

Integrated Coastal Zone Management (ICZM) Framework and Ecosystem Approach: eutrophication phenomenon at the Mediterranean Sea.

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Abstract

The Mediterranean environment stressors and their effect on trophic state require the assessment of interconnection between land-based drivers, the real and potential pressures and impacts. To achieve this, it is necessary to consider as well, several social and economic factors that may influence decision-making around land-sea planning and the management of nutrient, pollutants and sediment transport. Moreover, once the ecological situation is characterized, it is advisable to establish the linking between the natural systems and the ecosystem services. In the Mediterranean Sea, it fairly demonstrated by ecosystem-based management approaches and the literature that human activities can affect the water column, the seafloor, and the biodiversity, among others. Moreover, it is a fact that these issues require a detailed piece of knowledge of a wide variety of geological, sociological, economical and biological variables, among others. Those variables are dependent on prioritises actions. One of them is the monitoring, mitigation and control of the eutrophication processes, which needs the deconstruction of the Integrated Coastal Zones Management (ICZM) approach into priorities actions, in accordance with the multi-level water characteristics and their interconnection, i.e., the coastal zone dynamics, and the multilevel governance.

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1. Introduction

Water is one of the most sensitive elements of the environment and a prerequisite for human well-being and the development of its activities as it provides several ecosystem services (Piroddi *et al.* 2016). However, there are several factors that can influence its ecological status.

Human activities and climate change induced ecosystem vulnerability can provoke several coastal morphology changes that can also negatively influence on the land-ocean interface (Ochoa-Hueso *et al.* 2017), which is a particularly fragile, sensitive and complex environment. Thus, the effect induced by progressive anthropic changes on the hydrodynamic characteristics of the coastal and estuarine waters (Morrow *et al.* 2017), and as well on the ocean circulation (Grifoll *et al.* 2016), can lead to a high variability of marine biogeochemical processes, and cause negative impacts on the status and services of the near shore ecosystem, on which coastal societies depend. Moreover, these changes can drive to dramatic economic and human health impacts (Powley *et al.* 2014).

In the near shore in general, and specifically, in the Mediterranean Sea, due to the existing strong demographic and economic pressures and to other environmental drivers (i.e. wind speed, acidification, eutrophic depth, thermohaline depth, evaporation-precipitation abundance) the boundary status and the water column stability across the longitudinal environmental gradient can result directly impacted (Reygondeau *et al.* 2017). The tendency of the population to develop its activities on the coast - especially in the Mediterranean Sea - can increase the stress on its ecosystems and their surrounding areas and cause impacts on water quality and sediment characteristics, fauna diversity, flora richness, and their ecological interactions (Piroddi *et al.* 2017). Several examples can observe at some lagoons of Tunisia (Khedhri *et al.* 2016), lakes of Egypt (Abukila, 2015), rivers, estuaries, and littoral of Algeria (Kies and Kerfouf, 2014b), Spain (Grinyó *et al.* 2016), France (Kapsenberg *et al.* 2016), Italy (Katsanevakis *et al.* 2016), and Albania (Blanfuné *et al.* 2016).

Moreover, the Mediterranean Sea faces a variety of environmental problems, including habitat morphological alteration, water degradation, eutrophication, introduction of alien species, shoreline erosion, and increase of the surface water vulnerability (Maugendre *et al.* 2015) and the deep sea due to climate change induced sea level rise and ocean warming (Yasuhara and Danovaro, 2016), among others. These facts make necessary an integrated management strategy for this coastal zone (Zaucha *et al.* 2016).

As one of the biggest environmental problems for coastal waters is the over-enrichment in nutrients – i.e. eutrophication – from natural and/or anthropogenic inputs, this issue has become a topic of great interest. Eutrophication frequently results from natural (Laspidou *et al.* 2017), human actions such as domestic wastewater discharge, river damming, agricultural activities (Maavara *et al.* 2015), and production of biofuels from energy crops (Van Wijnen *et al.* 2015),

which have an effect on water quality in rivers and coastal seas, and several ecosystem components and their ecosystem services (Colella *et al.* 2016).

In fact, serious eutrophication cases had been observed in the Mediterranean Sea, such as the ones of certain lagoons of Tunisia and France (Leruste *et al.* 2016), some estuaries and coastal zones of Spain (Aparicio *et al.* 2016), Greece (Pavlidou *et al.* 2015), among others.

The introduction of an excess of nutrients into the coastal areas results in a number of direct and/or indirect impacts (Coppens *et al.* 2016). The most common is eutrophication that can cause the following impacts: (1) overproduction of algal biomass (Bužančić *et al.* 2016); (2) loss of near shore habitat such as sea grass beds due to light reduction and soil erosion (Lopez-Merino *et al.* 2017); (3) variability in marine biodiversity, species distribution, and community composition (Abou Zaid *et al.* 2014; Pilotto *et al.* 2015); (4) reduction of water transparency due to increases in organic particles (Higuera *et al.* 2014); (5) and depletion of dissolved oxygen: hypoxia and anoxia (Segura-Noguera *et al.* 2016).

Furthermore, these effects can cause adverse impacts further up, along the trophic chains (Zoccarato and Umani, 2015) causing the death of pelagic and benthic fauna or at least, its disturbance. Some examples are the case of some shellfish affected by toxic phytoplankton species, and the apparition of microbial organisms that can impact directly and/or indirectly on the human health (Ridanovic *et al.* 2017). The aim of the present study will point out some environmental consequences of eutrophication and its relevance in the Mediterranean, in addition describe participatory approaches that should be involved to support the implementation of the Marine Strategy Framework Directive to manage the Mediterranean resources.

2. Material and Methods

Integrated Coastal Zone Management (ICZM) approach: ICZM (2012-2019) can be understood as a dynamic, multidisciplinary and interactive process to promote and guarantee the sustainable management of the littoral. It should include the ecosystem-based approach actions for the maintenance of the functionality of the coastal ecosystems for the reduction of human conflicts relative to management and/or use of resources (Santoso and Halog, 2017). In sum, a multi-sectorial approach towards the sustainable development seems to be necessary (Gambino *et al.* 2016) (Figure 1).

Moreover, ICZM should cover the full cycle of information collection, planning, decision making, management and monitoring of implementation and use the informed participation and cooperation process of all coastal stakeholders to assess the societal goals of a given coastal area and to take action towards meeting these objectives. ICZM seeks, over the long-run, to balance environmental, economic, social, cultural and recreational objectives, all inside the bounds set by natural dynamics (Potts *et al.* 2015; Freire-Gibb *et al.* 2014).

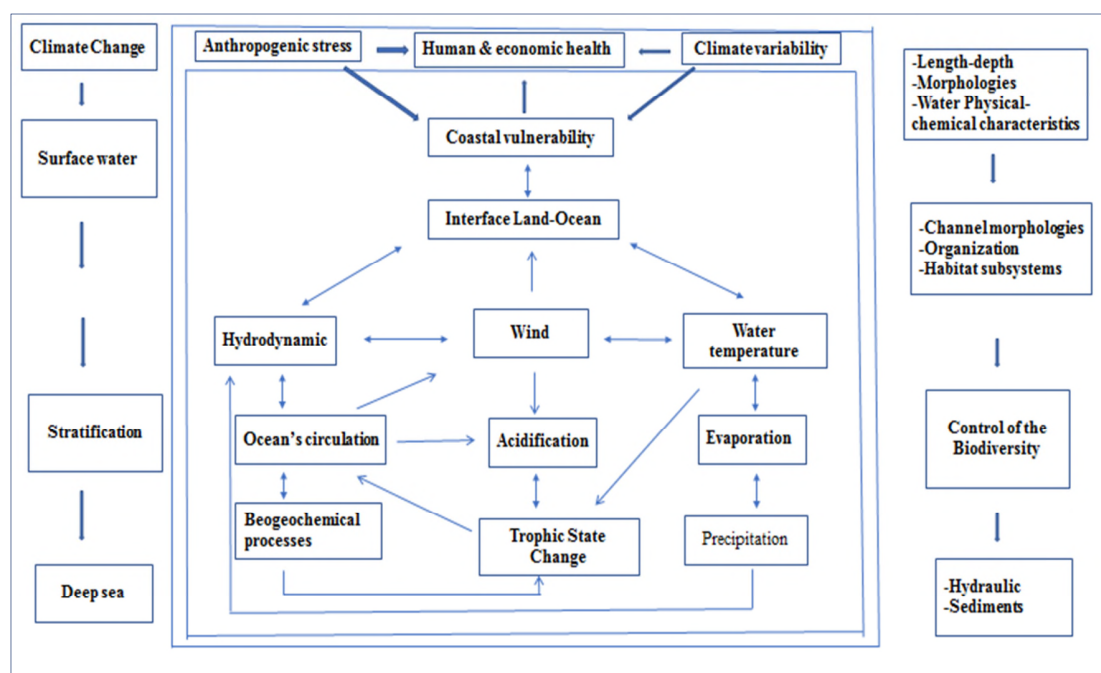


Figure 1: Conceptual diagram of human stressors and climate interactions on biogeochemical processes, effect on trophic state.

'Integrated' in ICZM can be relative to the integration of objectives and many instruments are needed to meet these objectives (Knežević and Petović, 2016). This fact implies all relevant policy areas, sectors, and levels of administration, which signifies the integration of the terrestrial and marine components of the target territory, in both, time and space. Defining the coastal zone is of particular importance to the implementation of ICZM. But the indistinctness of borders as a result of the dynamic nature of the coast makes it tough to obviously outline, especially in regard to the Mediterranean Sea.

ICZM at the Mediterranean Sea have been applied to achieve the Good Environmental Status (GEnS) of its ecosystems by 2020 (Knežević and Petović, 2016). (Figure 2).

It should conduct this part of the ocean towards a sustainable multi-dimension (local, national, regional, international, and temporal), ensuring the continuity of the futures generations and among others minimising the eutrophication (Annexe I of the Marine Directive, Descriptor 5).

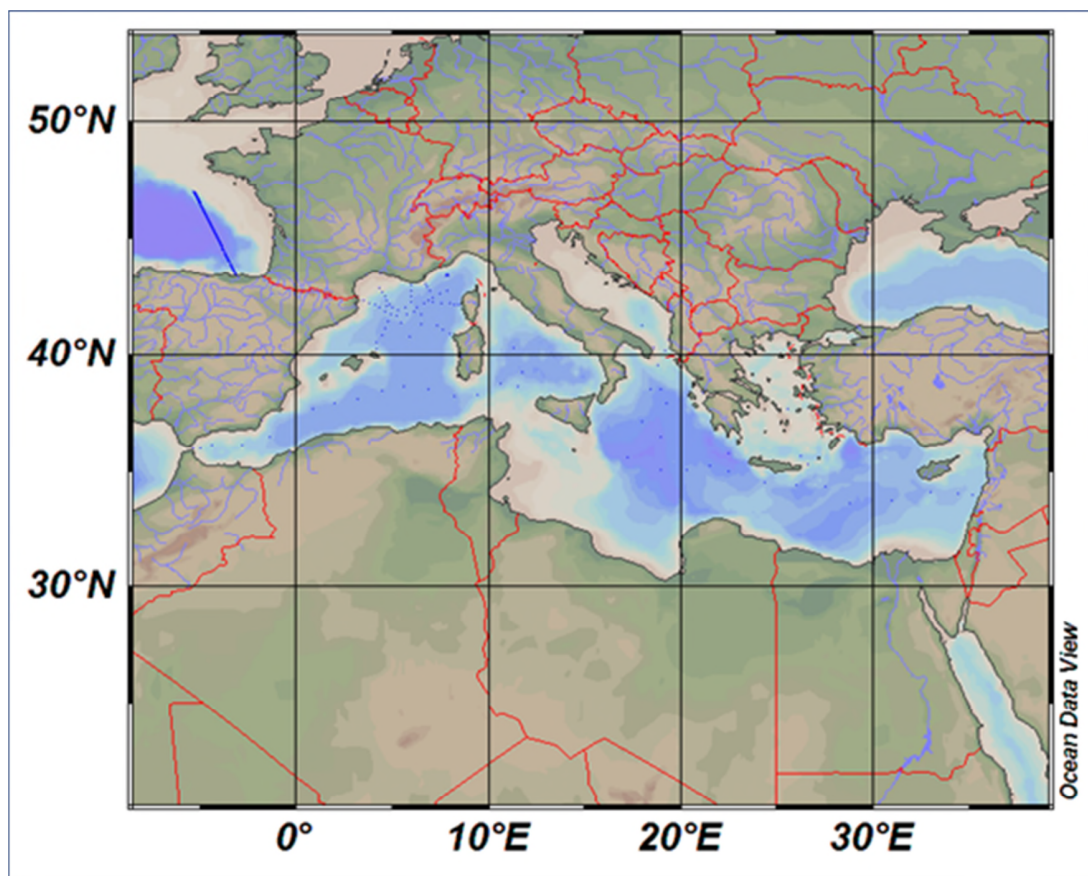


Figure 2: The Mediterranean Sea. The map was created using Ocean Data View (<https://odv.awi.de>).

The implementation of the Ecosystem Approach Process (2016-2021) at sensitive and vulnerable coastal areas (Jeppesen *et al.* 2017) such as the Mediterranean, in order to assess their status and as a basis for further and/or strengthened measures (La Notte *et al.* 2017), will allow countries to propose adequate measures to achieve the Good Environmental Status. In this way, ICZM could be implemented by the countries themselves taking into account their local specificities (Teixeira *et al.* 2014), focusing on innovation and blue growth based on ecosystem services (Karydis *et al.* 2015). Furthermore, it will bring more objectivity in the management of their coastal zones with the adoption of ecosystem approach in the coastal zones (Liquete *et al.* 2016).

A study case: Mediterranean Sea: common issues of the countries along the Mediterranean Sea are, the artificialization of the coast driver by over expanding tourism and urbanisation (Ghodbani and Berrahi-Midoun, 2013; Nakhli, 2010), the alteration of coastal dynamics and the degradation of its ecosystems and habitats (Roca *et al.* 2016), the increase of environmental risks along the coast, the loss and degradation of the landscape, the development of environmental problems due to aquaculture (Abdou *et al.* 2017) and the dwindling of the traditional fishery industry (Gambino *et al.* 2016), among others.

3. Results and Discussion

Coastal issues interconnection: the patterns of climate inputs, and the population distribution and activities (Masria *et al.* 2014) underpin the variety between the ‘type’ and the ‘intensity’ of drivers and pressures (Table 1, Figure 3) across the four sub-regions of the Mediterranean.

Table 1: Assessment of land based Drivers, Pressures and Mediterranean and Estuaries Coastal Impacts.

		South West SW	South East SE	North West NW	North East NE	
		4: Impacts/Responses (IR)				
1: Drivers (D)	Agriculture	+++	+++	+++	+++	
	Urbanization	+++	+++	+++	+++	
	Industrialization	++	++	+++	+++	
	Deforestation	+++	++	++	++	
	Damming/ diversion	++	+++	++	++	
	Various	+++	+++	+++	+++	
	Eutrophication/pollution	Medium (L.M)	Major	Medium (L.M)	Major	
2: Pressures (P)	Nutrients depletion	Medium	Medium	Medium	Medium	
	3: States (S)	Erosion/Sedimentation	Major	Major	Major	Major
		Biodiversity loss	Major	Major	Major	Major
	Pollution	Medium	Medium	Major	Major	
	Salinization	Major	Medium (L.M)	Major	Major	

Very important: +++; +/- important: ++; and less important: +; L.M: Local Major

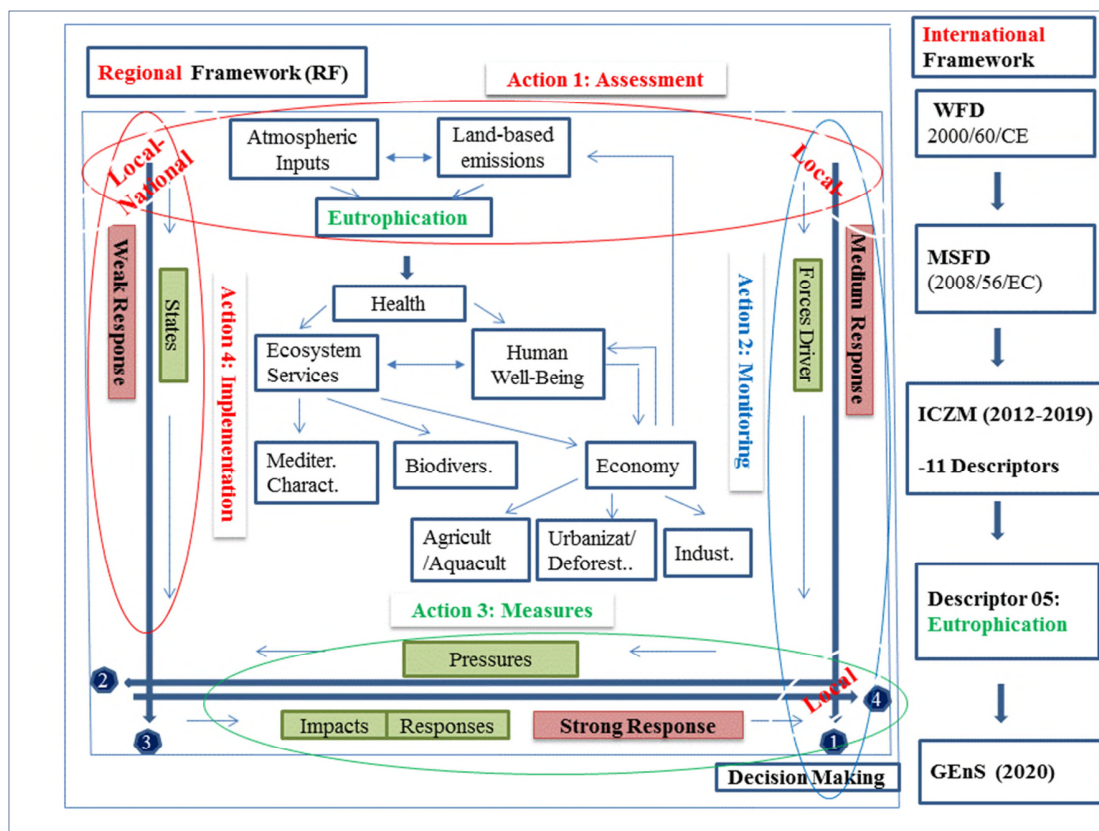


Figure 3: Integrated analysis of eutrophication: Conceptual model describing the linking between Ecosystem services, human well-being, and the complex ecosystem effects of Eutrophication within the Integrated Coastal and Estuarine Zones (Mediterranean Sea).

Agriculture and deforestation are contributing to significant increases in soil erosion and consequently increased sediment fluxes and discharge (Serra *et al.* 2008). Agriculture, together with urbanization and industrialization is provoking the degradation of the waters that discharges into estuaries and coastal seas. This fact leads to growing problems of pollution and eutrophication (Abdou *et al.* 2017). Industrialization coupled with deforestation can generate the aggravation of the Mediterranean environment problems and consequently provoke impacts over human health. All the socio-economic drivers referred play a part in the reported loss of biodiversity throughout the region, principally through the destruction of habitat and reduction in the volume and the quality of freshwater discharge through the coastal zone to the coastal sea. Diversion and damming usually in association with agriculture and locally intense urbanization are principal drivers for a coastal charge (Abdou *et al.* 2017). Increasing industrial developments, coastal urbanization, and high density coastal population add further pressures. Deforestation in upper catchments is a continuing concern.

The approach for the integrated analysis of ecosystem and human health, request a complex analysis using the Drivers-Pressures-State-Impact-Response (DPSIR) framework. The coastal

zone of the sparsely populated northern sub-region of the Mediterranean sustains anthropogenic pressures from coastal urban areas and industrial development, these represents the major drivers and modifications such as changes in the shorelines of the Mediterranean countries (Pilotto *et al.* 2015) and the relation with the multi-level changes in the regional and global circulation (Cossarini *et al.* 2017) and cycles as well as changes in sea level and wave regimes (Peyron *et al.* 2016). The most significant impact derived from the rapid economic growth in the lakes (Ferriol *et al.* 2016) and rivers basins is increased nitrogen loading to the coast (Kies, 2015). Pronounced state changes in the receiving marine environments of the rivers and estuaries result from eutrophication yielding algal blooms, oxygen depletion, contamination of water quality and the ecosystem components (Kies, 2015). The Dinoflagellate bloom of *Gymnodinium sp* and *Dinophysis sp* resulted in the loss of demersal and benthic fish stock, and the disturbance of macro-invertebrates (Leung, 2015).

Marine policies: for several decade, eutrophication (Figure 3) has been an international environmental concern in Europe which lead to the regional framework (RF) addressing the problem including the Barcelona Convention or MEDPOL for the Mediterranean (Ferreira *et al.* 2011). The two relevant European legislative frameworks that influence on this issue are the 2000 EU Water Framework Directive (WFD) “Directive 2000/60/EC” and the 2008 EU Marine Strategic Framework Directive (MSFD) “Directive 2008/56/EC” (Van Hoey *et al.* 2010). Whereas the WFD is limited to the territorial estuarine and coastal waters, stretching 12 m from the coast, the MSFD applies to the marine waters, stretching the 200 m limit of the Exclusive Economic Zone. The adequate implementation of these legislative agreements (Reyjol *et al.* 2014) depends on a proper definition of the phenomenon as well as measurable and practical indicators (Freire-Gibb *et al.* 2014). The MSFD is aimed at achieving a GEnS by 2020, following an ecosystem-based approach (Berg *et al.* 2015), and addresses the problem of climatic and human-induced eutrophication as one of eleven environmental quality descriptors which should be used in combination to assess the environmental status of marine (Cochrane *et al.* 2016), transitional and coastal waters. These eleven descriptors are: biological diversity, non-indigenous species, commercial fish, food webs, eutrophication, sea floor, hydro-geographical conditions, contaminants and pollution effects, contaminants in fish and other seafood, litter, and energy/noise (Noges *et al.* 2016).

The MSFD eutrophication quality descriptor refers to the adverse effects of eutrophication including “*losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters*” (Noges *et al.* 2016). According to UNEP/MAP, 2007, the assessment and monitoring of the eutrophication in the Mediterranean Sea requires monitoring parameters for the indicators (COM DEC 2010/477/EU) of eutrophication only for the Mediterranean Coastal waters (WFD) which are, Nutrients concentration in the water column (5.1.1); Nutrient ratios (silica, nitrogen and phosphorus), where appropriate (5.1.2); Chlorophyll concentration in the water column (5.2.1); Dissolved oxygen, i.e. changes due to increased organic matter decomposition and size of the area concerned (5.3.2).

Causes and consequences of eutrophication in multi-level: the main causes of eutrophication are the atmospheric inputs and land-based emissions, stages of the process driven (drivers) by over-enrichment of water by nutrients (medium response), especially compounds of nitrogen and/or phosphorus (pressures), leading to the increase growth primary production (weak Response) and biomass of algae (state); changes in the balance of organisms, and water quality degradation (impact), causing degradation of the health of the ecosystem services (strong response) which has an impact directly and/or indirectly on Mediterranean water characteristics, disturbance of the biodiversity community, economic imbalance affecting the different activities which human life depend such as the agriculture, aquaculture, fishing, urbanization/deforestation, and industrialization, it means impact directly and/or indirectly human well-being (strong Response). According to the literature, in the national level, the intensity of responses considers weak comparing to the local level, where the intensity of responses ranges between medium and strong (local Major) depend the environment types and intensity impact (Table 1, Figure 3).

Priorities actions to manage eutrophication in Mediterranean multi-level scales: the Mediterranean has multi-level scales, that requires prioritises actions to manage eutrophication, which needs the deconstruction of the ICZM into different priorities action in accordance with the level scale.

By Assessment in the local and National level (Weak to Medium Response), of the functioning of nutrients especially compounds of nitrogen and/or phosphorus in relation to drivers/pressures; and holistic monitoring in the local level (strong Response) of changes in the balance of organisms, and water quality degradation causing degradation of the health of the ecosystem services and human well-being; and measures in the local level (Medium to Strong Response) of growth primary production and biomass of algae, in the sensitives areas discharges such as basin rivers, estuaries, lacks, and lagoons (Basset *et al.* 2013), causing eutrophication process affecting surrounding zones, causing degradation of the economic and human health; needing implementation of projects oriented at solving priority environment and sustainable development related problems of some hot spots for eutrophication in selected areas (local level), contributing to the formulation and implementation (national level) of relevant national policies and strategies with projects results and solutions proposed (the implementation of ICZM, Descriptor 5 related to the eutrophication, and indirectly by offering methodologies and procedures tested under specific local conditions and national instruments such as big data phytoplankton (Robinson *et al.* 2017), phytoplankton community “Chlorophyll a” (Mangoni *et al.* 2016), and Data Eutrophication Management, Geospatial Data and Metadata (Pons and Maso, 2016), land-use planning, sea-use planning, norms, standards, economics instruments, to achieve a GEnS. The Trophic Index “TRIX” (Vollenweider *et al.* 1998) that was proposed for assessment and monitoring of the eutrophication in the Mediterranean Sea requires data on Chlorophyll a, oxygen saturation, dissolved inorganic nitrogen and dissolved inorganic phosphorus, but the literature demonstrate the inefficacy of TRIX as a reliable tool to classify eutrophication status in transitional waters (Salas *et al.*, 2008). In addition, data about hydrodynamic and hydro-chemical parameters,

hydrogeology parameters, biomass and abundance of zooplankton, benthic invertebrates, coastal fish length should be monitored (Pons and Maso, 2016).

The adoption of a multidisciplinary approach, covering the different fields involved in designating and assessing transitional, coastal, and marine waters. Ecosystem-based management of activities affecting water-column, seafloor, and their biodiversity, requiring knowledge of a wide variety of ecological and biological variables (Danovaro *et al.* 2017) such as the multi-level water characteristics and their interconnection, biodiversity, life cycles, functional variables, trophic interactions, and organic-matter cycling, supported by abiotic measurements and (Noges *et al.* 2016) detailed habitat mapping (Valle *et al.* 2015) by disseminating the results and experience achieved contributing to the formulation and implementation of relevant regional policies and strategies, at a wider multi-level water governance systems and International Relations (Daniell *et al.* 2014), and transnational threats and risks in Organizations and Time, requiring knowledge-based management (O'Brien *et al.* 2016), by co-operating, exchanging, and offering results, methodologies and procedures to other regions, evaluation and assessment techniques including environmental impact assessment in better times, forecast and modelling tourism capacity, strategies, climate changes and vulnerability assessment of landscape-seascape/territory.

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Appendix S1. Non-exhaustive list of social and economic factors that may influence decision-making around land-sea planning and the management of nutrient and sediment loading once the ecological situation are characterized using the decision tree.

Topic	Element	Description
Culture and Politics	Presence and Use	The presence of people in the region of interest, and their relative dependence on the oceans for all of the services listed below.
	Access	Some communities may hope to limit access of outsiders to their coastal oceans; others may have been excluded from parts of the coastal oceans they would like to regain access to.
	Culture	Some communities may disproportionately value access to culturally meaningful places, practices, and species.
	Existing Legal Structure Land Tenure	The feasibility and expected success of land-sea planning are partially dependent on whether legal options exist to enact and enforce it. In some regions, shifting communities and resource use in space may be relatively feasible, while in others it may be all but impossible due to constraints on land use or other cultural, political, and legal factors.
Revenue and Livelihoods	Tourism	Runoff and subsequent ecological degradation may reduce the tourism value of coastal ecosystems, particularly coral reefs.
	Fisheries	Revenue and subsistence from coastal fisheries may be an important consideration, although runoff will not necessarily decrease catch or value in the fishery.
	Aquaculture	Aquaculture has the potential to exacerbate runoff issues by increasing pollutant and nutrient loads in rivers, or to mitigate them if suspension feeders are cultivated near the river mouth.
Health and Nutrition	Harmful Algal Blooms	In some cases, nutrient loading leads to HABs, which have adverse impacts on human health and on fisheries.
	Toxicity and Pathogens	Pollutants and pathogens transported by rivers have clear consequences for human health and may originate from numerous sources including mines, sewage, and aquaculture.
	Nutrition and Food Security	Land-sea planning may be more of a priority in communities that rely primarily on seafood for nourishment, or that highly value having access to seafood in addition to other food sources.
Ecosystem Services	Coastal Defenses/Buffer s	Habitats that buffer storms and filter runoff, such as salt marshes and wetlands, may provide a valuable service to coastal communities.
	Aesthetics and Sense of Place	Community members may inherently value some coastal areas more than others, possibly for their natural beauty or their historical meaning.
	Recreation	How local communities use the region recreationally, and which places they value for this purpose, may be relevant.
Watershed Context	Land Regulations of Human Activities	Some watersheds may already regulate runoff-producing activities such as sewage disposal, agriculture, and deforestation, while others may have no controls on those drivers.
	Land Regulations with Ancillary Marine Benefits	Converse to the above consideration, some legislation enacted for entirely different purposes may have unintended positive effects in the oceans, particularly when drivers are mitigated upstream for terrestrial conservation purposes.