The Mediterranean Large Marine Ecosystem - Prioritization of the transboundary problems, analysis of impact and causes

Final report, 12 July 2022

MED PROGRAMME

gef | UN environment programme | Mediterranean Action Plan Barcelona Convention

MED POL | Regional Activity Centre for Sustainable Consumption and Production | Plan Bleu

1.1 Reducing Pollution from Harmful Chemicals and Wastes in Mediterranean Hot Spots and Measuring Progress to Impacts

This report has been elaborated in the framework of the GEF Mediterranean Sea Programme (MedProgramme).

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Table of contents

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Table of illustrations

FIGURES

TABLES

I. Introduction

A. CONTEXT

The current study on the long-term global regulations of the Mediterranean Large Marine Ecosystem (LME) is a component of the update of the Transboundary Diagnostic Analysis (TDA) of the Mediterranean Sea. It is undertaken in the framework of the Global Environment Facility (GEF) MedProgramme Child Project 1.1. The objectives of MedProgramme are to accelerate the implementation of the agreed-upon priority actions, with the aim to reduce the major transboundary environmental stresses affecting the Mediterranean Sea and its coastal areas, while strengthening climate resilience and water security and improving the health and livelihoods of coastal populations. The current study also contributes to the MED 2050 Programme (MED 2050), which looks into possible visions and scenarios of the future of the Mediterranean by 2050, building solid and realistic transition paths towards a sustainable and inclusive future.

B. OBJECTIVES

The overarching objectives of the TDA are to identify, quantify, and set priorities for environmental problems that are transboundary in nature, as a first step to support the development of new Strategic Action Programmes (SAPs) beyond 2023. Within this context, the specific objective of this study was to **identify and prioritize the long-term global regulation problems facing the Mediterranean Large Marine Ecosystem (LME)**, laying out the foundations of an analysis and assessment of the long-term global regulation problems. This was done by gathering and interpreting information on the direct and indirect environmental and socio-economic impacts, and analyzing the immediate, underlying, and root causes for the transboundary issues[1], in full accordance with the GEF TDA methodology (GEF IW: Learn (2020))[2]. The outcomes will feed directly into sub-chapter *Long-term global regulation affecting the Mediterranean LME* of the TDA.

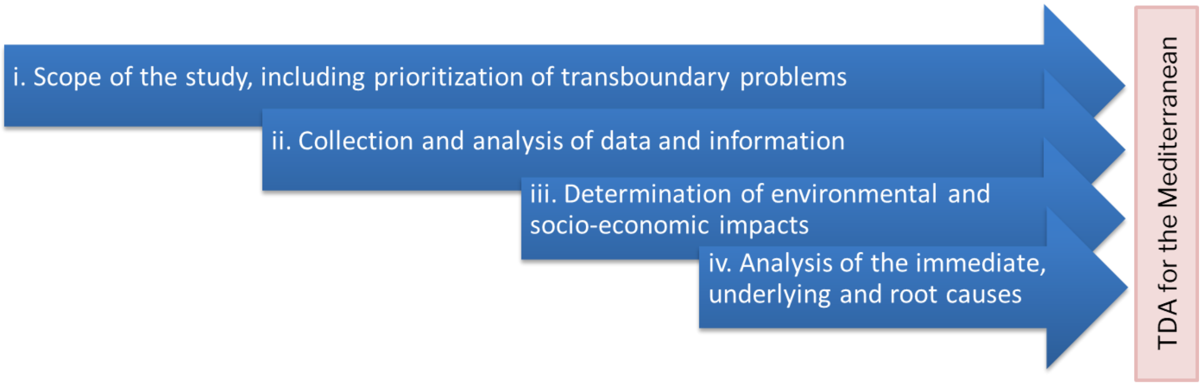
[1] Note that for the purpose of this assessment the terms “problem” and “issue” are used interchangeably

[2] GEF IW:Learn (2020). Transboundary Diagnostic Analysis/Strategic Action Programme Manual. TDA-SAP Methodology (https://iwlearn.net/manuals/methodologies)

II. Methodology

The approach followed in the development of this assessment was structured along four tasks (Figure 1).

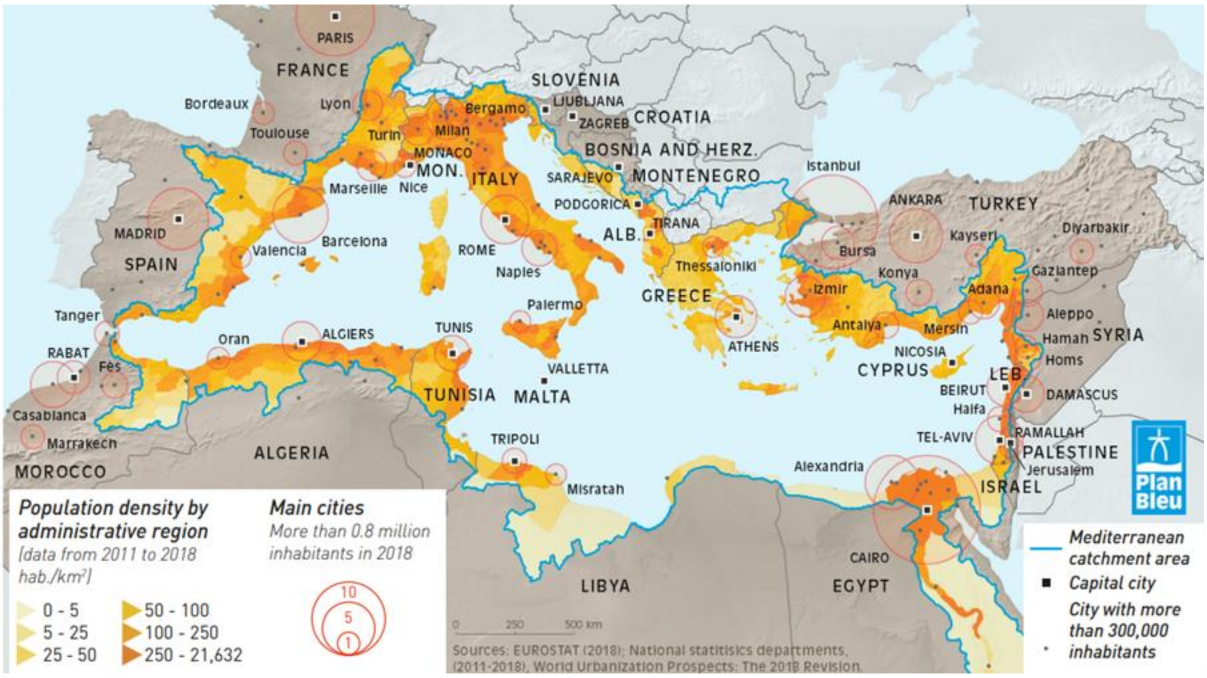
Figure 1. Schematic showing the four methodological tasks



- **Scoping, including prioritization of transboundary problems**

The geographical delineation of the study was established as the "end part of the water cycle/system" at the coastal, i.e. the coastal hydrological basins, and marine zones (Figure 2). This is in line with the remit of UNEP/MAP and covering the riparian Mediterranean countries that are Contracting Parties of the Barcelona Convention.

Figure 2. Map of the Mediterranean region showing the geographical delineation of the study, marked by the coastal hydrological basins on land and the Mediterranean LME



The identification and qualification of transboundary issues took into consideration the nine issues previously identified and presented in the TDA Objectives, Milestones and Work Plan report (Annex 1). However, the prioritization step was limited to the five sub-issues identified under the issue in question: *Long-term global regulation affecting the Mediterranean LME* (see Chapter 3). These are:

i. Changes in circulation patterns
ii. Seawater warming
iii. Acidification
iv. Changes in biogeochemical cycling
v. Waste overload

Prioritization was done against the following set of agreed criteria:

a. Transboundary nature– geographical and temporal scale
b. Future risk of the problem
c. Relationship with other transboundary problems
d. Sufficient scientific evidence to qualify the sub-issue
e. Irreversibility of the problem
f. Link to achieving the Sustainable Development Goals (SDGs) in the region

Criteria a, b, c and e were taken from GEF IW: learn (2020), while d and f were tailored to the specificities of the Mediterranean LME. The set of criteria was agreed upon with Plan Bleu and the 6th UNEP/MAP GEF MedPCU - TDA Group Meeting (February 2022). They provide a systematic and objective way to characterize the sub-issues. Based on the above set of criteria, a score was assigned to each sub-issue, ranging between 0 (no importance), 1 (low importance), 2 (moderate importance) and 3 (high importance) indicating the relevance of the sub-issue from the perspective of the present day and perceived importance in the future[3]. The outcomes of this step are elaborated in Chapter 3.

- **Collection and analysis of data and information**

Existing data and information were collected and analyzed in an interdisciplinary and holistic manner, with the aim to interpret information on the environmental impacts and socio-economic consequences of the five selected sub-issues under the issue - *Long-term global regulation affecting the Mediterranean LME*. The aim of this data stock-taking exercise was to identify high-quality datasets with quality assurance defined, as well as gaps and unknowns, in order to provide a sound baseline for the TDA (Chapter 4). Whenever possible, regular and established dataflows and databases, populated with long-term data (from 1950 onwards), were prioritized over project-based or ad-hoc data sources. This task gathered data and information from different workstreams and assessments of the region (Annex 2).

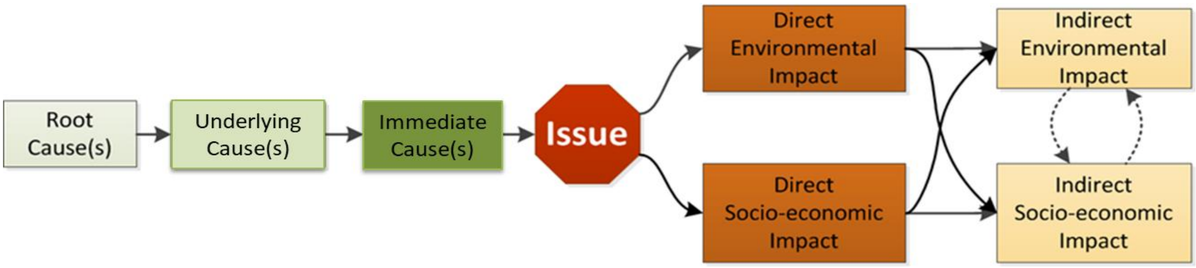
The outcomes also informed the selection of a set of Monitoring and Evaluation (M&E) indicators. The M&E indicators cover different types, including stress reduction and environmental status indicators, and are proposed as a long-term monitoring tool to measure the progress for the SAPs.

- **Determination of the environmental and socio-economic impacts**

The collected data and information were analyzed and interpreted to determine and assess the environmental and socio-economic impacts of the five selected sub-issues under the issue - *Long-term global regulation affecting the Mediterranean LME*. The results of this task are presented in Chapter 5. The analysis was guided by the downstream (right hand) side of the “Causal Chain Analysis” (CCA) (Figure 3), an analytical framework proposed by GEF IW: Learn for the assessment of transboundary issues, their causes and impacts, including positive/negative, direct/indirect environmental and socio-economic impacts. Due to the limited time and resources, this task did not include the development of new economic valuation of ecosystem services or benefits assessments “from scratch” but sourced its underlying information from existing bibliography.

[3] Note that the assessment of importance of the sub-issues, including their impacts, in the future is only done qualitatively and does not take into consideration future scenarios.

Figure 3. Generic flow-diagram type Causal Chain Analysis (CCA) showing the identification of the direct/indirect environmental and socio-economic impacts, and their relationships



- **Analysis of the immediate, underlying, and root causes**

The CCA was primarily applied to the identification and analysis of the immediate, underlying, and root causes of the five transboundary sub-issues (left hand side of the CCA – Figure 3).

- *Immediate causes* are usually the direct technical causes of the problem (e.g. enhanced nutrient inputs). They are often most tangible, with distinct areas of impact and therefore most straightforward to locate, quantify and prioritize.
- *Underlying causes* are broadly defined as underlying resource uses and practices, and their related social and economic causes, including governance-related causes. The analysis of underlying causes requires the identification of the related sectors and the governance framework within which they operate.
- *Root causes* are often related to fundamental aspects of macro-economy, demography, consumption patterns, environmental values, and access to information and political processes.

The three types of causes may not necessarily be distinct from one another. In the simplified CCA (Figure 3), they are schematically represented as a linear chain. However, in reality there may be links between causes and their effects, or the same cause leading to several different effects. Activities in different sectors (e.g. fisheries, industry etc.) may result in specific causes and impacts but these are likely to interact with other sectors. As part of this task, immediate, underlying and root causes, including sectors affecting the long-term regulation of the Mediterranean LME were identified, together with information on linkages between different levels and scales.

III. Qualification and prioritization of the long-term global regulation sub-issues affecting the Mediterranean LME

The analysis presented here focuses on the five sub-issues under the issue - *Long-term global regulation affecting the Mediterranean LME*. In this context, the term and scope of 'long-term global regulation' is understood to be the long-term maintenance of the physical, chemical or biological structural conditions related to the *natural* and *systemic* regulation and functioning of the Mediterranean LME. Under these conditions, the LME is naturally functioning and capable of providing the full spectrum of ecosystem services, which may be subject to transformations due to both natural and anthropogenic causes (e.g. climatic variability and change). Hence, "regulation" is not intended in terms of laws and legislation but rather in terms of system dynamics. For the purpose of this report, long-term global regulation processes can be associated with the regulating and maintenance-type ecosystem services and corresponding functions, as presented below (Table 1).

Table 1. Overview of regulation and maintenance-type ecosystem services that are related to the long-term global regulation of the Mediterranean LME

Ecosystem service type	Function	Identified sub-issues
Mediation of flows (e.g. coastline stability, connectivity, habitats protection)	Water circulation	Changes in circulation patterns, including thermohaline circulation, marine cold engines, links to the hydrological cycle and oceanographic processes
Maintenance of physical, chemical and biological conditions (e.g. CO_2 sequestration, pH buffering)	Climate regulation, including carbon sequestration and storage	Seawater warming, including marine heat waves
		Acidification
	Biogeochemical regulation	Biogeochemical cycling, including sediment, nutrient and phytoplankton dynamics, oxygen depletion
Mediation of waste, toxics and other nuisances (e.g. bio-remediation, sound attenuation)	Dilution, absorption and breakdown of waste from sea- and land-based sources	Waste overload

Source: Adapted and elaborated from the Common International Classification of Ecosystem Services (CICES) framework (Haines-Young and Potschin, 2013)

In line with the above definition, the qualification of the scope and components of the long-term global regulation problems facing the Mediterranean LME focused on the five following "sub-issues":

i. Changes in circulation patterns
ii. Seawater warming
iii. Acidification
iv. Changes in biogeochemical cycling
v. Waste overload

The selected sub-issues are fully in line with the concept of planetary boundaries[4]. First introduced by Rockstrom et al. (2009), this approach defines "the safe operating space for humanity", maintained through the Earth's regulatory capacity, biophysical subsystems and processes. When human activities exceed a level that disrupts the systems that

[4] The nine planetary boundaries identified by Rockstorm et al. (2019) are: 1. **Climate change**; 2. Change in biosphere integrity (biodiversity loss and species extinction); 3. Stratospheric ozone depletion; 4. **Ocean acidification**; 5. **Biogeochemical flows (phosphorus and nitrogen cycles)**; 6. Land-system change (for example deforestation); 7. Freshwater use; 8. Atmospheric aerosol loading (microscopic particles in the atmosphere that affect climate and living organisms); 9. **Introduction of novel entities (e.g. organic pollutants, radioactive materials, nanomaterials, and micro-plastics)**. The planetary boundaries in **bold** link directly to the five sub-issues.

keep Earth in a desirable stable state, these boundaries are crossed leading to nonlinear and irreversible impacts and, in some cases, abrupt environmental changes and crises.

A. QUALIFICATION OF IDENTIFIED SUB-ISSUES

***Changes in circulation patterns**:* Water circulation is driven by ocean currents and the movement of water masses across the water column. It is the process that supports oceanographic connectivity, regulates water temperature and the exchange of oxygen, nutrients, sediments and other inorganic substances, setting the habitat conditions for living organisms.

During the past decade, the water masses of the Mediterranean Sea have experienced strong and fast increases in temperature and salinity, with deep water masses becoming saltier (MedECC, 2020). Deepwater is considered a stable medium, which allows for the precise quantification of trends in heat and salt content. Changes in temperature and salinity perturb the general thermohaline circulation[5] and may also lead to the impairment of deepwater formation, the so-called cold-water engines (Boero, 2014).

***Seawater warming**:* Since the beginning of the 1980s, average sea surface temperatures have increased throughout the Mediterranean basin (García-Martínez et al., 2017; Pastor et al., 2020; MedECC, 2020). This increase is marked by large sub-regional differences and stronger warming in the Eastern basins (Adriatic, Aegean, Levantine and north-east Ionian Sea). In addition, over the last decades "marine heatwaves", defined as periods of extremely high sea surface temperature that persist from days to months and can extend up to thousands of kilometers, have become more frequent, intense and spatially extensive (MedECC, 2020; Juza et al., 2022). Temperature anomalies, even of short duration, can dramatically impact Mediterranean biodiversity.

Acidification: Carbon sequestration by the oceans through the uptake of CO_2 and its transport and storage in deep-sea compartments is an important ecosystem service related to climate regulation. Carbon sequestration and storage act as a sink for atmospheric carbon, slowing climate change. The ocean generally holds about fifty times more CO_2 than the atmosphere (Bopp et al., 2017). The capacity of the Mediterranean Sea to absorb anthropogenic CO_2 per unit area is relatively higher than the global ocean due to its higher alkalinity and the ventilation of deep waters over shorter timescales (MedECC, 2020). As the levels of CO_2 in the atmosphere increase, the elevated uptake of CO_2 by the oceans causes acidification. The average surface pH change for the Mediterranean Sea is −0.08 units, same as for the global ocean. However, deepwaters of the Mediterranean Sea exhibit a larger anthropogenic change in pH than typical global ocean deepwaters due to faster ventilation times (Palmieri et al., 2015).

Changes in biogeochemical cycling[6]*:* The Mediterranean Sea is generally considered an oligotrophic basin, with primary productivity decreasing from the west to the east and some local regions of enhanced productivity e.g. the Alboran Sea or the northern zones of the Adriatic Sea. Primary productivity is influenced by circulation and vertical mixing that brings available nutrients to phytoplankton (Harley et al., 2006 in Richon et al., 2019). Changes in physical processes, such as the modification of vertical mixing, can have dramatic effects on the availability of nutrients to phytoplankton, on plankton community dynamics and ultimately on the productivity of the entire marine food webs. Temporal and spatial dynamics in marine productivity are also impacted by riverine and atmospheric inputs of nutrients. This implies that freshwater and wastewater management and agricultural practices, as well as damming and river discharge alterations could have downstream impacts on the total marine productivity of the Mediterranean Sea.

Waste overload: Oceans and seas provide the service of waste assimilation to some extent – the capacity to dilute, disperse, absorb, transform and remove harmful substances and waste (through biophysicochemical processes) when disposed into the marine environment. The concept of assimilative capacity was formulated around the use of the marine (or freshwater) environment to dispose of mainly organic wastes and associated effluents. Organic material, such as uncontaminated sewage sludge, inorganic forms of nutrients, and some acids, among other materials, may be neutralized by the sea (e.g. pH buffering). If this assimilative capacity exceeds the volume of waste received, the environment remains unharmed. If, however, the volume of waste exceeds the assimilative capacity, or the industrial and sewage wastes contain chemicals that are extremely toxic even at low concentrations (such as mercury, cryolite

[5] Thermohaline circulation describes the movement of ocean currents due to differences in temperature and salinity in different regions of water. Temperature and salinity change the density of water, resulting in the water to move accordingly. Source: https://energyeducation.ca/encyclopedia/Thermohaline_circulation

[6] Biogeochemical cycling, or more generally the cycling of matter, refers to the pathway by which a chemical substance cycles the biotic and the abiotic compartments of Earth. Source: https://en.wikipedia.org/wiki/Biogeochemical_cycle

and DDT[7]), including radioactive industrial wastes, this comes with significant harm to biodiversity and human health. At present, with many diverse pollution sources, ecosystems show a limited capacity to handle harmful substances and solid wastes (e.g. marine litter) and to assimilate them; therefore, leading to waste overloading with degradation and biodiversity loss as consequences.

The establishment and application of different and specific legislation (e.g. emission limit values (ELVs) - the maximum allowable concentration of a pollutant in an effluent discharged to the environment) safeguard the receiving environment from controlled discharges.

B. PRIORITIZATION OF SUB-ISSUES

The outcomes of the prioritization exercise of the five sub-issues against the prioritization criteria are shown in Table 2. As described in the Chapter 2, a score was assigned to each sub-issue on the basis of the literature review and expert judgment. This score indicates the *perceived* relevance of the sub-issue. For criteria scoring 1 (low) or 3 (high), a justification of the score attained was provided.

Table 2. Prioritization of sub-issues using the set of selected prioritization criteria (a. Transboundary nature–geographical and temporal scale; b. Future risk of the problem; c. Relationship with other transboundary problems; d. Sufficient scientific evidence to qualify the sub-issue; e. Irreversibility of the sub-issue; f. Link to achieving the Sustainable Development Goals (SDGs) in the region. Scoring: 1 (lower importance) or 3 (higher importance); 0 (not relevant)

	Criteria							
Sub-issue	a	b	C	d	e	f	Total score	Justification (for criteria scoring 1 or 3)
i. Changes in circulation patterns, including thermohaline circulation, the development of marine cold engines	3	2	2	3	2	1	**13**	a. Movement of water bodies is transboundary in nature and does not follow administrative boundaries d. Sufficient data (in situ & modelling) is available to qualify and quantify changes in circulation f. No direct link to specific SDGs
ii. Seawater warming, including marine heat waves	3	3	2	3	2	2	**15**	a. This increase is marked by large sub-regional differences and stronger trends in the Eastern basins (Adriatic, Aegean, Levantine and North-East Ionian Sea) b. It is virtually certain that sea surface warming will continue during the 21st century by 1 to 4°C depending on the scenario (low or high greenhouse gas emissions). It is also likely that deep waters will warm more in the Mediterranean than in other oceans in the world d. Sufficient data (in situ & modelling) is available to qualify and quantify changes in temperatures
iii. Changes in biogeochemical cycling, including nutrient, phytoplankton and sediment dynamics	3	3	1	1	2	3	**13**	a. All Mediterranean waters, even the deepest, are affected by ocean acidification driven by uptake of atmospheric CO_2 b. Despite significant uncertainties related to the measurements of pH changes, some studies have proposed that the Mediterranean Sea will experience amplified acidification relative to the global average surface ocean c. Mainly depending on the other transboundary issues d. Estimations of anthropogenic CO_2 concentrations from data-based approaches are limited and with large uncertainties. Resultant concentrations vary by more than a factor of two in the Mediterranean Sea

[7] Dichlorodiphenyltrichloroethane

								f. Direct link to SDG Target 14.3: Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels
iv. Acidification	2	2	2	1	2	3	**12**	d. Limited period covered by the instrumental record on the biogeochemical characteristics of the basin, making it difficult to perform a comprehensive study on the links between nutrient loads and biological productivity for an extended time period f. Direct link to SDG Target 14.1 Prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and nutrient pollution
v. Waste overload	2	2	3	1	2	1	**11**	c. Strong link to other transboundary issues related to pollution (4.1. Land and sea-based chemical, biological and physical pollution in transitional waters, coasts and offshore and 4.2. Sources and fate of litter and waste pollution, including offshore seafloor) d. Very limited information on the quantification of the waste assimilative/accommodative capacity of the Mediterranean Sea f. Although the sub-issue indirectly links to SDG 14.1.1, the aim is to prevent and significantly reduce pollution at source and not to rely on waste assimilative capacity

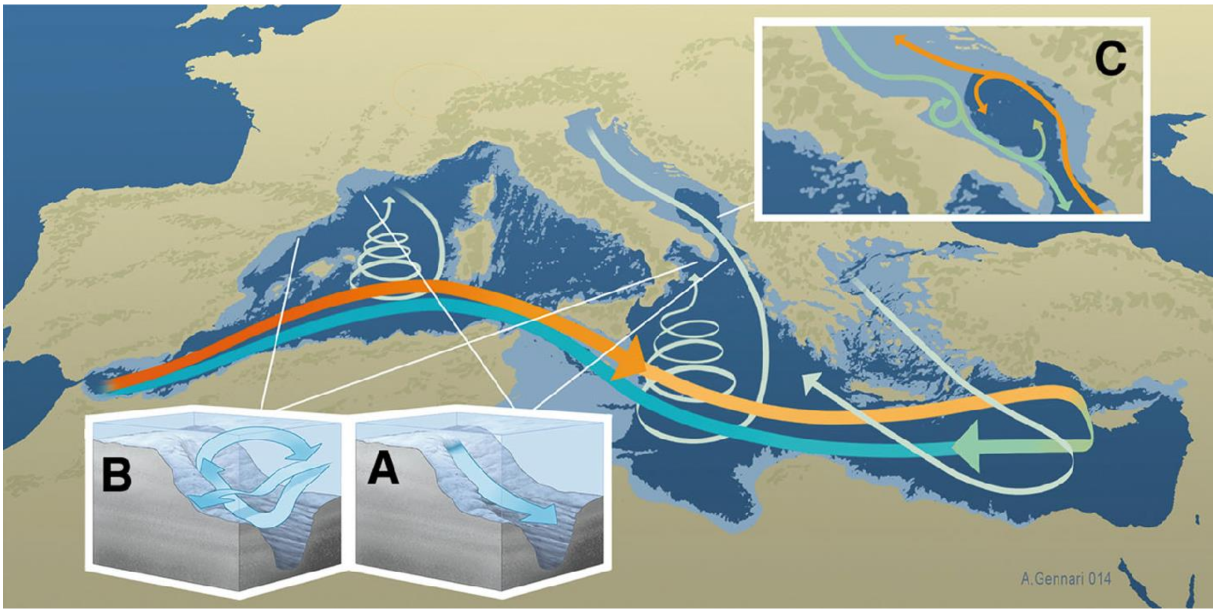
IV. A baseline on the long-term global regulation sub-issues affecting the Mediterranean LME: collection and analysis of data and information

This chapter presents the key outcomes of the information and data stock-taking exercise undertaken for each sub-issue. The aim was to provide a sound baseline that will inform the TDA Mediterranean update report and enable measuring the progress towards the future SAP implementation.

- **Changes in circulation patterns**

The general circulation patterns of the Mediterranean Sea are characterized by a shallow current entering the basin through Gibraltar Strait and reaching the Eastern basin. A deep countercurrent of intermediate Levantine water flows out from the deeper part of the Gibraltar Strait, as a way to counteract the imbalance between evaporation rates and freshwater riverine inputs. Such a bidirectional circulation, where surface water flows into a basin and deeper water flows out of the basin, is known as an anti-estuarine circulation (Krom et al., 2010). The two-way exchange flow at Gibraltar Strait is mainly driven by the density differences between the water masses on either side of the strait, implying the existence of an overturning cell or thermohaline circulation that ventilates the deep waters (Figure 4). Key oceanic physical processes, such as the open-sea deep convection, lead to the formation of cold and salty deepwater masses. The cold engines of the Gulf of Lion, the Northern Adriatic and the Northern Aegean are sites of deepwater formation, where the cold, saline and oxygenated surface waters sink to the bottom, renewing the deep waters.

Figure 4. Map of the large- and small-scale circulation patterns in the Mediterranean Sea. The cold engines of the Gulf of Lion, the Northern Adriatic, and the Northern Aegean sites where deepwater formation and renewal take place are also shown. (A) refers to the canyon system along the coast that can also generate upwelling currents; (B) reinforced deep-water renewal, supplementing the cold engines; and (C) coastline of Otranto Strait that induces the formation of gyres and eddies.



Source: Art Alberto Gennari from Boero (2014)

Until recently, the deepwater formation regions in the Gulf of Lion and the Adriatic areas were the best-known. However, abnormal winter conditions in the late-1980s to the mid-1990s have led to changes in deepwater formation in the Aegean Sea, known as the Eastern Mediterranean Transient (EMT), during which the North Aegean "cold engine" replaced the Northern Adriatic one. The EMT, which was not predicted by oceanographic models (Boero, 2014), is considered as the most significant intermediate-to-deep Mediterranean overturning perturbation reported by instrumental records. It is also a major climatic perturbation of circulation causing physico-chemical impacts, such as an increase in the Levantine basin salinity (Richon et al., 2019 and references therein).

In-situ data gathered between 2005 and 2017 in the Western basin revealed enhanced thermohaline variability in the deep and intermediate water masses (Schroeder et al., 2016). The observed increasing trends of deepwater temperature and salinity were enhanced by exceptional deepwater formation events that took place in the Gulf of Lion in 2004–2005 and 2012–2013. During the period 2005–2017, the yearly increases in temperature and salinity were more than 2.5 times faster than during 1961–2004. The abrupt shift towards higher temperature and salinity resulted in a significant change in the deepwater properties of the Western basin (Amitai et al., 2020). These events were identified as part of the Western Mediterranean Transition (WMT), which followed the EMT. By 2014, the whole layer below 500 m, i.e. the halocline/thermocline[8], had densified to values of 29.11–29.12 kg m^{-3} (Schroeder et al., 2016), as compared to the potential deepwater density of 29.1 kg/m^3 considered by Pinot et al. (2002). Since then, the formation of large amounts of anomalously warm and salty deepwater continued and the new deepwater started propagating eastwards filling up the entire basin.

The Western basin deepwater is characterized by a temperature of 12.7 °C and a salinity of 38.4 psu, while the Eastern basin deepwater has a temperature of 13.6 °C and a salinity of 38.7 psu. According to García-Martínez et al. (2017), the trends for deepwater temperatures in the Western basin, Eastern basin and the whole basin were 0.0024 ± 0.0014 °C yr^{-1}, 0.0018 ± 0.0025 °C yr^{-1} and 0.0020 ± 0.0018 °C yr^{-1}, respectively. The salinity trends were 0.0009 ± 0.0004 psu yr^{-1}, 0.00055 ± 0.00052 psu yr^{-1} and 0.0007 ± 0.0003 psu yr^{-1} respectively. These values coincided with a compilation of values cited from other studies, which however showed discrepancies amongst them, mainly attributed to the data scarcity, the interpolation method or the data quality control. Studies cited in MedECC (2020) indicated deepwater warming trends of 0.04°C ±0.001 °C $decade^{-1}$ and 0.015±0.003 psu $decade^{-1}$ since 1961. The previous Mediterranean TDA (UNEP/MAP/MEDPOL, 2005) stated that in the last 40 years there has been a slight but noticeable increase of deepwater temperature of +0.12 °C (0.003 °C yr^{-1}) and salinity of +0.05 % (0.00125 % yr^{-1}). The changes in temperature and salinity of the Mediterranean waters reveal that the functioning of the present Mediterranean is out of a stable equilibrium state (García-Martínez et al., 2017).

Sub-issue *i. Changes in circulation patterns*	
Key sources of data and information	- Krom et al. (2010) - Boero et al. (2014) - Schroeder et al. (2016) - García-Martínez et al. (2017) - MedECC (2020) and references therein - Richon et al. (2019) - Amitai et al. (2020) - Copernicus Marine Services (https://marine.copernicus.eu/)
Identified gaps	- There is wide interest in understanding whether Mediterranean circulation perturbations like the EMT are frequent or cyclical and how they may have altered Mediterranean/Atlantic interactions. However, the record of historic hydrographic observations is short and scattered, with limited precision data before the 1950s; - The effects of global warming on thermal stratification in coastal waters remain under-investigated;

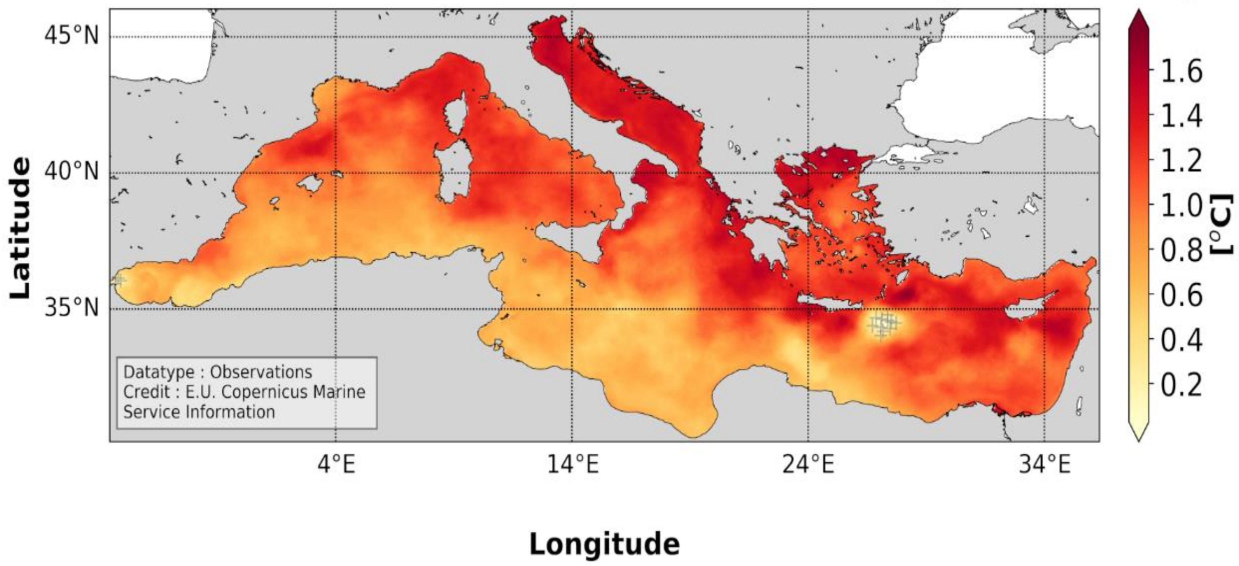
[8] A halocline is a vertical zone in the oceanic water column in which salinity changes rapidly with depth. This is located below the well-mixed, uniformly saline surface water layer. Source: https://www.britannica.com/science/halocline.
A thermocline is an oceanic water layer in which water temperature decreases rapidly with increasing depth. A widespread permanent thermocline exists beneath the relatively warm, well-mixed surface layer. Source: https://www.britannica.com/science/thermocline

	- Important knowledge gaps on how climate change will alter the thermohaline circulation of the Mediterranean Sea still exist.
Proposed key indicators	- Mixed Layer Depth (MLD) - Long-term trends in deepwater salinity, temperature and density

- **Seawater warming**

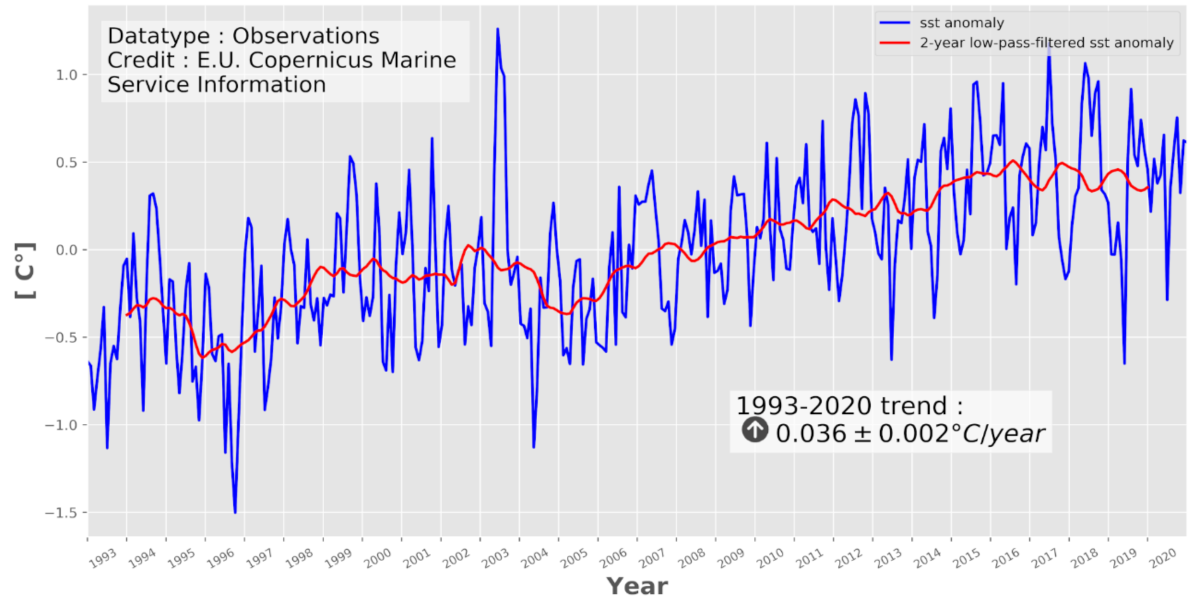
Since the beginning of the 1980s, average surface temperatures (SST) of the Mediterranean Sea have increased in the range between +0.29 and +0.44 °C per decade (Darmaraki et al., 2019). The surface warming rate is around three to four times higher than in the global ocean (von Schuckmann et al., 2020; Juza and Tintoré, 2021). Basin-averaged trend estimations of SST are around 0.041 ± 0.006°C yr^{-1} over 1982–2018 (Pisano et al., 2020), 0.037 ± 0.003°C yr^{-1} over 1982–2019 (von Schuckmann et al., 2020) and 0.038 ± 0.002°C yr^{-1} over 1982–2020 (Juza and Tintoré, 2021). Trend values over 1982–2020 have been averaged at 0.032 and 0.044 ± 0.002°C yr^{-1} in the Western and Eastern basins, respectively (Juza and Tintoré, 2021). Stronger warming trends have been observed in the Eastern basin (Pastor et al., 2018), involving the whole upper mixed layer (Rivetti et al., 2017). Figure 5 and Figure 6 show the spatial and time series cumulative Mediterranean SST trend over the period 1993-2020. A clear general warming tendency ranging from 0.0086 °C yr^{-1} to 0.064 °C yr^{-1} is observed. The spatial pattern of the SST trend (Figure 5) shows a distinct behavior between the Western and Eastern basins, with the magnitude of the trend increasing moving eastwards. The trend for SST (Figure 6) shows minima during 1993 and 1996, and distinct maximum SST values in summer 2003. More information on these trends can be found in the Ocean State Report – First edition (von Schuckmann et al., 2016).

Figure 5. SST Cumulative Trend (1993-2020) in the Mediterranean Sea



Source: https://marine.copernicus.eu/access-data/ocean-monitoring-indicators/mediterranean-sea-cumulative-trend-map-sea-surface

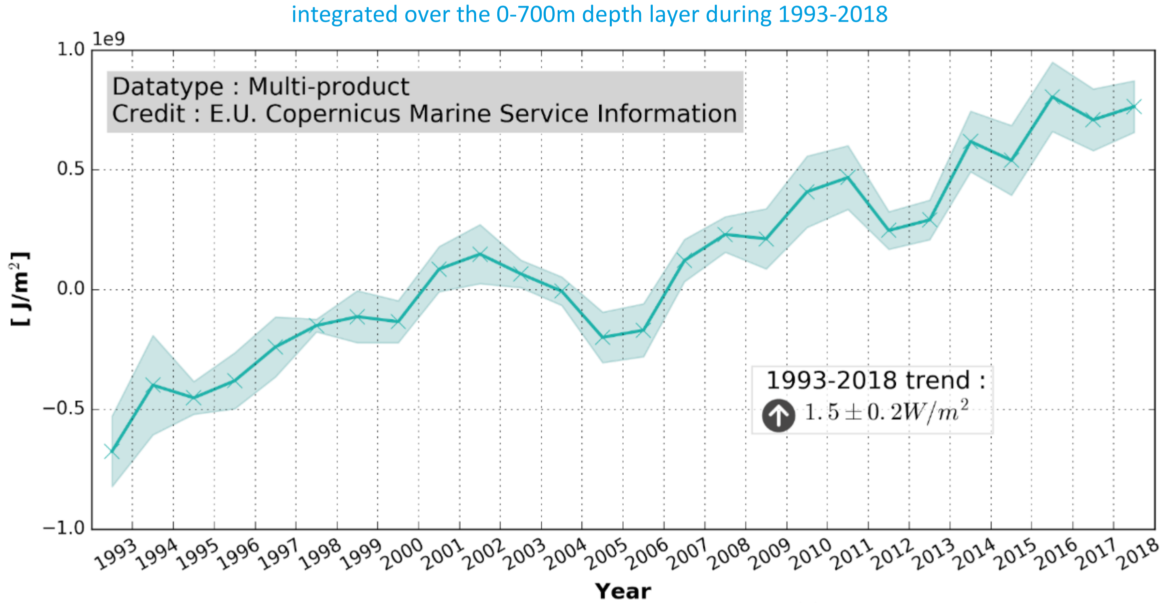
Figure 6. Time series of monthly mean (blue line) and 24-month filtered (red line) SST anomalies in the Mediterranean Sea during the period 1993-2020, relative to the climatological period 1993-2014



Source: https://marine.copernicus.eu/access-data/ocean-monitoring-indicators/mediterranean-sea-anomaly-time-series-sea-surface

The ocean plays an important role in climate regulation by absorbing a large amount of the sun's radiation and excess heat. Seawater warming is not limited to the surface but propagates down the water column. In the period 1993-2018, the mean time series ocean heat content anomaly over the Mediterranean Sea showed a continuous increase of 1.5±0.2 Wm^{-2} [9] in the upper 700m (Figure 7). An increase in the rate was observed after 2005 as compared to the previous decade.

Figure 7. Time series of annual mean area averaged ocean heat content in the Mediterranean Sea (basin wide) and integrated over the 0-700m depth layer during 1993-2018



Source: https://marine.copernicus.eu/access-data/ocean-monitoring-indicators/mediterranean-sea-heat-content-anomaly-0-700m

9 Heat, describing the transfer of thermal energy between molecules within a system, is measured in Joules or Watts (1Watt -= 1 Joule per second). Temperature, describing the average kinetic energy of molecules within a material or system, is measured in Celsius (°C), Kelvin(K), Fahrenheit (°F), or Rankine (R). Heat is classified as a process variable (a measure of change), whereas temperature is a state variable (a measurable physical property). Source: https://energyeducation.ca/encyclopedia/Heat_vs_temperature

On shorter timescales, SST anomalies become an essential indicator for extreme events, such as marine heatwaves. In the whole Mediterranean Sea, marine heatwaves are increasing substantially in intensity, duration and frequency (MedECC, 2020). However, this trend shows a strong spatial variability with major differences between the Western and Eastern sub-basins. The recent study by Juza et al. (2022) provides the decadal trends in marine heatwaves indices (intensity, duration and number of events) differentiated per sub-basin (West basin, Adriatic Sea and East basin). All sub-regions are experiencing positive trends of all characteristics with unprecedented intensification in recent years (Table 3).

Table 3. Ranges of mean marine heatwaves indices values for different sub-periods and the whole period (1982-2020), the linear trends for the three sub-regions (Western basin, Adriatic Sea and Eastern basin)

MHW indices	Sub-basins	Mean1982–1991	Mean1992–2001	Mean2002–2011	Mean2012–2020	Mean1982–2020	Trendover 1982–2020
Mean intensity(°C)	WMed	0.32–0.49	0.33–0.46	0.52–**0.93**	0.53–0.73	0.43–0.64	0.24–0.46 ± 0.0007
	Adriatic	0.41–0.51	0.44–0.57	0.68–**0.90**	0.62–0.85	0.53–0.71	0.35–0.52 ± 0.0007
	EMed	0.25–0.38	0.32–0.42	0.42–0.55	0.48–**0.66**	0.38–0.50	0.28–0.41 ± 0.0006
Max intensity(°C)	WMed	0.65–1.01	0.69–1.01	1.25–2.14	1.51–**2.25**	1.04–1.53	1.06–2.02 ± 0.003
	Adriatic	0.80–0.99	0.93–1.21	1.74–2.26	1.97–**2.48**	1.35–1.72	1.66–2.13 ± 0.002
	EMed	0.46–0.74	0.71–0.94	1.02–1.44	1.38–**1.99**	0.95–1.25	1.03–1.67 ± 0.003
Mean duration(days)	WMed	7.9–11.6	7.4–8.7	9.3–14.3	11.4–**16.0**	9.2–12.2	4.8–10.0 ± 0.03
	Adriatic	7.4–8.5	8.0–9.4	11.6–12.7	14.2–**16.5**	10.8–11.1	8.7–12.1 ± 0.03
	EMed	5.7–10.2	7.5–9.5	10.2–11.5	12.8–**23.8**	9.3–11.8	6.5–14.9 ± 0.04
Number of events	WMed	0.7–1.0	1.0–1.8	2.4–3.4	3.8–**5.8**	2.3–2.7	4.5–6.3 ± 0.01
	Adriatic	0.5–0.8	1.5–1.7	2.4–2.8	5.3–**5.9**	2.5–2.6	5.6–6.5 ± 0.01
	EMed	0.1–0.9	0.9–1.5	2.4–3.4	4.2–**5.9**	2.1–2.5	4.2–7.1 ± 0.009

Sub-regional decadal maxima are highlighted for each sub-basin (in bold) and over the whole Mediterranean (in red).

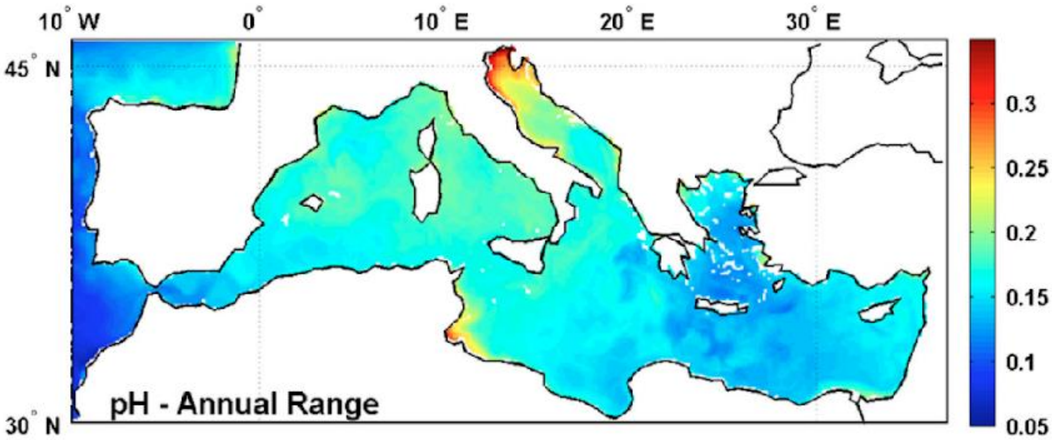
Source: Juza et al. (2022)

Sub-issue *ii. Seawater warming*	
Key sources of data and information	- Rivetti et al. (2017) - Bensoussan et al. (2019) - Darmaraki et al. (2019) - Pastor et al. (2018) - Pastor et al. (2020) - von Schuckmann et al. (2020) - Juza and Tintoré (2021) - Juza et al. (2022) - Copernicus Marine Services (https://marine.copernicus.eu/)
Identified gaps	- The warming and salinization rates of deepwaters remain highly uncertain and depend on various factors, such as the characteristics of surface waters, or the intensity of the present and future Mediterranean thermohaline circulation; - SST (and salinity) are monitored from satellites. However, satellites are not appropriate to measure temperature distributions with depth.
Proposed key indicators	- SST cumulative trend - Ocean heat content - Intensity, duration and number of marine heatwaves per sub-basin

- **Acidification**

Similar to the global ocean, the seawater surface pH in the Mediterranean is assessed to have decreased by -0.08 units since the beginning of the 19th century (MedECC, 2020). According to UNEP/MAP and Plan Bleu (2020) and references therein, since the pre-industrial period, acidification estimations in the Mediterranean ranged from -0.055 to -0.156 pH units (Hassoun et al., 2015), with a rate of 0.09 to 0.028 pH units per decade observed in the upper layers of both the Western (Kapsenberg et al., 2017) and the Eastern basins (Hassoun et al., 2019). All Mediterranean Sea waters are already acidified, especially those of the Western basin where ΔpH is rarely less than −0.1 pH unit. Despite the high acidification levels, both Mediterranean basins are still highly supersaturated in calcium carbonate minerals (Hassoun et al., 2015), implying that the dissolution of calcium carbonate is not thermodynamically favored. Lacoue-Labarthe et al. (2016) indicated that seasonal pH amplitudes can be very large, particularly in the relatively shallow North Adriatic Sea, which also has a large seasonal temperature range (Figure 8).

Figure 8. Spatial distribution of seasonal pH ranges driven by physical processes only



Source: Lacoue-Labarthe et al. (2016)

Minimizing and addressing the impacts of ocean acidification, including through enhanced scientific cooperation at all levels constitutes SDG 14.3, under which indicator SDG 14.3.1 measures the average marine acidity (pH) at agreed suite of representative sampling stations. The purpose of this indicator is to monitor the carbon system by measuring four parameters: pH, total dissolved inorganic carbon (DIC), carbon dioxide partial pressure (pCO_2) and total alkalinity (TA). In order to be able to constrain the carbonate chemistry of seawater, it is necessary to measure at least two of the four parameters[10]. Currently there is no SDG 14.3.1 data by Mediterranean countries in the global SDG database, with the exception of France, Italy and Spain [11].

Sub-issue *iii. Acidification*	
Key sources of data and information	- Hassoun et al. (2015) - Palmieri et al. (2015) - Lacoue-Labarthe et al. (2016) - MedECC (2020) - UNEP/MAP and Plan Bleu (2020) - SGD 14.3 data (https://unstats.un.org/sdgs/dataportal/database)
Identified gaps	- Significant uncertainties remain on the quantification of the Mediterranean Sea's storage of anthropogenic CO_2. This quantity cannot be measured directly as the anthropogenic component cannot be distinguished from the much larger natural background; - Long-term observational records, especially in coastal zones, are required to identify the acidification trends; - The assessment of local changes along coastlines still requires improved boundary conditions, particularly for riverine and groundwater discharge of nutrients, carbon, and total alkalinity, combined with developments to improve coastal aspects of the physical and biogeochemical models; - Studies that include the full natural carbon cycle and the effects of climate change are lacking. This includes the predictions of future changes while weighing geochemical against climate factors;

[10] *https://unstats.un.org/sdgs/metadata/files/Metadata-14-03-01.pdf*
[11] *https://unstats.un.org/sdgs/dataportal/database*

	- Lack of monitoring of ocean acidification in key areas of the Mediterranean Sea, including regular assessments of the likely socio-economic impacts; - Due to the significant uncertainty about the effects of the acidification on marine systems, predicting its future impacts remains challenging.
Proposed key indicators	- SDG 14.3.1 average marine acidity (pH)

- **Changes in biogeochemical cycling**

The Mediterranean Sea is characterized by relatively low inorganic nitrogen (N) and phosphorus (P) concentrations, with decreasing levels of nutrients eastwards (Tanhua et al., 2013). The Western and Eastern basins have distinct biogeochemical properties. The Eastern basin is most oligotrophic, with very low nitrate (< 0.5 µm) and phosphorus (< 0.2 µM) concentrations (Pujo-Pay et al., 2011). Phytoplankton biomass in the Mediterranean Sea is also low, with a primary productivity in the Eastern basin about three times lower than in the Western basin (Table 4).

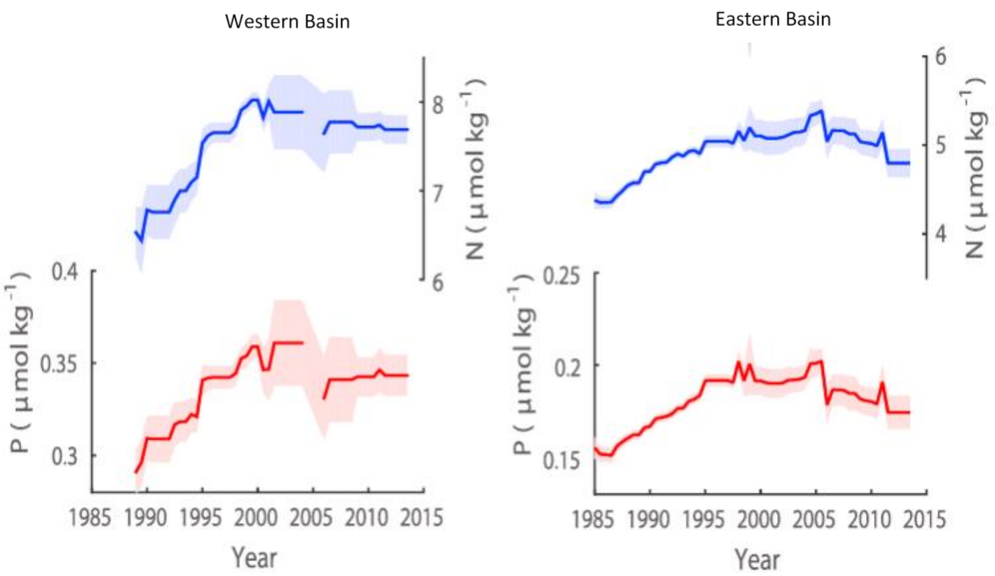
Table 4. Average primary productivity values in the Eastern and Western Mediterranean areas, compared to average values from the global ocean

Area	Primary Productivity (g C m^{-2} y^{-1})
Eastern Mediterranean Sea	10-143
Western Mediterranean Sea	37-475
Average open oceans	75
Average continental shelves	300
Average upwelling regions	500

Source: Powley et al. (2017a) and references therein.

The compilation of observational data on N and P concentrations for the period 1985–2014 by Moon et al. (2016) provided more insight into the temporal changes in nutrient dynamics (Figure 9).

Figure 9. Plot of the 5-year moving average for, N (blue line), and P (red line) data collected in (a) the Western basin (left) and (b) the Eastern basin (right). The color shading indicates the range of the 95 % confidence intervals



Source: Modified from Moon et al. (2016)

In the Western basin, the seawater concentrations of both N and P increased from 1989 until 2000, plateaued at high levels before decreasing slightly. In the Eastern basin, after an increase between 1985 and 1998, both N and P concentrations gradually decreased thereafter. Based on these trends, the overall rates of increase in N and P in the Western basin (1.89 µmol N kg^{-1} $decade^{-1}$ and 0.07 µmol P kg^{-1} $decade^{-1}$) were found to be considerably higher than in the Eastern basin (0.78 µmol N kg^{-1} $decade^{-1}$ and 0.05 µmol P kg^{-1} $decade^{-1}$) (Moon et al., 2016).

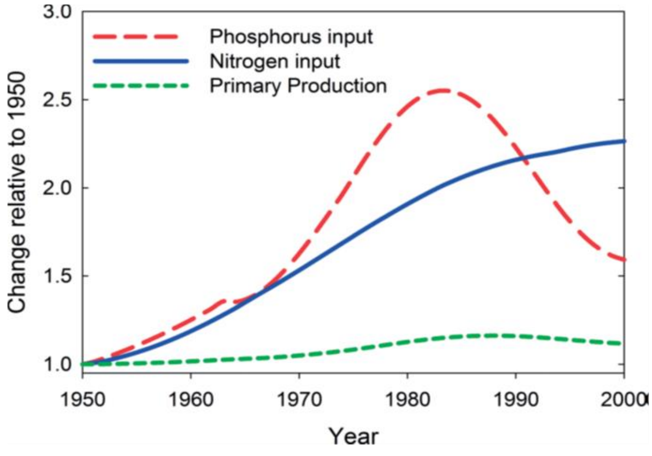
Moon et al. (2016) attributed the observed trends in N and P concentration to the trends in riverine inputs and atmospheric deposition resulting from anthropogenic activities. The riverine influx of N continued to increase until the early 1990s, followed by stabilization. The riverine input of P increased until the early 1980s and then decreased following improvements in wastewater treatment. Similarly, the modelling study by Pagès et al. (2020) linked the depletion of phosphate availability in the subsurface layer of the Eastern basin to the significant decrease of phosphate in riverine inputs since the end of the 1980s. Other external inputs of nutrients include the Strait of Gibraltar and atmospheric deposition. These are of major importance for the biogeochemistry of the Mediterranean Sea, although their resulting impacts remain poorly understood.

The extensive modelling work by Powley et al. (2018) focused on unraveling the relative roles of anthropogenic nutrient inputs and thermohaline circulation in driving inter-annual changes in nutrient distributions. The results pointed towards variations in thermohaline circulation as a main regulatory mechanism determining the spatial and temporal variations in N and P measurements. Temporal variations in annual primary production over the 1950-2030 period were primarily dominated by variations in deepwater formation rates, followed by changes in riverine P inputs for the Western basin and atmospheric P deposition for the Eastern basin.

The large and rapidly growing coastal population around the semi-enclosed Mediterranean Sea contributes to significant inputs of nutrients from anthropogenic activities. Yet, the offshore waters of the Mediterranean are characterized by extremely low biological productivity. Eutrophication is not commonly observed in the basin, with the exception of local and restricted problems in areas subject to land-based inputs, such as in the North Adriatic Sea, Venice Lagoon or lagoons in the Nile Delta. This contrasts with other semi-enclosed seas, such as the Baltic Sea which receives comparable loads of nutrients per unit area, but is highly susceptible to nutrient enrichment, eutrophication and its ecological impacts.

Powley (2017) investigated the implications of the anti-estuarine circulation for the biogeochemical processes in the Mediterranean Sea. Between 1950 and 2030, the anti-estuarine circulation contributed to the removal of at least 45 % of the anthropogenic nutrient inputs to both Western and Eastern basins. This natural "self-cleaning" capacity (Powley et al., 2017a) buffers efficiently the enhanced inputs of nutrients, especially in the Eastern basin. Newly added nutrients to the surface water are rapidly transferred to the deepwater layers, either by downwelling of surface water or settling of biological debris. Much of the additional dissolved N and P in the intermediate water, including the highly bioavailable nutrients, are removed from the Eastern basin by outflow through the Strait of Sicily through the anti-estuarine circulation. Similarly, enhanced nutrient inputs are exported from the Western basin to the North Atlantic Ocean, whereas the rest accumulates in the deepwater layer. Despite the significant increase in land-derived inputs of N and P from rivers and atmospheric deposition during the 1950-2000, reaching levels 2.6 and 2.3 times higher than in 1950, respectively, the corresponding increase in primary production in the open waters of the Mediterranean Sea was limited to 10–20 % (Figure 10). In fact, model simulations predicted that the Mediterranean Sea would remain oligotrophic, even taking into account the various possible changes in physical circulation and N and P inputs during the remainder of the 21st century (Powley, 2017a). In contrast, other sources e.g. MedECC (2020) claim that nutrient enrichment of Mediterranean Sea may result in a high increase in phytoplankton growth and biomass, leading to eutrophication.

Figure 10. Reconstructed relative changes of land-derived reactive phosphorus and nitrogen inputs to the Mediterranean Sea and corresponding changes in primary productivity, from the year 1950 to 2000



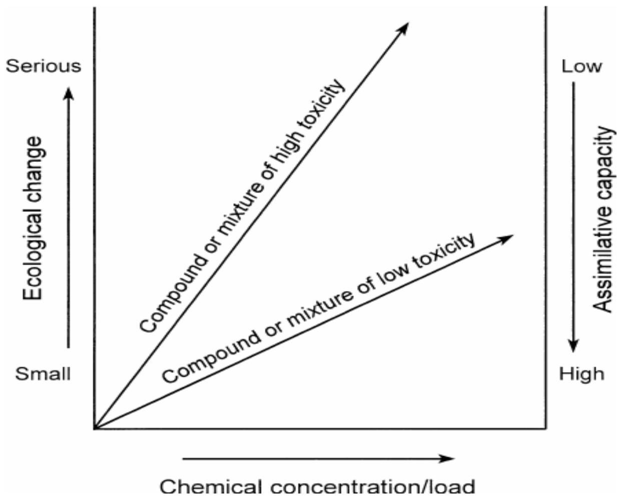
Source: Powley et al. (2017a)

Sub-issue *iv. Changes in biogeochemical cycling*	
Key sources of data and information	- Moon et al. (2016) - Powley (2017) - Powley et al. (2017a) - Powley et al. (2017b) - Powley et al. (2018) - Pagès et al. (2020)
Identified gaps	- Lack of long-term data series of: i. systematic nutrient (inorganic and organic) analyses and flow determinations across the Straits of Gibraltar and Sicily and ii. N and P concentrations in the deeper water layers; - Sustained N and P data over decadal time periods using appropriate methods that are able to accurately determine their low concentrations in offshore waters; - A regional observational network that delivers high-quality biogeochemical and physical data; - Lack of thorough evaluation of the relative contributions of atmospheric deposition and riverine input to the nutrient dynamics in the Mediterranean Sea; - Inconclusive scientific outcomes on which mechanism regulates trends in nutrient concentrations – thermohaline circulation or nutrient inputs; - The effects of changes in circulation due to seawater warming on marine biogeochemistry are poorly understood.
Proposed key indicators	- Total inputs of N and P loading into the Mediterranean Sea (millions of tonnes per year), including source appropriation (riverine inputs, atmospheric deposition and direct discharges) - Trends in primary productivity

- **Waste overload**

The determination of how much waste can be absorbed by the marine environment before irreversible damage occurs presents a pragmatic and rational approach for permitting the controlled disposal of anthropogenic wastes in the ocean as opposed to imposing uncompromising zero discharges. The assimilative capacity may serve as a basis for determining the maximum ecologically permissible pollutant loads or ELVs, which are a function of the toxicity and the induced ecological change (Figure 11). ELVs are determined through a combined approach taking into account best available techniques and compliance with quality standards to be achieved, such as the Good Environmental Status of the receiving environment. For example, the Regional Plans on Urban Wastewater Treatment and Sewage Sludge Management in the Framework of Article 15 of the Land Based Sources Protocol (Decision IG.25/8) provide the ELVs for a set of parameters, and make reference to ELVs for other emerging pollutants, such as microplastics and microbiological parameters. A risk-based assessment of the environmental and health implications of the discharges is required for the establishment of ELVs.

Figure 11. The relationships between ecological change, chemical load, and assimilative capacity. Source: Roux et al. (1999)



When it comes to plastic waste, the fate of plastic marine debris is strongly influenced by fragmentation, photo-oxidation and biodegradation, leading to the generation of micro and nanoplastics. The Mediterranean Sea is a hotspot for plastic pollution due to significant volumes of plastic waste that it receives, estimated at around 730 tonnes a day (UNEP/MAP and Plan Bleu, 2020). The slow degradation of plastic, characteristic of its durability, implies extended persistence in the environment. Bioassimilation represents the final stage of plastic biodegradation and occurs when plastic has reduced to a molecular weight that can be consumed by microorganisms. However, such synthetic and man-made substances are foreign to the biosphere and hence cannot be fully assimilated / neutralized without consequences.

Some studies regard the term “assimilative” a misnomer. Contrary to the process of assimilation, by which the receiving system is ultimately benefitting, the assimilation of waste does not benefit the receiving environment. Krom (1986) suggested its replacement by “accommodative” capacity reflecting the processes which occur when pollutants are discharged into a water body. Here, to integrate the numerous pollution sources and trends in the Mediterranean Sea, the term ‘waste overload’ is preferred in the sense that the potential assimilative capacity is declining as a result of the transboundary pollution at the different spatial and temporal scales, as well as to avoid giving the false impression that the oceans and seas can assimilate anthropogenic pollution.

Sub-issue *v. Waste overload*	
Key sources of data and information	- Krom (1986) - Roux et al. (1999) - Neverova-Dziopak (2015)
Identified gaps	- More recent scientific literature on the concept of waste assimilation is limited, potentially indicating that the concept is no longer commonly used; - A baseline for the waste assimilation capacity for the Mediterranean Sea could not be established; - Although the parameter ELVs could be considered as a proxy of the assimilation capacity, these relate to point source discharges. Other sources, such as sea-based sources from ships are not considered.
Proposed key indicators	- N/A

V. An analysis of the IMPACTS associated with the long-term global regulation sub-issues affecting the Mediterranean LME

This chapter provides more information on the impacts of five selected sub-issues. The impacts are analyzed systematically and differentiated between direct/indirect and environmental/socio-economic. Direct interactions with other sub-issues are highlighted. To the extent possible, the description of the impacts has been substantiated with literature review. In some cases, "potential" impacts are also included.

A. IDENTIFICATION OF IMPACTS

1. Changes in circulation patterns

Sub-issue	Impacts					
	Direct	**Indirect**				
Changes in circulation patterns	Deepening of thermocline & reduction in deepwater formation	Stratification	Deoxygenation of deep waters	Changes in benthic and pelagic ecosystems	Loss of ecosystem services	Economic losses
	Changes in the spatial distribution of substances/water quality parameters (e.g. N & P)	**Changes in biogeochemical cycling (sub-issue iv.)**	Changes in marine productivity	Changes in biodiversity		

Environmental	Socio-economic

The widespread increase of the thickness and temperature of the mixed layer and a deepening of the summer thermocline have already been observed (Rivetti et al. 2017), linked to the summer stratification of the water column. These physico-chemical changes have impacted ecological processes at various levels. Changes in circulation patterns causing the impairment of ''cold engines'' and the reduction of deepwater formation are considered as the "worst possible scenario", which would have dramatic impacts on biodiversity. A lack of deepwater renewal is associated with the risk of permanent stratification and deoxygenation of the deepwater, impacting e.g. the cold-water coral communities which are exposed to lower levels of oxygen. Studies of sapropels (dark-coloured sediments rich in organic matter) in the Eastern basin have indicated that the alternations between oxic and anoxic deep waters were linked to changes in thermohaline circulation, which in turn were caused by natural climate fluctuations (Powley et al. 2017a). This raises concerns that changes in circulation patterns, in part caused by the ongoing seawater warming trend (see sub-issue ii.), could potentially trigger the appearance of hypoxic or anoxic bottom waters in the Mediterranean Sea.

As already discussed above, other studies have linked the changes in circulation patterns to the changes in the distribution of nutrients, with consequences on biogeochemical cycling, including primary production. For example, Mojtahid et al. (2015) reported a severe drop in the diversity of planktonic foraminifera in the South-Eastern Levantine Basin in response to water column stratification, and the disappearance of deep-dwelling species e.g. *Globorotalia inflata* that are influenced by water column mixing. The response of marine ecosystems to paleoclimatic changes in circulation patterns and productivity has been extensively discussed in MedECC (2020). Changes in circulation, in tandem with seawater warming and changes in biogeochemical cycling, have been attributed to the increased frequency of bottom water hypoxia or anoxia in coastal areas of the northern Adriatic, and associated mass mortalities of benthic fauna.

2. Seawater warming

<table>
<tr><th rowspan="2">Sub-issue</th><th colspan="5">Impacts</th></tr>
<tr><th>Direct</th><th colspan="4">Indirect</th></tr>
<tr><td rowspan="6">Seawater warming</td><td>Increased stratification</td><td>Changes in circulation patterns (sub-issue i.)</td><td colspan="3"></td></tr>
<tr><td>More frequency and longer marine heatwaves</td><td rowspan="2">Physiological stress on flora and fauna, e.g. Gorgonians corals and endemic species</td><td>Mass mortality events, including fish kills</td><td rowspan="3">Impacts on the blue bio-economy sectors (fisheries, aquaculture)

Negative impacts on coastal tourism</td><td rowspan="3">Economic losses in the fisheries, aquaculture and tourism sectors</td></tr>
<tr><td>Lower dissolved oxygen/deoxygenation</td><td>Northward shift of native species</td></tr>
<tr><td>Reduction in primary production</td><td rowspan="3">Changes in biodiversity patterns, e.g. fish populations

Changes in ecosystem functioning</td><td>Jellyfish blooms</td></tr>
<tr><td>Increase of thermophilic species, including toxic, pathogenic, tropical non-indigenous species</td><td colspan="3" rowspan="2"></td></tr>
<tr><td>Formation of marine mucilage</td></tr>
</table>

Environmental	Socio-economic

The impacts of seawater warming of the Mediterranean are intrinsically related to the changes in circulation patterns (see sub-issue i.). The key convergence point is that warmer surface water mixes less well with deep water, resulting in stratification and decreased oxygenation. In addition, the solubility of oxygen decreases with increasing temperatures, whereas the rates of reactions increase. The abnormal deepening of the warm surface layer has caused mass mortalities of organisms that do not tolerate high temperatures, especially in the northern coast of the Mediterranean basin (Garrabou et al., 2019; MED2050 Programme[12]). In their review on temperature impacts on deep-sea biodiversity, Yasuhara and Danovaro (2016) reported that temperature shifts as low as 0.1°C were sufficient to cause significant changes in biodiversity and in the community structure of deep-sea nematode assemblages.

Seawater warming has induced declines in the abundance of the Mediterranean seagrass meadows of *Posidonia oceanica* through increased shoot mortality (e.g. Marbà and Duarte, 2010), and led to the mass mortality of the bivalve *Pinna nobilis* (e.g. Vázquez-Luis et al., 2017; Cabanellas-Reboredo et al., 2019). Rising temperatures have also caused northward shifts of fish populations in search of cooler waters. For example, in Italy local fishers have reported increased catches of barracuda (*Sphyraena viridensis*), a thermophilic species that was rare until two decades ago and Dusky groupers (*Epinephelus marginatus*) that can now reproduce in more northern latitudes (WWF, 2021). Higher sea temperatures lengthen the duration of jellyfish blooms and increase winter breeding in some species. In general, small pelagic species, thermophilic and/or exotic species of smaller size and of low trophic levels, could benefit from changes in temperature. Large-sized species, often with commercial interest, may be faced with conditions that reduce their survival (MedECC, 2020). The impacts of seawater warming on marine biota are two-fold: the direct impact of increasing temperature on organism physiology, and the effect of warming on other biotic (e.g., microbial activity, metabolic rates) and abiotic (e.g., oxygen solubility) components of ecosystem functions (Vaquer-Sunyer and Duarte, 2013).

The Mediterranean is undergoing major changes in environmental conditions. Boero (2014) described these systemic alterations as: *tropicalization* (favoring the establishment of tropical species); *meridionalization* (northward shift of species that in the past thrived only in the southern portion of the basin); impairment of cold-water engines; changes in the reproductive patterns of species modified by thermal conditions; species extinction; abundance of jellyfish and declining fish populations. For the majority of these changes, rising seawater temperature is the common denominator.

[12] MED2050 Programme – Factsheet 11 – Climate change and its terrestrial and marine impacts

Marine heatwaves can be considered as an extreme form of seawater warming. These short periods of abnormally high temperatures cause immediate shifts in the distribution of mobile species, drive regime shifts (large, abrupt and persistent changes in the structure and function of ecosystems) and cause local extinctions, including mass mortality events and commercial losses in aquaculture.

3. Acidification

Sub-issue	**Impacts**			
	Direct	**Indirect**		
Acidification	Increased stress on marine habitats and biodiversity e.g. bivalves and coralligenous systems	Changes to biodiversity	Changes in ecosystem functioning	
	Reduction in calcification rates of calcifying organisms	Impacts on production of marine resources	Impact on blue bio-economy sectors (fisheries, aquaculture, algae cultivation)	Economic losses
				Decreased food security
	Harmful algal blooms in coastal waters	Contamination of seafood	Toxicological risk to human health upon consumption	

Environmental	Socio-economic

Studies of the impacts of ocean acidification on Mediterranean marine ecosystems have reported a myriad of responses (MedECC, 2020 and references therein). These extend to marine and coastal ecosystem services, food provision, carbon absorption, climate regulation, coastal protection, and ultimately affecting human health (Falkenberg et al., 2020). One of the most harmful impacts of acidification in the Mediterranean Sea will be on fisheries, which are already under increasing threat. Although adult finfish seem able to withstand the projected increases in seawater CO_2, degradation of seabed habitats and increases in harmful blooms of algae and jellyfish might adversely affect fish stocks (Lacoue-Labarthe et al., 2016). The sensitivity of shell-forming species, such as bivalve mollusks to changes in acidity (as well as temperature) presents a threat to the aquaculture sector (Rodrigues et al., 2015). Recruitment and seed production could be possible bottlenecks for shellfish aquaculture in the future, since early life stages are vulnerable to acidification and warming. Marine areas with economic activities directly depending on marine resources, e.g. capture fisheries and aquaculture production, may face impacts on employment and economic losses. Thus, ocean acidification should be factored into fisheries and aquaculture management plans.

Tourism is also vulnerable to acidification. Touristic and recreational activities may, for example, be affected through the impact of degraded marine ecosystems (loss of coralligenous species) and jellyfish outbreaks.

4. Changes in biogeochemical cycling

Sub-issue	Impacts					
	Direct	Indirect				
Changes in biogeochemical cycling	Increasing/ decreasing availability of essential nutrients and oxygen to marine organisms	Changes in marine productivity/ ecosystem status	Changes in species distribution	Changes in productivit y and stability of local ecosystem s	Decline in population viability Impact on breeding grounds	Lower socio-ecological resilience

Environmental	Socio-economic

Changes in biogeochemical cycling lead to changes in marine productivity and species distributions. The Mediterranean is characterized by a few biological production hotspots, some of which are under the influence of riverine inputs of nutrients. In turn, the overall productivity and stability of local ecosystems may be affected, thereby ultimately affecting the food available to (other) fish, birds and marine mammals.

Deep-sea ecosystems are greatly dependent on surface primary production through "marine snow" – the deposition of organic material from upper water to the deep sea. One of the few regional studies on the sensitivity of biological productivity and plankton communities in the Mediterranean Sea to future climate change pointed towards an overall decrease in phytoplankton biomass in response to stratification (Lazzari et al., 2014). The impacts on marine ecosystems due to changes in biogeochemical cycling and marine productivity are strongly linked to the impacts of changes in circulation described above. In addition, impacts of changes in marine productivity and species distributions will be also described as part of the CCA of TDA issue 3. *Nature value loss, focusing on marine habitats, biodiversity and ecosystems* (see Annex 1).

5. Waste overload

Sub-issue	Impacts			
	Direct	Indirect		
Waste overload	Contaminated sediments	Bioaccumulation and biomagnification	Impacts on biodiversity	Impacts on fisheries, including negative social implications
	Contaminant plumes	Ecotoxicological effects	Human health impacts	

Environmental	Socio-economic

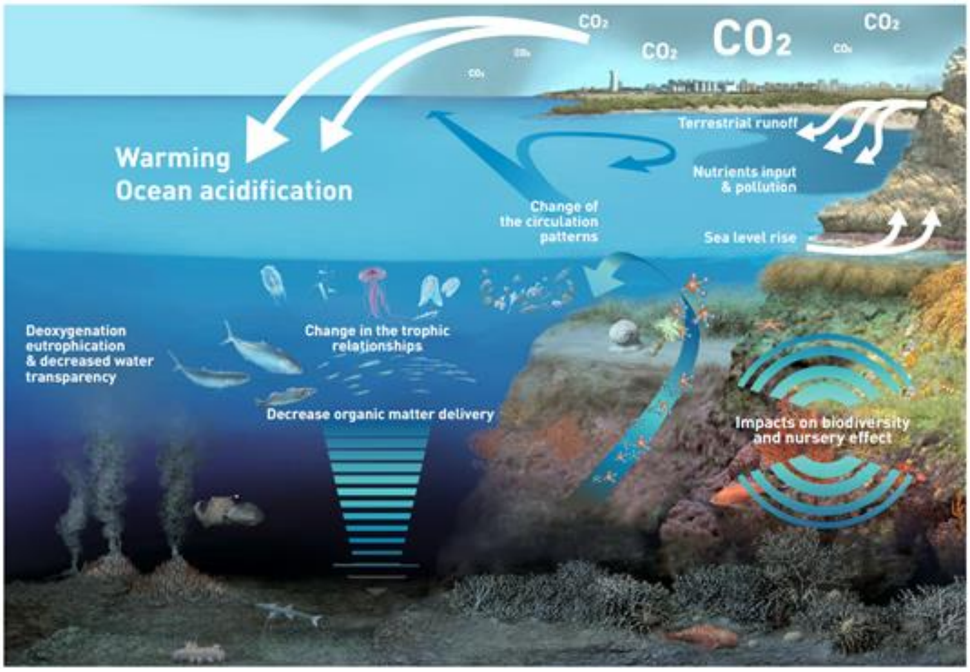
The marine environment has some capacity to dilute, absorb and break down (detoxify) waste. Yet, this comes at the expense of significant harm to biodiversity and human health of both current and future generations. Waste disposal above the waste accommodative capacity thresholds causes contamination of the marine environment by plastics, chemicals, oil and other pollutants. Toxic substances affect biodiversity and human health through the food chain and can ultimately impact fisheries, leading to negative social implications. Marine debris can be ingested by or cause entanglement of organisms, posing direct threat to marine biota, ultimately causing broader impacts on ecosystem services. Exposure of organisms to chemicals can lead to toxicological effects on fish, mammals and mollusks, impacting human health through the food chain.

The environmental and socio-economic impacts of pollution will be extensively described as part of the CCA of other TDA issues, notably issues 1. *Land and sea-based chemical, biological and physical pollution in transitional waters, coasts and offshore* and 2. *Sources and fate of litter and waste pollution, including offshore seafloor* (see Annex 1).

B. CUMULATIVE IMPACTS

Although each individual impact is conducive to change, the Mediterranean LME is subjected to multiple synergistic stressors leading to cumulative impacts. Cumulative impacts, in particular of long-term regulatory issues that are superimposed by short-term impacts, are difficult to resolve and predict. Very often, the impacts of acidification are compounded with those from seawater warming and deoxygenation, although they operate on different time scales. Ocean acidification seems to have a slower effect on several organisms, whereas the increase of temperature causes more immediate stress in most species (Lejeusne et al., 2010). Collectively, they are likely to reduce marine productivity, affect species distribution, reduce the resilience of marine ecosystems and trigger local extinctions, with detectable effects on the individual, population, and ecosystem scale. Episodic events, such as jellyfish and harmful algal blooms are linked to more than one sub-issue, such as seawater warming and acidification. The impacts of changes in circulation patterns, seawater warming and acidification on the marine ecosystems in the Mediterranean Sea are illustrated below (Figure 12). The extent of the impacts of climatic (and non-climatic) drivers on the marine ecosystems are yet to be investigated. This is because these slow, but significant ecosystem transformations are still ongoing, impacting different compartments of the ecosystems, e.g. pelagic, benthic, with consequences manifested at different scales, e.g. local and regional (MedECC, 2020).

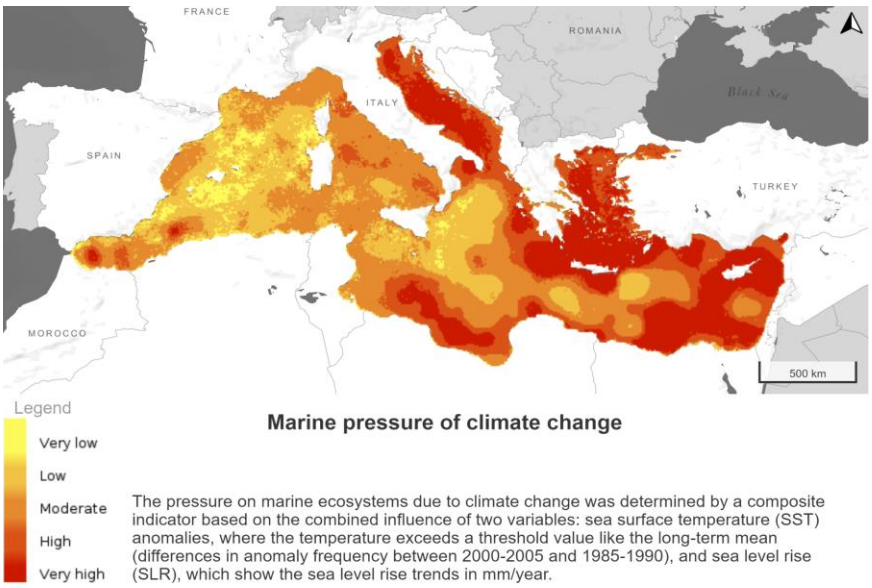
Figure 12. Impacts of changes in circulation patterns, seawater warming and acidification on the marine ecosystems in the Mediterranean Sea



Source: MedECC (2020)

Synergies between impacts are also manifested cumulatively on sectors such as fisheries, aquaculture and tourism, although the combined consequences, for example of seawater warming and acidification on fisheries, remain uncertain. The systematic and intertwined nature of these challenges calls for integrated and ecosystem-based management approaches, supported by spatially-based composite risk assessments, as illustrated by the example shown in Figure 13.

Figure 13. Pressure on marine ecosystems due to climate change determined by a composite indicator based on the combined influence of two variables: SST anomalies and sea level rise (SLR). Note that sea level rise was not specifically discussed in this report



Source: WESR and MapX

VI. An analysis of the CAUSES of the long-term global regulation sub-issues affecting the Mediterranean LME

This chapter provides more information on the "causes" of five selected sub-issues, differentiated between immediate, underlying and root causes. Common causes across sub-issues are also highlighted.

A. IDENTIFICATION OF CAUSES

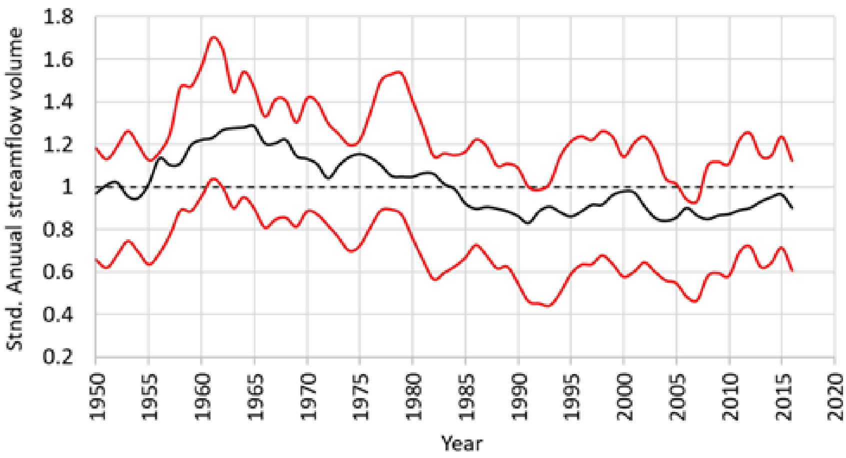
1. Changes in circulation patterns

	CAUSES						**Sub-issue**
Root	**Underlying**					**Immediate**	
Unsustainable economic development	Human activities, e.g. burning of fossil-fuels	Emissions of heat-trapping greenhouse gases	Global warming Increase in air temperature	Absorption of excess heat by oceans Changes in precipitation and evaporation Damming of rivers	**Seawater warming (sub-issue ii.)** Reduction of freshwater inputs	Changes in seawater density	Changes in circulation patterns

Unsustainable economic development driven by human activities, e.g. those resulting in the emission of heat-trapping greenhouse gases, are identified as the common roots and underlying causes of multiple sub-issues. These are discussed collectively in Section 6.2 on common causes.

A key underlying cause for the observed changes in circulation patterns is global warming. The cascade of causes leads to changes in seawater density, resulting from the interplay between increased seawater temperature and reduction of freshwater inputs. Since 1965, the Mediterranean basin has experienced a clear negative trend in riverine discharges, with volumes consistently lower than the average since the early 1980s (Masseroni et al., 2020 – Figure 14).

Figure 14. Standardized annual streamflow pattern for the period 1950-2015. Black line shows the simple rolling average of the standardized annual streamflow volume behavior over the entire Mediterranean area. Red lines show the 25th and 75th percentiles of the standardized annual streamflow volume series.



Source: Masseroni et al. (2020)

The changes in seawater density between the surface and deeper-water layers determine the rate at which deepwater forms. As argued by Powley et al. (2017a), the difficulty resides in predicting which way climate change will affect the density of Mediterranean surface waters and hence the thermohaline circulation. The expected higher temperatures and reduced precipitation have opposite effects on the density of seawater: higher temperatures decrease the density, while reduced precipitation and higher evaporation rates increase the density. So far, there is no consensus on which direction the circulation of the Mediterranean Sea may be heading.

2. Seawater warming

CAUSES					Sub-issue
Root	Underlying			Immediate	
Unsustainable economic development	Human activities, e.g. burning of fossil-fuels	Emissions of heat-trapping greenhouse gases	Increase in air temperature	Absorption of excess heat by oceans	Seawater warming

The causes of seawater warming partly overlap the causal chain for changes in circulation patterns, pointing towards unsustainable economic development and its consequences as the root and underlying causes. The increase in air temperature, leading to the absorption of excess heat by oceans, is the direct cause of seawater warming.

3. Acidification

CAUSES					Sub-issue
Root	Underlying			Immediate	
Unsustainable economic development	Human activities, e.g. burning of fossil-fuels	Emissions of heat-trapping greenhouse gases	Increase in atmospheric CO_2	Uptake of CO_2 by seawater	Acidification

The increase in atmospheric CO_2 results in the increased uptake of CO_2 by seawater. Hassoun et al. (2015) estimated the anthropogenic carbon concentrations absorbed throughout the whole water column to range between 35.2 and 101.9 µmol kg^{-1}. When compared to the global ocean, the Mediterranean Sea is able to absorb relatively more anthropogenic CO_2 per unit area because it is more alkaline. This high uptake is also related to its active overturning circulation through which the deepwaters are ventilated over shorter timescales. For this reason, the deepwaters exhibit a larger anthropogenic change in pH than typical global ocean deep waters (between -0.005 and -0.06 units; Palmiéri et al. (2015)).

Significant uncertainties still exist on the determination of past trends of anthropogenic carbon absorption by the Mediterranean Sea. This is because direct measurements in the water column are hampered by the presence of natural CO_2. Alternative data-based approaches are limited, leading to diverging concentration estimates that differ by more than a factor of two.

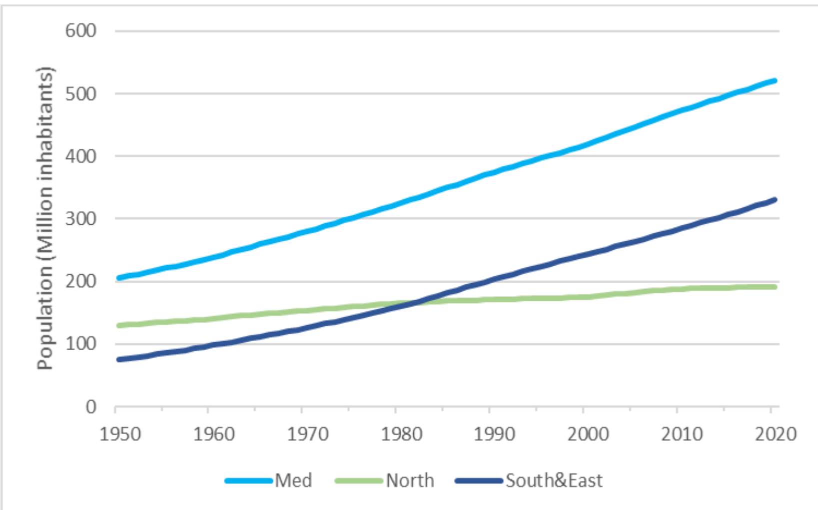
4. Changes in biogeochemical cycling

CAUSES						Sub-issue
Root	Underlying				Immediate	
Increase in coastal population	Anthropogenic activities	Anthropogenic emissions*	Measures to abate land-based nutrient inputs	Changes in nutrient inputs (riverine, atmospheric, direct discharges)	Changes in spatial distribution of substances/ water quality parameters (e.g. N & P)	Changes in biogeochemical cycling
		Damming of rivers				
Unsustainable economic development		Emissions of heat-trapping greenhouse gases	Increase in air and sea temperatures	**Changes in circulation patterns (sub-issue i.)**		

* From urban effluents, industrial discharges, agricultural runoffs, aquaculture, coastal development and tourism activities etc.

One of the persistent drivers in the Mediterranean is the increasing trend in its population (EEA-UNEP/MAP, 2020). The total population of the Mediterranean countries has surpassed half a billion people in 2016 (502 million inhabitants) and currently stands at 522 million (UN DESA data for 2020 - Figure 15). One third of the Mediterranean population lives in coastal administrative regions, which represent less than 12 % of the surface area of all Mediterranean countries. More than half of the population resides within the coastal hydrological basins (UNEP/MAP, 2017). The intensification of urbanization in coastal areas is further exacerbated by the growing number of tourists visiting the Mediterranean region.

Figure 15. Total population growth of Mediterranean countries (1950-2020) in million inhabitants.

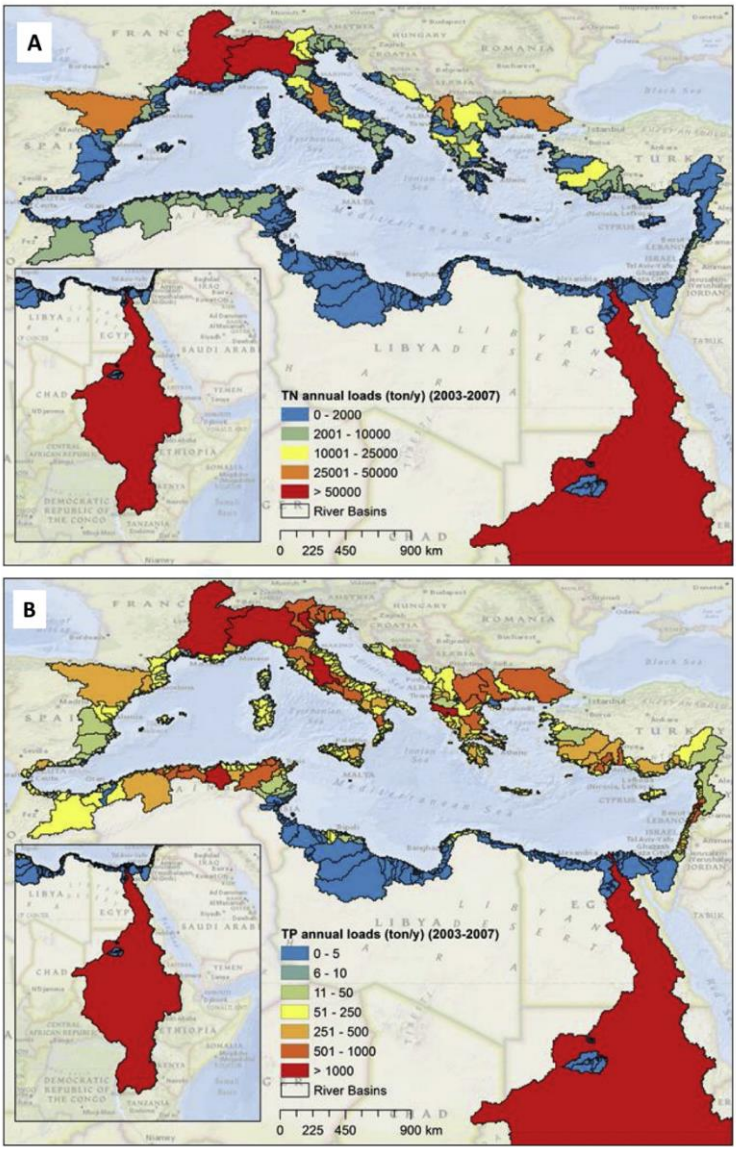


Source: UN DESA (https://population.un.org/wpp/Download/Standard/Population/)

Various anthropogenic activities, both as point and diffuse sources, lead to N and P emissions. Loads of nutrients from diffuse sources include inputs from agriculture, atmospheric deposition and mobile sources like shipping. Their contribution is commensurate with point sources (EEA-UNEP/MAP, 2020). The latter include emissions from municipal treatment plants or sewage outfalls, and industrial activities, such as power-generation plants, food and beverages, textile manufacturing, and the production of pulp and paper. Although most point sources are land-based, others can be sea-based, such as aquaculture, considered as an emerging sector in the region with prospects for further growth. A quantitative source apportionment assessment is not available at the regional level.

The overall inputs of N and P are about 1.5-4.5 and 0.1-0.4 Mt yr^{-1}, respectively (MedECC, 2020). The pathways of nutrient inputs are riverine, atmospheric deposition and direct discharges. Figure 16 shows the mean annual river basin discharges of N and P for the period 2003-2007. According to Powley et al. (2018), the largest driver of the predicted changes in the mean primary productivity of the Western basin is riverine supply, whereas in the Eastern basin atmospheric deposition plays a key role in regulating the changes in primary production. Although the impact of direct wastewater discharges is more likely to be local, and hence may not necessarily have a pronounced transboundary effect, Powley et al. (2016) estimated it to be on the same order of magnitude as riverine inputs of N and P.

Figure 16. Mean annual river basins discharge of (A) total nitrogen (TN) and (B) total phosphorus (TP) for the period 2003-2007



Source: Malagó et al. (2019)

Apart from N and P, other anthropogenic emissions to water, including heavy metals, such as cadmium (Cd), lead (Pb), mercury (Hg) and copper (Cu), are of greater concern due to their toxic nature. Pollutants may take different pathways before reaching the marine environment. For example, heavy metals, mineral oils and other types of hydrocarbons contaminating the soil may eventually leach through the watersheds into the marine environment. Emissions released to air, such as greenhouse gases, e.g. CO_2 and acidifying pollutants, e.g. sulphur oxides (SOx) and nitrogen oxides (NOx), particulate matter (PM10), volatile organic compounds (VOCs) and persistent organic pollutants (POPs) (EEA-UNEP/MAP, 2020) can all reach the marine environment through wet or dry atmospheric deposition.

The causal analysis of this sub-issue clearly highlights how land-based activities and management measures on land (e.g. wastewater management, agricultural practices, as well as damming and river discharge alterations) can directly impact the functioning of the marine system, such as marine productivity. In addition, the damming of rivers depletes sediment yields, which in part may enhance coastal erosion as well as cause other changes in the biogeochemical cycling controlled by particulate matter.

5. Waste overload

CAUSES				Sub-issue
Root	Underlying		Immediate	
Unsustainable economic development models	Increased generation of waste	Waste management practices leading to controlled and uncontrolled discharges of waste into the sea	Dilution, dispersion, absorption and removal of waste, or the contrary, accumulation	Waste overload

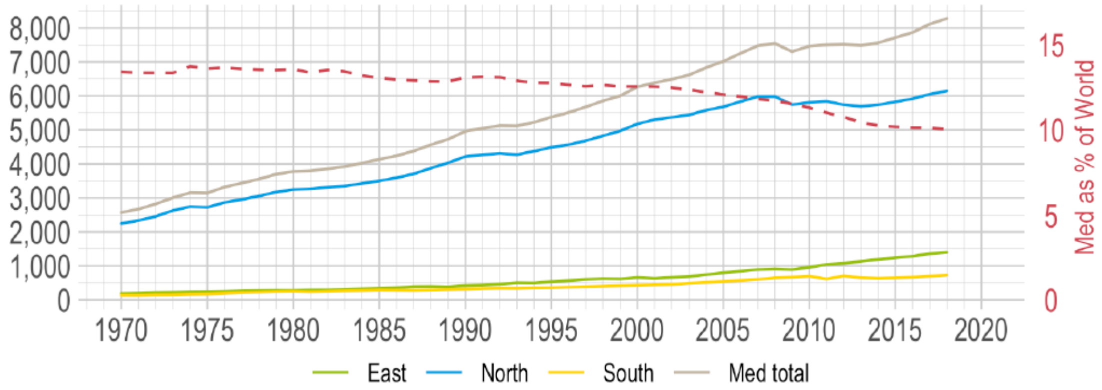
Controlled discharges of waste rely on the determination, to the degree made possible by available techniques, of the maximum amount of waste that can be discharged into different natural environments without having environmental implications, i.e. without exceeding the accommodative capacity. Economic development models based on the linear extraction of resources, rather than systemic circular models of reuse and recycling, accelerate the unsustainable production and consumption patterns conducive of the take-make-waste paradigm (EEA-UNEP/MAP, 2020). In the absence of appropriate waste management infrastructure, the generated waste may lead to uncontrolled leakages and deliberate dumping, hence exceeding the permissible maximum flux of waste material.

B. COMMON CAUSES

Although the causal analyses of the five sub-issues were developed separately, they are interrelated through common root and underlying causes. Undoubtedly, climate change, through its various manifestations and causal pathways, is the common root cause affecting the overall LME regulation and functioning. It links the sub-issues at different levels and scales. The Mediterranean is a climate change hotspot where vulnerabilities are exacerbated due to synergies with other drivers, namely growing populations, unsustainable economic development and corresponding increases in demands for resources. The accelerated pace of these drivers underpins the observed modifications in the hydrological, biogeochemical and ecological functioning of the Mediterranean LME.

Despite periodic economic instabilities caused by geopolitical, financial or health crises, the Mediterranean countries have experienced significant economic development since the 1960s. The Gross Domestic Product (GDP) for the Mediterranean countries shows an overall increasing trend in the last 50 years, despite remarkable variations and persistent gaps between the Northern and Southern shores (Figure 17).

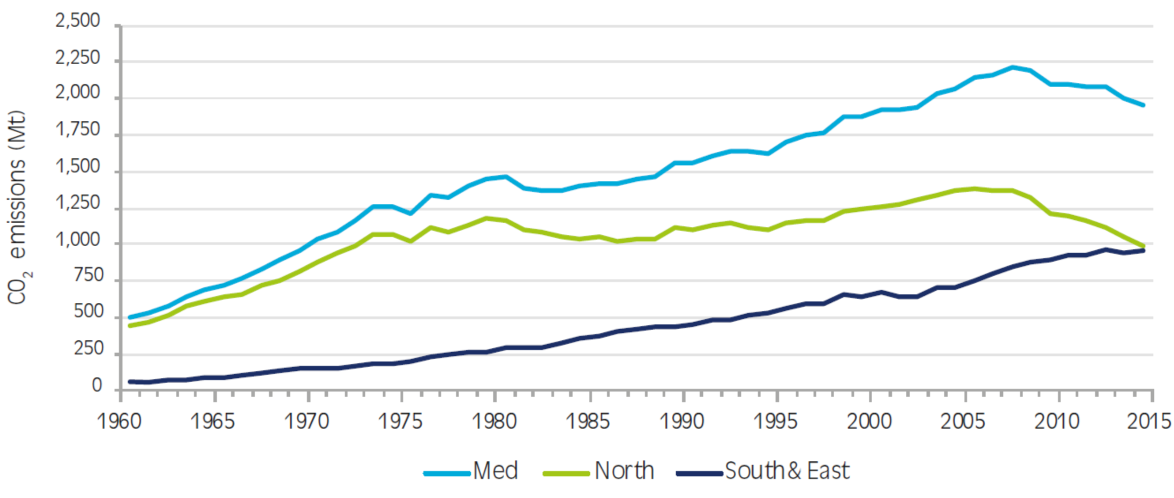
Figure 17. Gross domestic product in the Mediterranean (in billion constant 2015 USD), total and per sub-region, 1970-2018



Source: World Bank WDI (2020)

This economic development has been based on unsustainable resource consumption and resulted in major negative externalities. It has contributed directly to increased emissions of CO_2 – the primary greenhouse gas emitted through human activities. Fossil fuels overall dominate energy supply in the Mediterranean region, with heavy environmental and health impacts. Northern Mediterranean countries are responsible for relatively higher CO_2 emissions than Southern Mediterranean countries, reaching a peak in 2005. Nevertheless, emissions from Southern countries have been increasing steadily since the 1960s due to the concurrent increase in economic development and population growth, reaching comparable levels to the Northern countries in 2015 (Figure 18).

Figure 18. CO_2 emissions of Northern and South-Eastern Mediterranean countries and total CO_2 emissions of Mediterranean countries



Source: UNEP/MAP and Plan Bleu (2020) and references therein

Summary and conclusions

The assessment of the “long-term global regulation problems facing the Mediterranean LME” was structured along the following five selected sub-issues:

i. Changes in circulation patterns
ii. Seawater warming
iii. Acidification
iv. Changes in biogeochemical cycling
v. Waste overload

These sub-issues were derived from the regulatory and maintenance-type ecosystem services framework and are in line with the concept of planetary boundaries – the “safe operating space for humanity” that can be maintained through the Earth’s regulatory capacity, biophysical subsystems and processes (Rockstrom et al., 2009). The assessment shows that in the Mediterranean LME, this regulatory capacity, biophysical subsystems and processes are undergoing changes, meaning that the “safe operating space for humanity” is also changing.

Long-term global regulation issues and their change e.g. due to changes in climate and climatic variability, result in impacts on marine and coastal zones, interactions with physical and biological domains, ecosystem functioning and related vulnerabilities, transboundary contaminant transport and related risks in the marine and coastal zone etc. The baseline assessment showed that these are multifaceted issues, which contain scientifically unresolved or inconclusive complexities, often limited by long-term time series datasets, different sub-basin (Western and Eastern) functioning and other key knowledge gaps. All sub-issues are interlinked to various degrees, through physical, ecological and socio-economic pathways. Although the sub-issues are ‘marine’ in nature, their scope, including the causes and impacts, cross the air-land-sea interphases. Two cases in point are the reduced freshwater inflows causing changes in circulation patterns and variations in nutrient inputs from rivers, and atmospheric deposition leading to changes in biogeochemical cycling. The cross-cutting analysis of the five CCAs is also a clear manifestation of the triple crisis – climate change, pollution and biodiversity loss, clearly highlighting the need for holistic and integrated management plans.

The outcomes of the prioritization exercise point towards “seawater warming” as the most important sub-issue, although the prioritization scores should be only considered in an indicative and qualitative manner. The rising temperatures (and hence salinity) of the Mediterranean Sea during the past decade provide evidence of the sensitivity of the Mediterranean basin to respond rapidly to global warming and to changes in the regional freshwater budget due to its reduced dimensions and semi-enclosed character. Other sub-issues, such as changes in circulation patterns and in biogeochemical cycling are wholly or in part the result of seawater warming. Climate change and global warming emerged as the common cause for four of the five sub-issues. As for the impacts, each sub-issue results in a range of environmental and socio-economic impacts. Although each individual impact is conducive to change, multiple synergistic stressors lead to cumulative impacts. The impacts of long-term regulatory issues are often superimposed by short-term impacts, making them difficult to resolve. Just like other oceans of the world, the Mediterranean Sea is affected by global threats that cannot be entirely addressed with local action, although many impacts can be relieved with appropriate local or regional measures.

Apart from the interlinkages between the sub-issues and their CCAs, links can be drawn with the other eight issues considered in the TDA (Table 5).

Table 5. Overview of possible links between the five sub-issues considered under "Long-term global regulation affecting the Mediterranean LME" and the eight problem/issues to be considered for the TDA

"Long-term global regulation affecting the Mediterranean LME" sub-issues	Other issues to be considered for the TDA							
	1	2	3	4	5	6	7	8
i. Changes in circulation patterns	x	x		x			Cross-cutting issues	Cross-cutting issues
ii. Seawater warming			x	x				
iii. Acidification			x	x	x			
iv. Changes in biogeochemical cycling	x			x				
v. Waste overload	x	x				x		

1. Land and sea-based chemical, biological and physical pollution in transitional waters, coasts and offshore
2. Sources and fate of litter and waste pollution, including offshore seafloor
3. Nature value loss, focusing on marine habitats, biodiversity and ecosystems
4. Climate change adaptation, mitigation and socio-ecological resilience
5. Coastal belts degradation, sustainability and restoration
6. Socio-economic drivers of transformation, green recovery and sustainable blue finance
7. Observing infrastructures, including joint IMAP national monitoring data flows, regional and global indicators
8. Environmental digitalization, marine literacy and forecasting research

Being long term in nature, there are no "quick fixes" for the five sub-issues. However, this analysis showed the need to take into consideration the underlying regulatory mechanisms and their scientific complexities when designing policy measures and actions, as short-term signals may be masked by systemic, longer-term and integral processes. In addition, it also showed that tackling root causes would be the most logical, effective and efficient way to address multiple sub-issues simultaneously.

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Annex 1

Table 6. List of identified transboundary issues for the Mediterranean Sea LME region

TDA/SAP changes and challenges in the Mediterranean LME	Mediterranean transboundary areas of importance
1.Reversing Pollution	4.1. on Land and sea-based chemical, biological and physical pollution in transitional waters, coasts and offshore
2.Stopping Litter	4.2. Sources and fate of litter and waste pollution, including offshore seafloor
3.Enhancing Nature	4.3. on Nature value loss, focusing on marine habitats, biodiversity and ecosystems
4.Fighting Climate Change	4.4. on Climate change adaptation, mitigation and socio-ecological resilience
5.Sustaining Assets	4.5. on Coastal belts degradation, sustainability and restoration
6.Switching Livelihoods	4.6. on Socio-economic drivers of transformation, green recovery and sustainable blue finance
7.Integrating knowledge	4.7. on Observing infrastructures, including joint IMAP national monitoring data flows, regional and global indicators
8.Boosting Digitalization	4.8. on Environmental digitalization, marine literacy and forecasting research
9.Preventing Crises	4.9. on Long-term global regulation affecting the Mediterranean LME

Source: TDA Objectives, Milestones and Work Plan report, 2021

Annex 2

Data and information gathered from different workstreams and assessments of the region. The key ones included (excluding scientific papers):

Regional assessments (and references therein):

- UNEP/MAP and Plan Bleu (2020). State of the Environment and Development in the Mediterranean. Nairobi.
- MedECC (2020). Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report [Cramer, W., Guiot, J., Marini, K. (eds.)] Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, 632pp.
- EEA-UNEP/MAP (2020). Technical assessment of progress towards a cleaner Mediterranean. Monitoring and reporting results for Horizon 2020 regional initiative. Joint EEA-UNEP/MAP Report. EEA Report No 08/2020.
- UNEP/MAP (2017). Mediterranean Quality Status Report. Mediterranean Action Plan, Barcelona Convention and United Nations Environment Programme.
- Piante C., Ody D. (2015). Blue Growth in the Mediterranean Sea: the Challenge of Good Environmental Status. MedTrends Project. WWF-France. 192 pp.
- UNEP/MAP/MEDPOL (2005). Transboundary Diagnostic Analysis for the Mediterranean Sea.
- Copernicus Ocean State Reports

Data and indicators

- Sustainable Development Goals (SDG) data and indicators
- Mediterranean Strategy for Sustainable Development (MSSD) data and indicators
- Integrated Monitoring and Assessment Programme (IMAP) data and indicators
- Shared Environmental Information System (SEIS) data and indicators
- CMEMS Ocean Monitoring Indicators for the Mediterranean
- World Bank and UNstat databases for socio-economic data
- UNEP World Environment Situation Room (WESR) and associated cartographic tool MapX

Other sources

- GEF IW: Learn (2020). Transboundary Diagnostic Analysis/Strategic Action Programme Manual. TDA-SAP Methodology (https://iwlearn.net/manuals/methodologies)
- Med 2050 Programme outputs, in particular relevant thematic factsheets