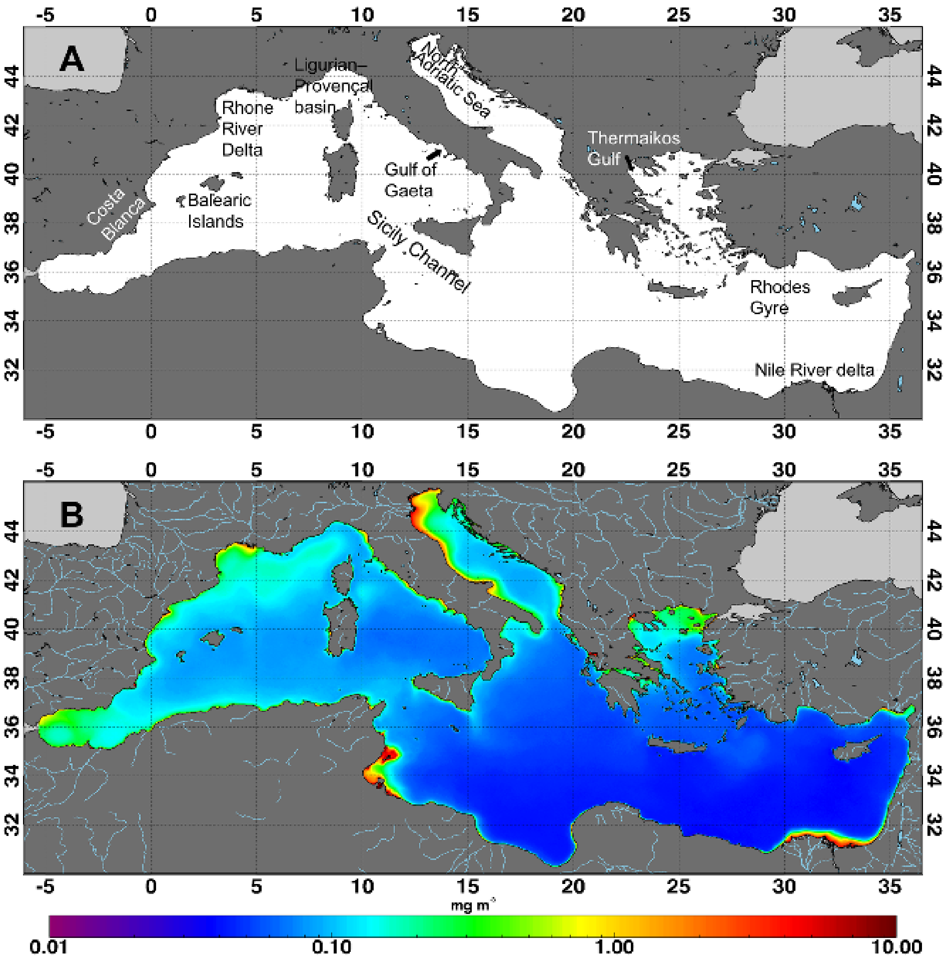

Figure 1. The Mediterranean basin and its chlorophyll *a* concentration pattern. (A) Geographic regions (B) chlorophyll a concentration (µg L^{-1}) climatology over the Mediterranean Sea relative to 1998–2009 time period. From: Colella *et al.*, 2016.

The assessment of eutrophication is a complex matter, since, in the case of coastal environments, "abundance and composition of phytoplankton are characterized by a high degree of space-time variability: the complexity of these areas, due mainly to the high variability of environmental factors and to the responses of the communities, make it difficult to define a regular annual cycle of phytoplankton" (Pugnetti *et al*., 2007. In Italian). This statement clearly indicates that in the field of eutrophication the statistical requirement is essential for an acceptable assessment strategy. The applied WFD requirements in regards of Coastal Water types reference conditions and boundaries in the Mediterranean were developed as a good compromise towards this challenge.

Assessment methods

UNEP/MAP's Pollution Programme (MEDPOL) has a monitoring programme since 1999, based on the contribution of data from Mediterranean countries, including chlorophyll-a. MEDPOL monitoring data was used for this assessment, noting that there are several gaps in the database where there has been inconsistent data reporting from each country over the years.

Coastal Water types reference conditions and boundaries for chlorophyll-a in the Mediterranean were agreed and adopted in the IMAP decision of 2016. (UNEP/MAP, 2016). These criteria were applied for the first time applied on the data available for the Mediterranean through the MED POL Database.

For eutrophication, it is accepted that surface density is adopted as a proxy indicator for static stability of a coastal marine system. More information on typology criteria and setting is presented in document UNEP(DEPI)/MED WG 417/Inf.15:

- Type I — coastal sites highly influenced by freshwater inputs,
- Type IIA — coastal sites moderately influenced not directly affected by freshwater inputs (Continent influence),
- Type IIIW — continental coast, coastal sites not influenced/affected by freshwater inputs (western Basin),
- Type IIIE — not influenced by freshwater input (Eastern Basin),
- Type Island — coast (western Basin).

Coastal water type III was split in two different sub basins, the western and the Eastern Mediterranean s, according to the different trophic conditions and is well documented in literature. It is recommended to define the major coastal water types in the Mediterranean for eutrophication assessment (applicable for phytoplankton only; Table 1).

Table 1. Major coastal water types in the Mediterranean

	Type I	Type IIA, IIA Adriatic	Type IIIW	Type IIIE	Type Island-W
σ_t (density)	<25	25<d<27	>27	>27	All range
salinity	<34.5	34.5<S<37.5	>37.5	>37.5	All range

With the view to assess eutrophication, it is recommended to rely on the classification scheme on Chlorophyll *a* concentration (µg L^{-1}) in coastal waters as a parameter easily applicable by all Mediterranean countries based on the indicative thresholds and reference values presented in Table 2.

Table 2. Coastal Water types reference conditions and boundaries in the Mediterranean

Coastal Water Typology	Reference conditions of Chl*a* (µg L^{-1})		Boundaries of Chl*a* (µg L^{-1}) for G/M status	
	G_mean	90% percentile	G_mean	90% percentile
Type I	1,4	3,33* - 3,93**	6,3	10* - 17,7**
Type II-FR-SP		1,9		3,58
Type II-A Adriatic	0,33	0,8	1,5	4,0
Type II-B Tyrrhenian	0,32	0,77	1,2	2,9
Type III-W Adriatic			0,64	1,7
Type III-W Tyrrhenian			0,48	1,17
Type III-W FR-SP		0,9		1,80
Type III-E		0,1		0,4
Type Island-w		0,6		1,2 – 1,22

* applicable to Gulf of Lion

** applicable to Adriatic

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In this assessment, aware that for most of the northern Mediterranean countries data are available also in other databases (i.e. EEA, EIONET, EMODnet), only datasets obtained from the MED POL Database for chlorophyll *a* were used. Data availability by country were as follows: Albania (2005-2006), Bosnia and Herzegovina (2006-2008), Croatia (2009, 2011-2014), Cyprus (1999-2015), Egypt (2009, 2010), France (2009-2010, 2011, 2012), Greece (2004-2006), Israel (2001-2012), Montenegro (2008-2012, 2014-2015), Morocco (2006, 2007), Slovenia (1999-2013, 2015-2016), Tunisia (2002-2013), Turkey (2005-2009, 2011, 2013).

RESULTS

Results and Status, including trends

The trophic status of the Mediterranean Sea is controlled by the highly populated coastal zone and the riverine input from a draining area of 1.5 million km^2 (Ludwig *et al.* 2009) that induce eutrophic trends in coastal areas. The blue offshore waters of the Mediterranean have been characterized as extremely oligotrophic with an increasing tendency for oligotrophy eastwards (Turley 1999). Eutrophication and oligotrophy in the Mediterranean is illustrated as chlorophyll *a* distribution in remote sensing imagery (Figure 1). This is due to the low nutrient content of EMS; the maximum concentrations recorded for nitrate were about 6 μmol L^{-1}, for phosphate 0.25 μmol L^{-1}, and for silicate 10–12 μmol L^{-1}, with the nitrate to phosphate ratio (N/P) >20 and in deep waters about 28:1, the EMS has been characterized as the largest phosphorus-limited body of water in the global ocean.

The coastal area of the southeastern part of the Mediterranean shows clearly eutrophic trends. Although the River Nile is the major water resource in the area, its freshwater fluxes are becoming limited because of the Aswan Dam and increasing trends in anthropogenic water use in the lower Nile. Eutrophic conditions in the area are mainly induced by the sewage effluents of Cairo and Alexandria. The Northern Aegean shows mesotrophic to eutrophic trends [2]. This can be explained by the river inputs from northern Greece and the water inflow from the nutrient rich Black Sea (Karydis and Kitsiou, 2012).

The nutrient regime and primary productivity in the Western Mediterranean Sea (WMS) are relatively higher compared to the EMS. There is limited nutrient supply through the Strait of Gibraltar due to different nutrient concentrations between the Atlantic and Mediterranean waters. The surface water entering from the Atlantic carry nutrients directly available for photosynthesis (EEA 1999) but at low concentrations. The phosphorus (phosphate) concentrations in the inflowing waters ranges from 0.05 to 0.20 μmol L^{-1}, the nitrogen (nitrate) concentrations being about 1–4 μmol L^{-1}, and the silicon (silicate) concentration is about 1.2 μmol L^{-1} (Coste *et al.* 1988). The nutrients of the surface layer are reduced as they propagate eastwards due to mixing with poor basin water and nutrient use by

[2] Eutrophic trends are related to the changes of impact of nutrients (pressures). They can be upward or downward. Consult Colella te al., 2016 for details of Mediterranean trend from satellite.

phytoplankton. However, the primary productivity of the main WMS, away from the coastal areas and influenced by rivers and urban agglomerations, is still higher than the primary productivity in the EMS.

The main coastal areas in the Mediterranean which are historically known to be influenced by natural and anthropogenic inputs of nutrients are the Gulf of Lions, the Gulf of Gabès, the Adriatic, Northern Aegean and the SE Mediterranean (Nile–Levantine). A recent work on nutrient and phytoplankton distribution along a large-scale longitudinal east–west transect (3 188 km) of the Mediterranean Sea extended over nine stations was published by Ignatiades et al. (2009). The results confirmed the oligotrophic character of the area and the nutrient and chlorophyll gradient characterized by decreasing concentrations from Gibraltar to the sea of Levantine. Phosphate maxima ranged from 0.05 to 0.26 μmol L^{-1}, nitrate from 1.87 to 4.04 μmol L^{-1}, chlorophyll *a* (chl*a*) from 0.39 to 0.96 μg L^{-1}.

The results of assessment and status of chlorophyll *a* concentration in the water column are presented on Figs 2-7 showing a rather limited figure of the Mediterranean region. The main reason is the data availability and quality. In Figure 2 it is clearly visible that for the great part of the region data are missing. The implementation of water type criteria for the purpose of IMAP are also limited. Even a rather weak criteria (10 samples in 10 years in surface layer - <= 10 m) were adopted the data availability for assessment were low.

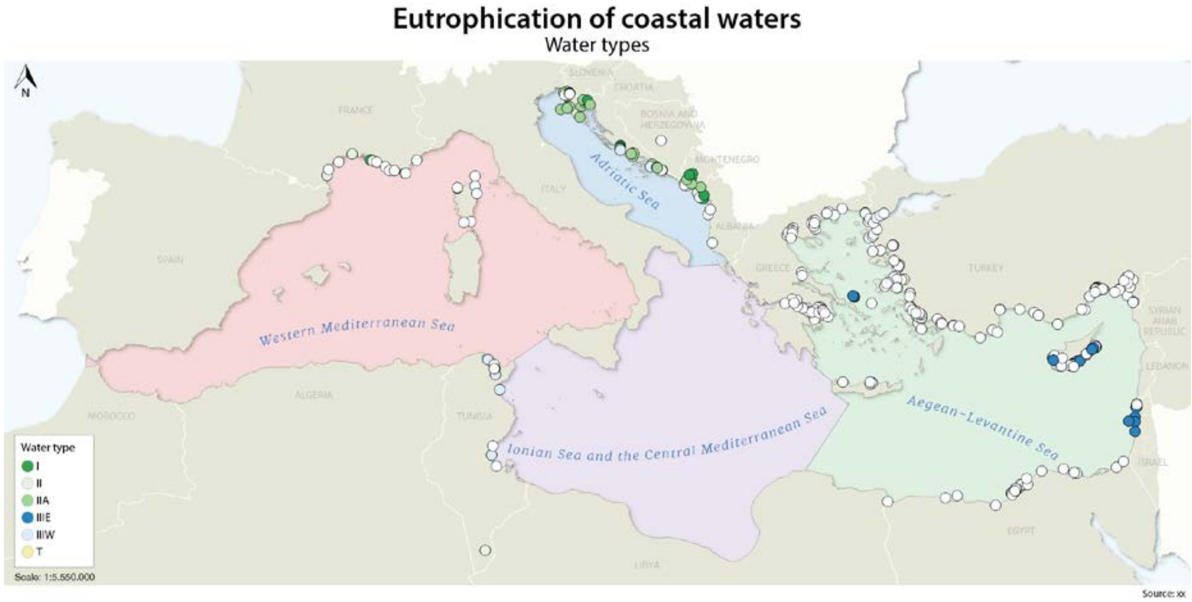

Figure 2. Stations in the Mediterranean region for which eutrophication parameter were sampled. Also are shown the water types (applicable for phytoplankton; IMAP. 2017) were minimal statistical requirements were satisfied (10 samples in the last 10 years and in the surface layer, <= 10 m)

On Figs 3-7 assessment data for all four sub-regions applying the Coastal Water types reference conditions and boundaries in the Mediterranean (applicable for phytoplankton; IMAP. 2017) are presented. For the Western Mediterranean Sea sub-region (Figure 3) only a limited set of data for France (from 2009 and 2012) were assessed indicating that none of the stations in the Golf of Lyon were in moderate state.

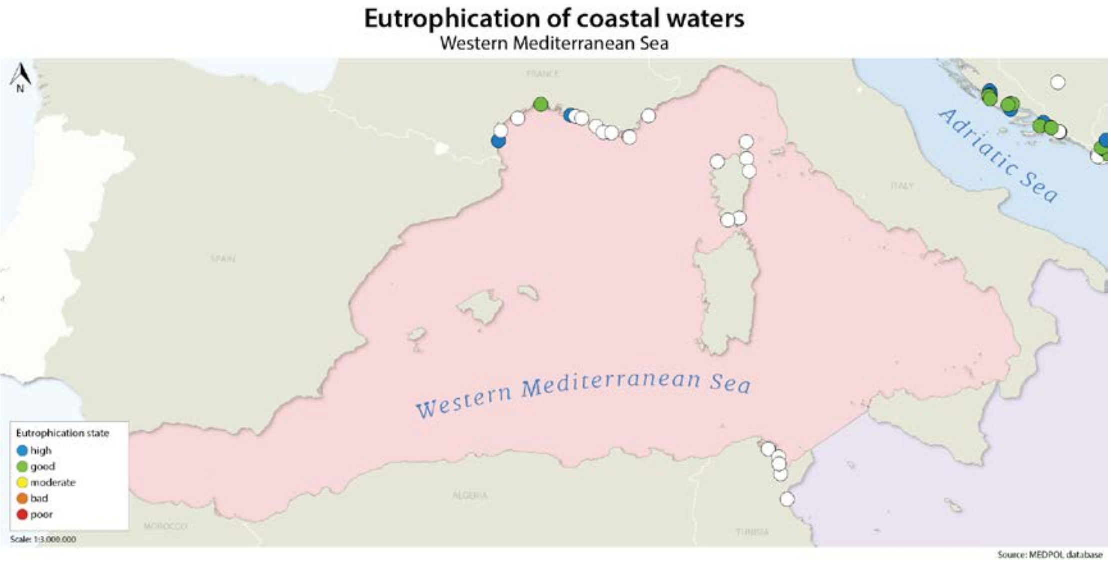

Figure 3. Stations in the Western Mediterranean Sea sub-region for which eutrophication were assessed. Coastal Water types reference conditions and boundaries in the Mediterranean were applied (applicable for phytoplankton; IMAP. 2017) for were minimal statistical requirements were satisfied (10 samples in the last 10 years and in the surface layer, <= 10 m)

In the Adriatic Sea sub-region (Figs 4-5) only the eastern part was assessed (Slovenia, Croatia and Montenegro). The applied criteria show that all the stations in the assessed area in good status in relation to the criteria. The Box and Whisker plot (Figure 5) shows even more details. Such a graphical representation is very useful for a geographical assessment and represent a good potential for the time series analysis.

Figure 4. Stations in the Adriatic Sea sub-region for which eutrophication were assessed. Coastal Water types reference conditions and boundaries in the Mediterranean were applied (applicable for phytoplankton; IMAP. 2017) for were minimal statistical requirements were satisfied (10 samples in the last 10 years and in the surface layer, <= 10 m)

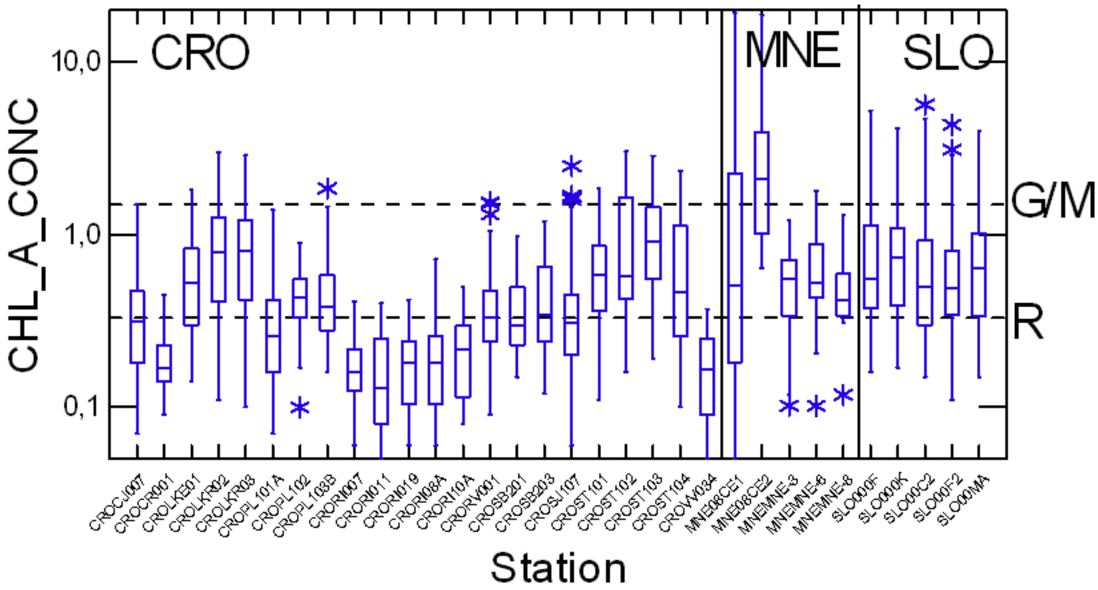

Figure 5. Box and whisker plot for chlorophyll *a* concentration in the Adriatic Sea sub-region (water type IIA) for which coastal Water types reference conditions and boundaries in the Mediterranean were applied (applicable for phytoplankton; IMAP. 2017) for Croatia (CRO), Montenegro (MNE) and Slovenia (SLO).

For the Ionian Sea and the Central Mediterranean Sea sub-region (the assessment was not performed as insufficient data were available.

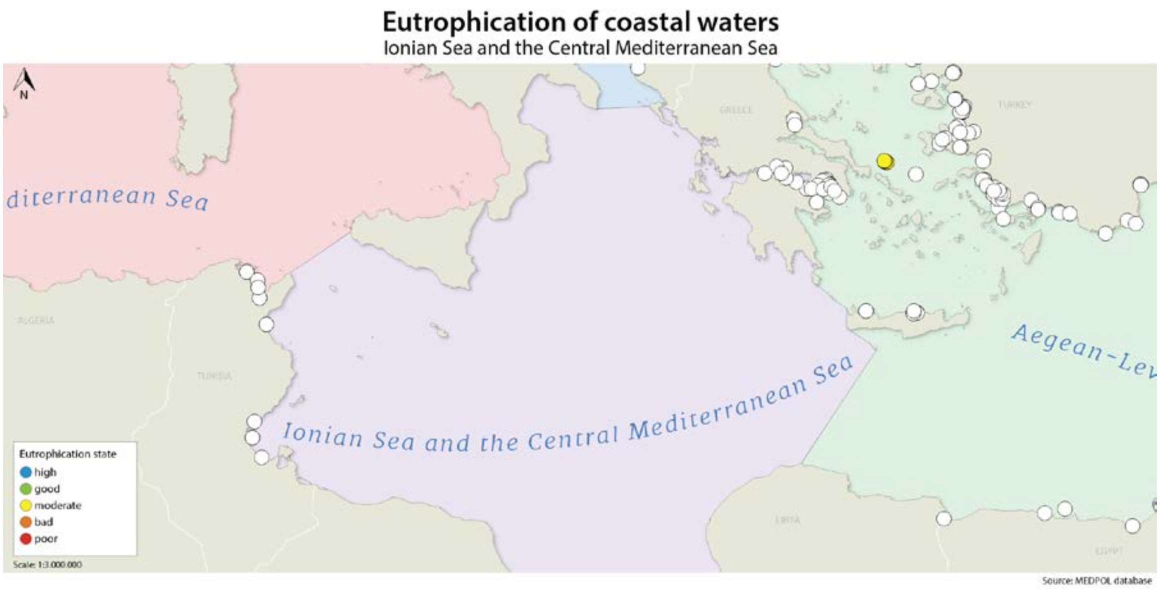

Figure 6. Stations in the Ionian Sea and the Central Mediterranean Sea subregion for which eutrophication were assessed. Coastal Water types reference conditions and boundaries in the Mediterranean were applied (applicable for phytoplankton; IMAP. 2017) for were minimal statistical requirements were satisfied (10 samples in the last 10 years and in the surface layer, <= 10 m)

In the Aegean-Levantine Sea subregion (Figs 7-8) the assessed country were Cyprus and Israel, and partially data for Turkey (Mersin area) were also used. The applied criteria (Water type IIIE) showed that practically all the stations in the Cyprus area are at list in good status. The Box and Whisker plot (Fig. 8) shows even more details. The data for Israel and Mersin area (Turkey) indicate that the areas were in moderate state. Probably the criteria for Water type IIIE in this area are too rigorous because it is close to the coast and ports.

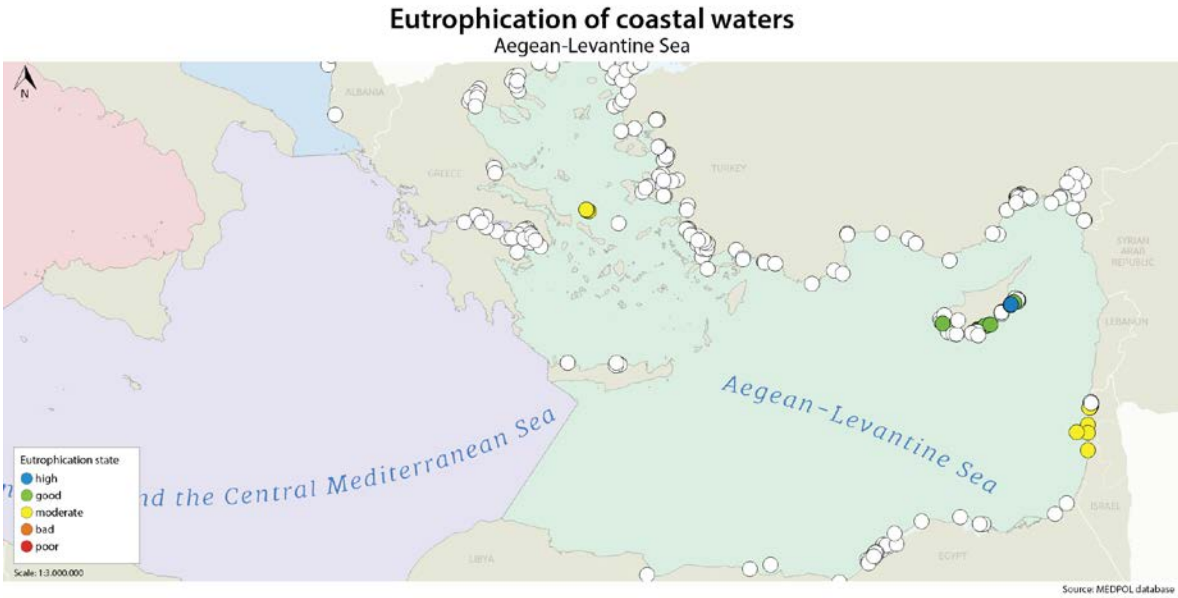

Figure 7. Stations in the Aegean-Levantine Sea sub-region for which eutrophication were assessed. Coastal Water types reference conditions and boundaries in the Mediterranean were applied (applicable for phytoplankton; IMAP. 2017) for were minimal statistical requirements were satisfied (10 samples in the last 10 years and in the surface layer, <= 10 m)

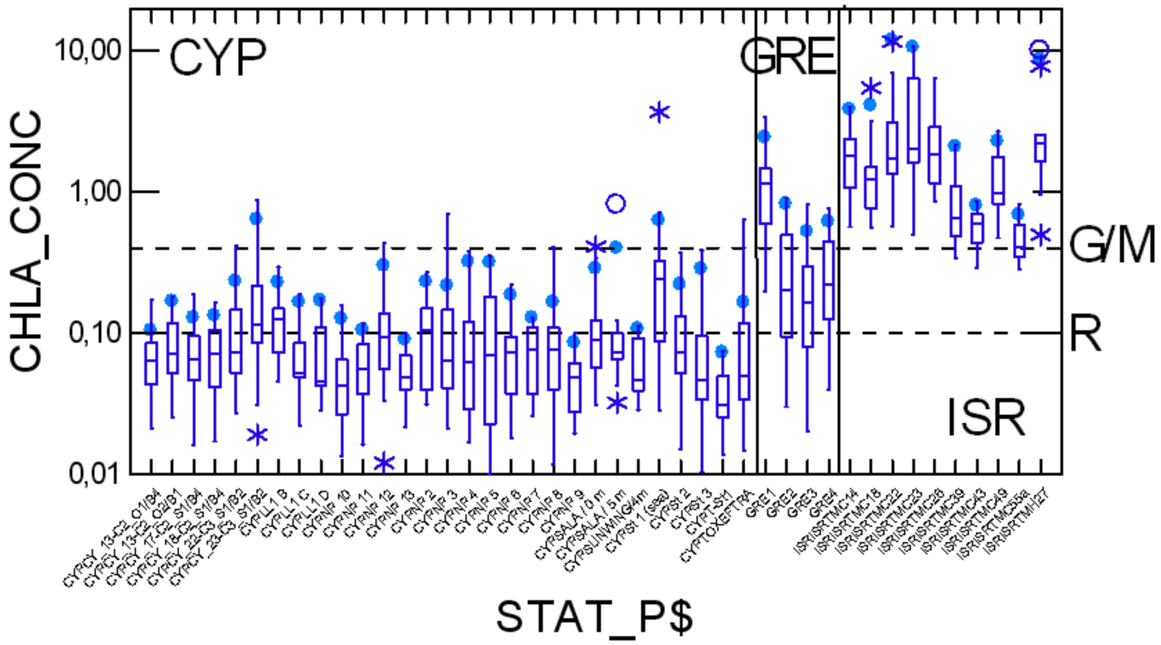

Figure 8. Box and whisker plot for chlorophyll *a* concentration in the Aegean-Levantine Sea sub-region (water type IIIE) for which coastal Water types reference conditions and boundaries in the Mediterranean were applied (applicable for phytoplankton; IMAP. 2017). The blue dots represent the 90-percentile value for Cyprus (CYP), Greece (GRE) and Israel (ISR)

At the eutrophication hot spots in the Mediterranean Sea a comprehensive chlorophyll *a* trend analysis would be beneficial. Significant chlorophyll *a* trends need to be detected from long time series that are able to capture biomass changes in coastal waters as the analysis of short time series can erroneously lead to interpret some spatial patterns produced by random processes as chlorophyll *a* concentration trends.

Satellite synoptic measurements for the estimation of chlorophyll *a* concentration trends have the potential to detect anomalous, local biogeochemical processes and to assess the different applications of environmental regulations. Recent use of this data (Colella *et al.*, 2016) allowed for a consistent monitoring of biogeochemical issues in the Mediterranean basin. At large scale, positive trends off the South-East Spanish coast, in the Ligurian–Provençal basin, and in the Rhodes Gyre region, while an intense negative trend in the North Adriatic Sea, off the Rhone River mouth, and in the Thermaikos Gulf (Aegean Sea) were detected.

This potential to assess eutrophication problems is welcome, however, the satellite framework might need of larger, multi-sensor datasets and it surely requires to be combined with the analysis of in situ supplementary, biogeochemical data.

CONCLUSIONS

The trophic status of the Mediterranean Sea is controlled by the highly populated coastal zone and the riverine input from a draining area. Offshore waters of the Mediterranean have been characterized as extremely oligotrophic with an increasing tendency for oligotrophy eastwards. The Eastern Mediterranean Sea (EMS) is still the most oligotrophic area of the whole Mediterranean basin, and the largest phosphorus-limited body of water in the global ocean.

The coastal area of the southeastern part of the Mediterranean shows clearly eutrophic trends. Although the River Nile is the major water resource in the area, its freshwater fluxes are getting limited because of the Aswan Dam and increasing trends in anthropogenic water use in the lower Nile. Eutrophic conditions in the area are mainly induced by the sewage effluents of Cairo and Alexandria. The Northern Aegean shows mesotrophic to eutrophic trends explained by the river inputs from northern Greece and the water inflow from the nutrient rich Black Sea.

The nutrient regime and primary productivity in the Western Mediterranean Sea (WMS) are relatively higher compared to the EMS. However, the primary productivity of the main WMS, away from the coastal areas and influenced by rivers and urban agglomerations, is still higher than the primary productivity in the EMS.

The main coastal areas in the Mediterranean which are historically known to be influenced by natural and anthropogenic inputs of nutrients are the Gulf of Lions, the Gulf of Gabès, the Adriatic, Northern Aegean and the SE Mediterranean (Nile–Levantine).

The available data show that in areas were assessment is possible the IMAP assessment criteria for eutrophication based on CI14 (Chlorophyll *a* concentration in the water column) are applicable and confirm the main status of eutrophication in the coastal area. In term of GES achievement in these areas (Eastern Adriatic and Cyprus) it is maintained.

Coastal Water type reference condition and boundaries for CI14 (Chlorophyll *a* concentration in the water column) have to be harmonised through the south Mediterranean region which has not yet participated in the assessment effort. The assessment can also help to identify areas were the criteria have to be improved. Of great help will be the implementation of a sampling strategy with simplified approach in monitoring design and data handling.
Satellite synoptic measurements for the estimation of chlorophyll *a* concentration trends have the potential to detect anomalous, local biogeochemical processes and to assess the different applications of environmental regulations.

Key messages

- offshore waters of the Mediterranean have been characterized as extremely oligotrophic with an increasing tendency for oligotrophy eastwards,
- the main coastal areas in the Mediterranean with permanent eutrophic trends are the Gulf of Lions, the Adriatic, Northern Aegean, and the SE Mediterranean (Nile–Levantine), and
- the available data show that in areas were assessment is possible the IMAP assessment criteria for eutrophication based on CI14 (Chlorophyll *a* concentration in the water column) are applicable and confirm the main status of eutrophication in the coastal area.

Knowledge gaps

There are no main gaps identified in the Mediterranean Sea concerning the assessment of the Common Indicator 14. However, significant chlorophyll *a* trends need to be detected from long time series that are able to capture biomass changes in coastal waters, and for that purpose data availability have to be improved. A possible approach is to use data stored in other databases were some of the Mediterranean countries regularly contribute. Satellite synoptic measurements for the estimation of chlorophyll *a* concentration trends have the potential to detect anomalous, local biogeochemical processes and to assess the different applications of environmental regulations.

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