CHAPTER 1 /

Introduction

The deep-sea is the largest and unexplored environment on the planet. It is defined as the region starting below the continental shelf-slope break[1]. Thus, it is formed by a large part of the continental margin and by the deep basin proper. Another definition that applies to the deep-sea habitat relates to the definition of bathymetric zones. The *bathyal* zone includes all the continental margin, from a 200 to 3000 m depth, while the *abyssal* zone embraces most of the deep seafloor between depths of 3000 and 6000 m and the *hadal* zone below this. The deep-sea comprises a variety of different habitats, from canyons and plains of mud, to rocky seamounts, mud volcanos, chemosynthetic environments, brine lakes, pockmarks and deep-water coral frameworks, among others. Covering 65% of the Earth's surface, less than 0.0001% of the deep-sea has been explored so far, making it the least explored environment on Earth[2,3]. Recent expeditions within the framework of the Marine Life Census have documented that deep-sea biodiversity is very unevenly distributed in different oceans and ocean basins[4].

Mediterranean scientists began studying life in the deep-sea in the 19th century. The Pola expedition (1890-1893) was the first systematic oceanographic expedition followed by the Dana (1908-1910) and Thor (1921-1922) expeditions[5], while Pérès and Picard[6] provided the first detailed deep biological observations with dredges in the Eastern Mediterranean and the Greek Seas. Nevertheless, most scientific studies on Mediterranean deep-sea ecosystems have occurred during the last one or two decades. These works, through different projects and initiatives, have expanded the knowledge of its hydrodynamics, geomorphology and biodiversity. A synthetic review of the existing information on Mediterranean deep-waters and ecosystems, including a strategic plan for research, conservation, management and monitoring, has been compiled by IUCN (2019)[7] with the contribution of many experts. Most scientific studies on deep-sea ecosystems took place after the development of the deep-water fishery sector in the early decades of the 20th century[8].

The Mediterranean Sea has always been central to the economies of the coastal countries and it is known to be under intense pressure from human activities as well as experiencing a strong interest for blue growth[9,10]. It is considered a marine biodiversity hot-spot with more than 17,000 marine species known in the area and a uniquely high percentage of endemic species[11,12]. It is composed mainly by deep-sea habitats, with a mean depth of 1500 m and a maximum depth of 5267 m, found in the Calypso Deep in the Eastern Ionian Sea. First estimations indicate that its deep-sea biodiversity (excluding prokaryotes) could be composed of approximately 2805 species of which 66% are still undiscovered[13]. Deep-sea biological resources have also been investigated more extensively in the last decades, particularly for the red shrimps (*Aristaeomorpha foliacea* and *Aristeus antennatus*), since they are the main target species of deep-water fisheries. The effect of deep-water fisheries on the commercial stocks as well as on bycatch of vulnerable species and associated habitats has also been the objective of several research projects and studies.

In the Eastern Mediterranean, various research projects and studies have been carried out in the deep-sea over the last 15 years with a number of multidisciplinary collaborations (i.e. projects, cruises etc.) revealing the complex geomorphological relief of its ecosystems with diverse geological, physical and biochemical characteristics that account for a wide variety of seabed features and benthic communities (see list provided in Annex). In the next few paragraphs, we review the geography and hydrology of this deep-water environment and how it affects deep-sea biodiversity.

Eastern Mediterranean Environment

The Mediterranean is divided into the western and central-eastern basins, which are separated by the Strait of Sicily. The Eastern Mediterranean Sea, as defined here, includes the Ionian Sea east of N18°E, the Libyan and Levantine Seas and the Aegean Sea. This rather small oceanic region connects three continents: Europe to the North, Asia to the East and Africa to the South. It belongs to the most active areas on the Earth in terms of plate tectonic movements and seismicity, as it hosts the active convergent margin between Eurasia and Africa. It is also characterized by complex geomorphology, a direct result of the tectonic processes prevailing in this area.

The Eastern Mediterranean Sea consists of three main deep basins: the Ionian, Aegean, and Levantine. For the purposes of this work, the Eastern Mediterranean Sea has been divided into five regions which will be described separately (Fig. 1.2). Major geomorphological elements define the boundaries between them. The Hellenic Arc marks the boundary between the Eastern Ionian Sea (region 1) and the Libyan Sea (region 4) in the south and the Aegean Sea in the north. The south-eastern edge of the Mediterranean Ridge separates the Libyan Sea from the Levantine Sea (region 5). The Aegean Sea is divided into two regions: the North Aegean Sea (region 2) extends north of the northern margin of the shallow Cyclades Plateau; the South Aegean Sea (region 3) extends between the Cyclades Plateau to the north and the Hellenic Arc to the south.

The Eastern Mediterranean deep-sea floor includes regions characterized by complex sedimentological and structural features: continental slopes, submarine canyons and landslides, base-of-slope deposits, seamounts, cold seepages (including mud volcanoes and pockmarks), hydrothermal vents, bathyal or basin plains with abundant deposits of muds and the deep-hypersaline anoxic basins.

In the following chapters we describe in more detail the geomorphology and main geomorphic features illustrating how volcanic, tectonic, hydrothermal and sedimentary processes sculpt geomorphology in the Eastern Mediterranean deep-sea, particularly seamounts and canyons, as well as species diversity and abundance.

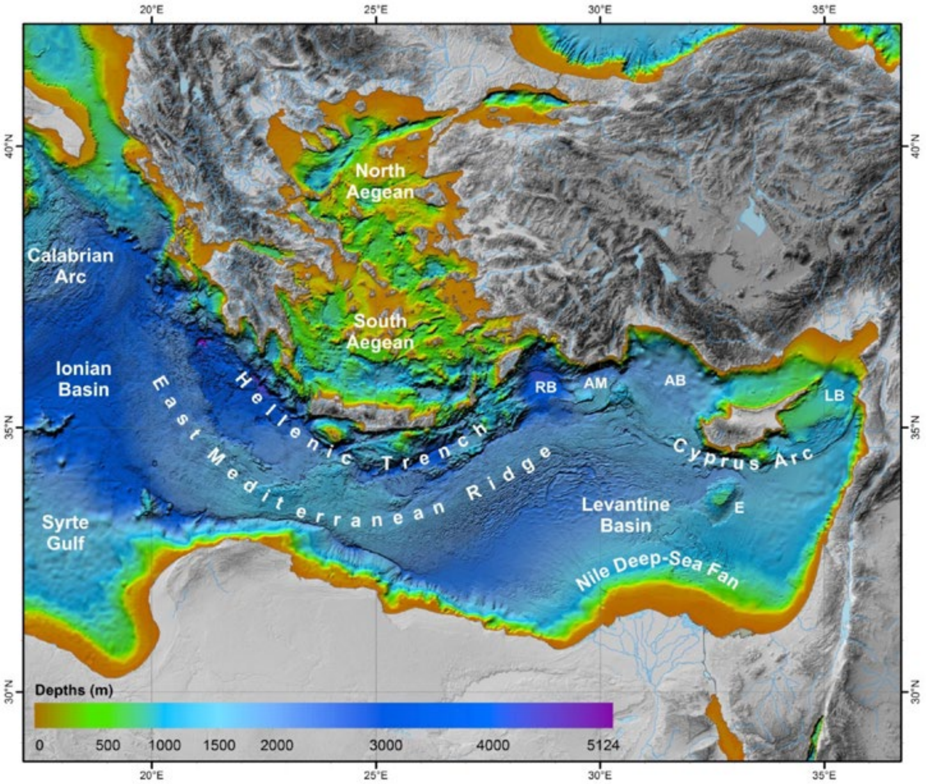

Fig. 1.1. Main geomorphological elements of the Eastern Mediterranean Sea. AB: Antalya Basin, AM: Anaximander Mountains, E: Eratosthenes Seamount, LB: Latakia Basin, RB: Rhodes Basin. Seafloor topography: "EMODNET Bathymetry" 250 m grid (2016). Land topography: SRTM90

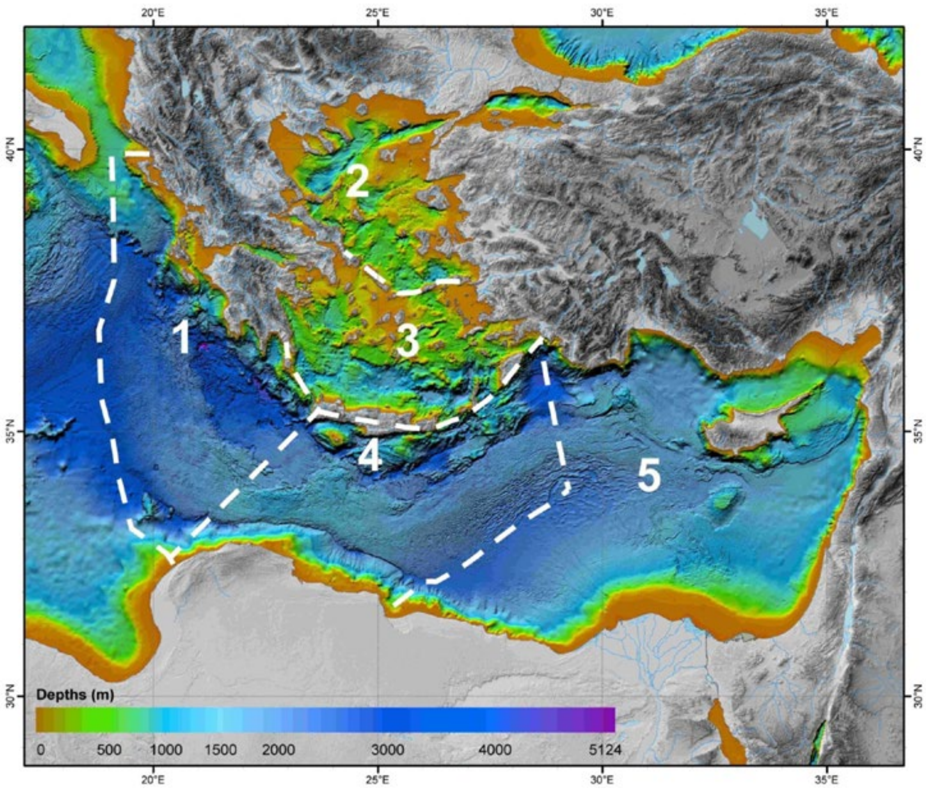

Fig. 1.2. The five regions of the Eastern Mediterranean Sea defined for the purposes of this work: Ionian Sea, 2: North Aegean Sea 3: South Aegean Sea, 4: Libyan Sea, 5: Levantine Sea. Seafloor topography: "EMODNET Bathymetry" 250 m grid (2016). Land topography: SRTM90


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HYDROGRAPHY

Kontoyiannis H. and Iona S.

The Eastern Mediterranean is known as the source region of the high-salinity intermediate water mass that spreads into the North Atlantic, after its propagation through the West Mediterranean and exit to the Atlantic through the Gibraltar Strait. In this respect, the basic physical identity of the Eastern Mediterranean is that it is a '**concentration basin'**, i.e., it receives lower salinity water from outside and then it generates and exports high-salinity water masses to the neighboring basins of the Black Sea and the Western Mediterranean.

The Eastern Mediterranean is connected to the West Mediterranean through the Strait of Sicily and to the Black Sea through the Dardanelles Strait in the North Aegean Sea (Fig. 1.3). It is also connected to the Red Sea through the Suez Canal; this connection is very small and is considered to be practically closed in view of the dynamic exchanges. In the Sicily Strait, the E. Mediterranean receives low-salinity (~37.0-37.7) **Modified Atlantic Water** (MAW) in the upper ~80 m and exports high-salinity (~38.0-38.5) Levantine Intermediate Water (LIW) in the deeper layers (~150-350 m). In the Dardanelles Strait, it similarly receives low-salinity (~26-30) Black Sea Water in the upper 20 m and exports subsurface high-salinity (~38.6-38.9) water of the North Aegean[14]. The main water masses that can be detected in the Eastern Mediterranean, apart from the MAW in the upper layer, are: 1) the **Levantine Intermediate Water (LIW)** in the approximate depth range ~150-400 m of the entire area from the Sicily Strait and the Ionian Sea to the wider area south of Crete and further to the East near Cyprus, which is considered as the source region of the LIW and 2) the **East Mediterranean Deep Water (EMDW),** at depths below ~3000 m with source region in the South Adriatic[15], apart from the period from the late 80s to the late 90s, when the source area of the EMDW was the Cretan Sea[16]. After the late 90s, the deep Cretan outflow occupies a depth layer at approximately 1500-2500 m[17].

> "Specific Mediterranean sub-regions are well known for their contribution to dense water formation processes; these regions are the Levantine, the Aegean and the Adriatic for the Eastern Mediterranean, and the Gulf of Lions for the Western Mediterranean"

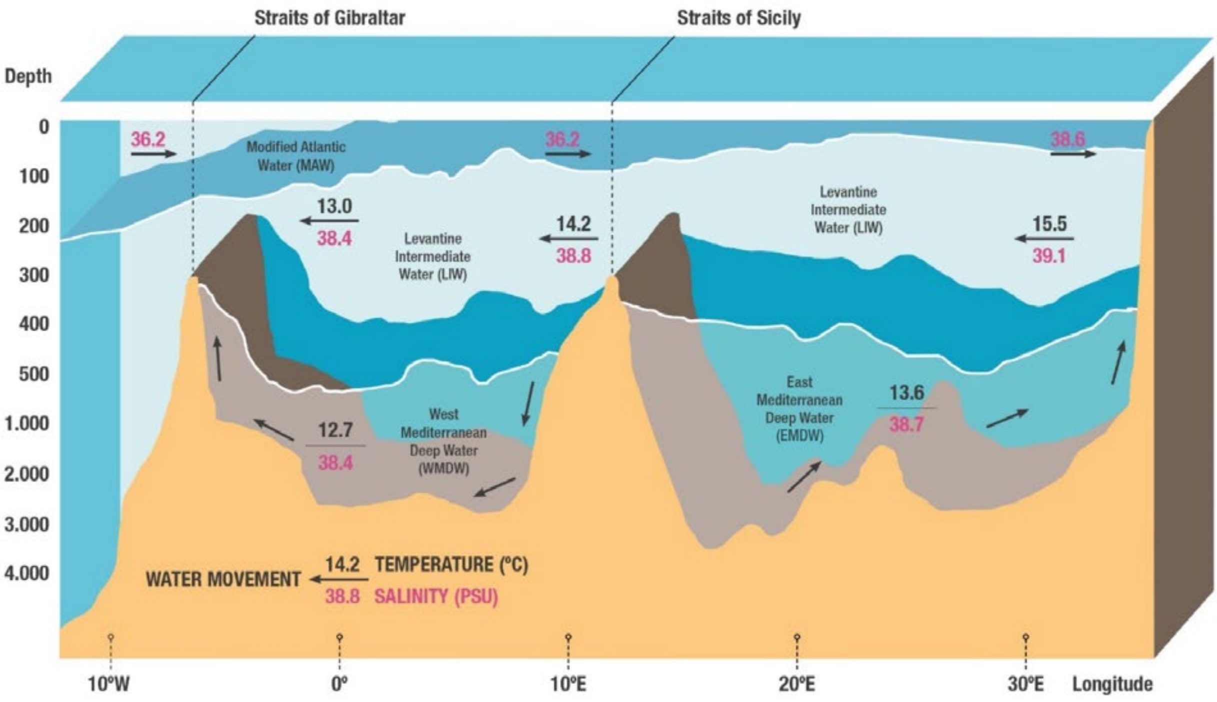

Fig. 1.3. Sea water mass circulation in the Mediterranean Sea.
Sources: Adapted from Zavattarelli, M., and Mellor, G.L., A Numerical Study[18] of the Mediterranean Sea Circulation, American Meteorological Society, 1995. GRID-Arendal.

The exchange or renewal time scale of the **Levantine Intermediate Water** that is present in the entire Mediterranean is approximately ~25 years, thus, the quantity of this water produced in a specific year will exit to the Atlantic after 25 years, whereas for deep waters, this time scale is in the order of 80 to 100 years[19].

The water flow structures and the currents in the Eastern Mediterranean are characterized by different scales ranging from sub-basin, i.e., flows extending throughout most of the basin's lateral extent, to mesoscale, i.e., cyclones or anticyclones with dimensions in the order of ~100 km[20]. Most of the mesoscale water flow structures are permanent, while some of them are recurrent and show seasonal and inter-annual flow variations. Fig. 1.4 shows the most prominent circulation features of the Mediterranean basin.

The speeds of the current flows in the Eastern Mediterranean at depths greater than 2000 m are in the order of ~2-5 cm/sec with maximum values around 10 cm/sec[21,22]. Deep and near-bottom abyssal currents southeast of Crete have been observed to increase by factor ~3 in the presence of bottom trapped topographic Rossby waves generated when a mesoscale circulation structure exhibits lateral shifts over the slopped bottom at ~4000 m[22].

The high salinity of the Eastern deep-sea environment is also characterized by a seasonal pycnocline (where water density increases rapidly with depth) that is typically developed during mid-spring to mid fall and it is well-developed during late August in the layer between 30 to 80 m deep. Moreover, there is a permanent pycnocline in the open waters of the Ionian and the Levantine basins between depths of 400-600 m, below 600-700 m the density gradients are minimal[23].

Table 1.1 and Table 1.2 present typical winter and summer mean temperatures and salinities in four different sub-areas of the deep-Eastern Mediterranean Sea as observed for the period 2000-2015. Hence, it can be observed at a depth of 500 m where the permanent pycnocline is located that extends roughly between a depth of ~400 to 600 m[21,23]. In the areas of the south-east Ionian and south of Crete at a depth of 2000m, the deep waters are influenced by the intermediate waters of Cretan origin[21]. Observations indicated how differences in temperature or salinity between winter and summer values are insignificant below a depth of 500 m as there is not a direct seasonal influence.

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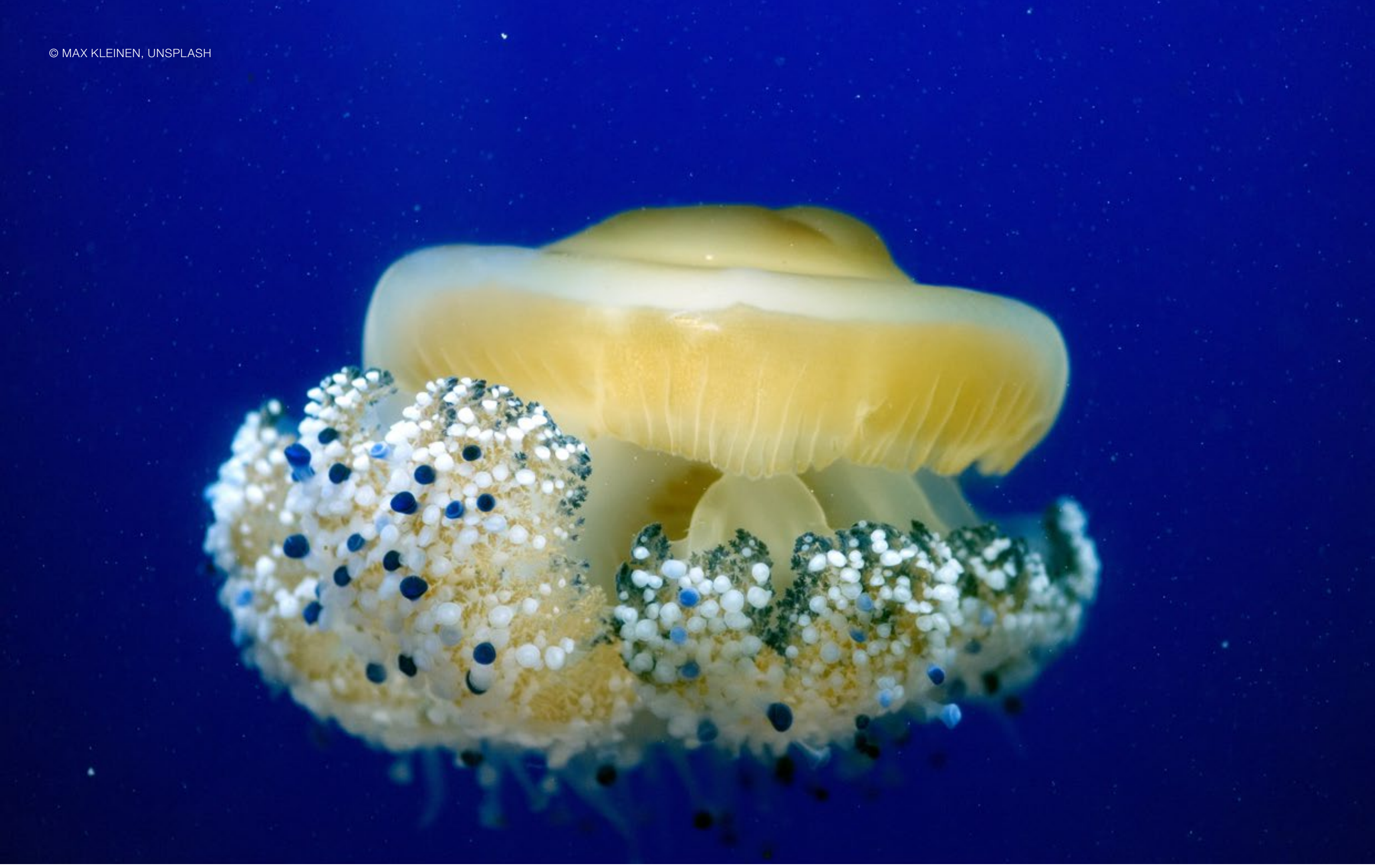

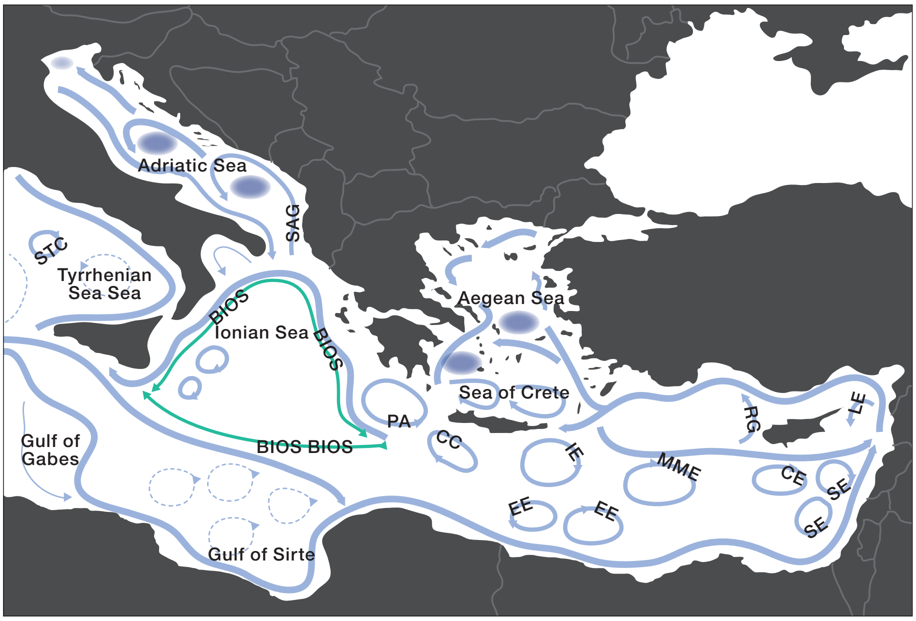

Bimodal Oscillation System
Dense water formation area
Eddy
Principal
Secondary
Seasonal or instability driven

BIOS: Bimodal Oscillation System
CC: cretan cyclon
CE: cyprus eddy
EE: egyptian eddies

IA: ionian antycyclones
IE: ierapetra eddy
LE: latakia eddy
MME: mersa matruh eddy

PA: pelops antcyclon
RG: rhodes gyre
SAG: south adriatic gyre
SE: shikmona eddy
STC: south tyrrhenian cyclon

Fig. 1.4. Map of the general circulation patterns in the Mediterranean basin with a schematic of basic characteristics of the Eastern Mediterranean general circulation based on results from Robinson et al. (1991). 1: Pelops Anticyclone (recurrent), 2: Cretan Cyclone (permanent), 3: Ierapetra Anticyclone (recurrent), 4: Mersa-Matruh Anticyclone (permanent), 5: Rhodes Cyclone, MMJ: Mid-Mediterranean Jet. Areas 1) the southeast Ionian (latitude of 37° N .), 2) the Lybian Sea i.e., the area south of Crete, 3) the eastern Levantine, i.e., the area west of 30° E, 4) the south Aegean Sea, i.e., south of latitude 37.6° N . and 5) the North Aegean Sea, i.e. north of 37.6° N.

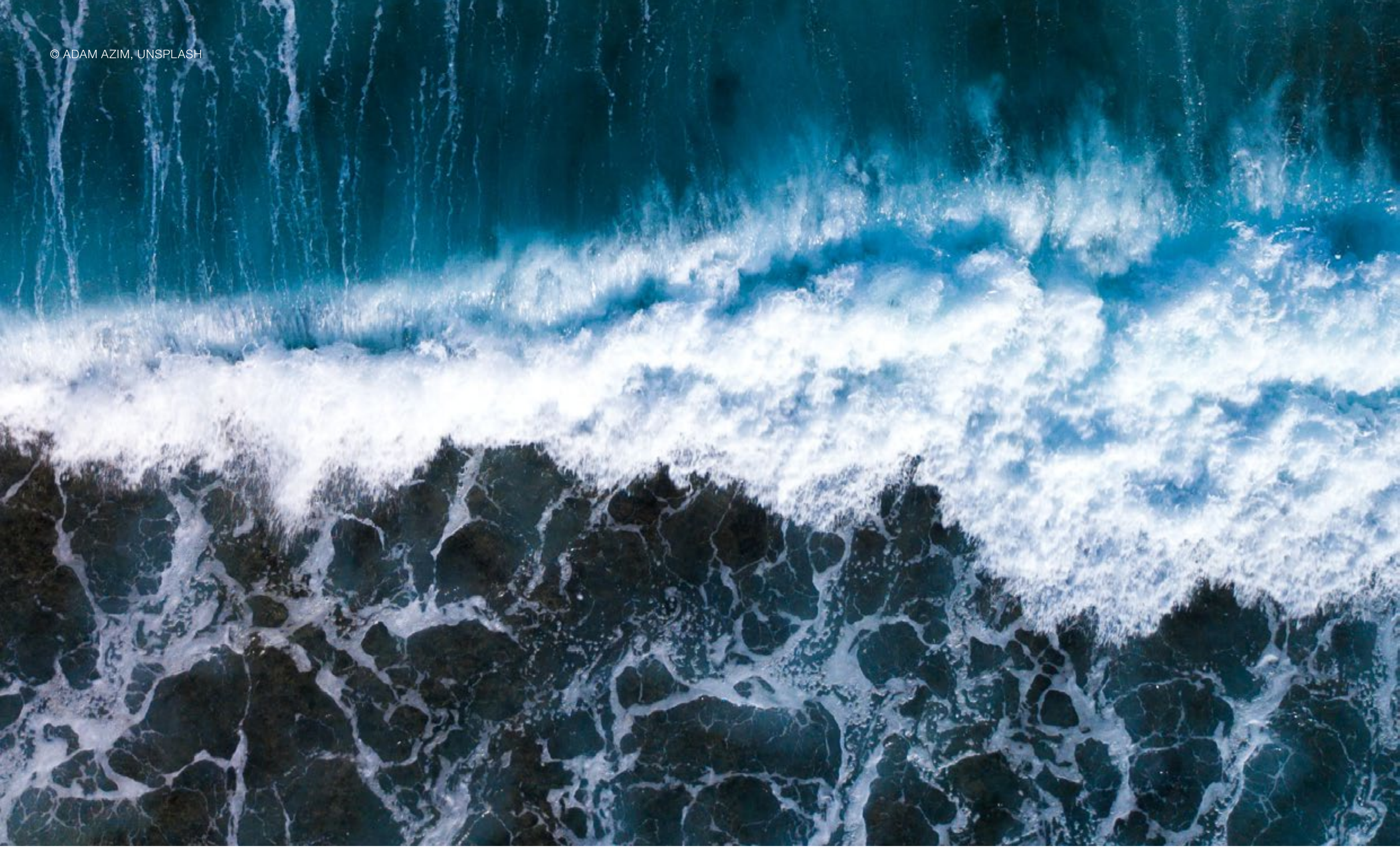
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Table 1.1. Mean winter values of temperature ($T_{in\text{-}situ}$) and salinity (Sal) in different basins of the Eastern Mediterranean over the period 2000-2015 at Southeast Ionian, North Aegean, South Aegean, Libyan Sea (area south of Crete) and East Levantine Sea. Both in-situ and potential (θ) temperatures are included; values are in degrees Celsius. Dashes represent no available field data. Source References[24,25].

	EASTERN IONIAN	NORTH AEGEAN	SOUTH AEGEAN	LIBYAN SEA	EAST LEVANTINE
Depth (m)	$T_{in\text{-}situ}$ / Sal ±spatial variation	$T_{in\text{-}situ}$ / Sal ±spatial variation	$T_{in\text{-}situ}$ / Sal ±spatial variation	$T_{in\text{-}situ}$ / Sal ±spatial variation	$T_{in\text{-}situ}$ / Sal ±spatial variation
200	15.06/38.953 ± 0.2 / ± 0.012	15.87/38.994 ±0.05 /±0.022	15.75/39.104 ±0.11/ ±0.007	14.30/38.852 ±0.16/ ±0.044	15.26/38.895 ±0.2/±0.045
500	14.33/38.828 ±0.066/±0.023	14.08/38.832 ±0.185/±0.028	13.94/38.846 ±0.029/±0.010	14.22/39.023 ±0.37/±0.005	14.56/38.940 ±0.021/±0.010
1000	13.75/38.748 ±0.008/±0.004	13.27/38.820 ±0.008/±0.004	14.29/38.740 ±0.008/±0.004	13.27/39.004 ±0.34/±0.052	14.29/38.975 ±0.34/±0.052
2000	13.84/38.75	13.95/38.80	13.96/38.79	--	--
3000	13.92/38.73	--	--	--	--

Table 1.2. Mean summer values of temperature ($T_{in\text{-}situ}$) and salinity (Sal) in different basins of the Eastern Mediterranean over the period 2000-2015 at Southeast Ionian, North Aegean, South Aegean, Libyan Sea (area south of Crete) and East Levantine Sea. Both in-situ and potential (θ) temperatures are included; values are in degrees Celsius. Dashes represent no available field data.

	EASTERN IONIAN	NORTH AEGEAN	SOUTH AEGEAN	LIBYAN SEA	EAST LEVANTINE
Depth (m)	$T_{in\text{-}situ}$ / Sal ±spatial variation	$T_{in\text{-}situ}$ / Sal ±spatial variation	$T_{in\text{-}situ}$ / Sal ±spatial variation	$T_{in\text{-}situ}$ / Sal ±spatial variation	$T_{in\text{-}situ}$ / Sal ±spatial variation
200	15.13/38.945 ±0.14/±0.016	15.765/39.042 ±0.45/±0.053	15.79/39.056 ±0.35/±0.021	14.84/39.118 ±0.28/±0.031	15.20/39.081 ±0.25/±0.040
500	14.28/38.881 ±0.10/±0.010	14.17/38.856 ±0.13±/0.023	14.08/38.825 ±0.10/±0.005	14.15/39.037 ±0.25/±0.014	14.61/38.986 ±0.08/±0.007
1000	13.81/ 38.767 ±0.008/±0.004	13.81/38.762 ±0.008/±0.004	13.74/38.752 ±0.008/±0.004	13.76/38.980 ±0.34/±0.052	14.30/38.987 ±0.04/±0.033
2000	13.84/38.75	13.95/38.80	13.92/38.793	--	--
3000	13.92/38.73	--	--	--	--

CHEMISTRY

Souvermezoglou E. and Krasakopoulou E.

The Mediterranean Sea has long been known as an impoverished area with nutrient levels too low to sufficiently support a large biomass. There is a limited supply to its surface waters both from its deeper layers and from external sources (the Atlantic water inflow, riverine discharges and atmospheric input), but the principal reason of its poverty is related to its hydrology and circulation as a concentration basin. This extreme oligotrophy that makes it a concentration basin, is related to the following characteristics: i) evaporation that exceeds rainfall and river runoff, ii) nutrient-poor Atlantic surface water that flows in through the Strait of Gibraltar, iii) nutrient concentrations that are further depleted towards the East due to primary production and iv) the export of organic matter, which is transported westward by the underlying deep Mediterranean compensation current[26]. This results in depletion of nutrients as phosphate (PO_4^{3-}), nitrate (NO_3^-) and silicate (SiO_4) in the euphotic zone and thus in low primary production rates.

The **extreme low nutrient regime of the Eastern Mediterranean** has been studied extensively in recent years[27,28] and is described as one of the lowest of the world's oceans with the eastern deep Levantine representing the most oligotrophic part[27,29,57]. The surface layer totally lacks phosphate and nitrate, while containing small amounts of silicate.

The nutrient depleted water surface layer is separated from the intermediate and deep-water layers by a transitional layer of 100-200 m thick, within which the concentration of nutrients increases rapidly. The concentration of nutrients in the intermediate and deep-water layers is somewhat constant, increasing in the following order: Aegean < Ionian < Levantine (Table 1.3). The oxygen is almost saturated in the surface layer (~6mL/L in winter and ~4.8 mL/L in summer). A sharp decrease of oxygen is observed in the transition layer, while in deep waters the concentrations are around 4.2 mL/L, decreasing in the order in which the nutrients increase: Aegean > Ionian > Levantine.

The distribution of oxygen and nutrients in the Mediterranean has been affected by the presence of mesoscale cyclonic and anticyclonic gyres in the area. The most interesting features in the Eastern Mediterranean are from west to east: the large anticyclonic flow region and southwest of the Peloponnese (**Pelops gyre**), a large cyclone, namely **Cretan cyclone**, situated to the east of this anticyclone and southwest of Crete, the **Ierapetra anticyclone** and the **Rhodes cyclone**[27].

Table 1.3. Mean concentrations of oxygen (ml/L) and nutrients (μM) at three depths below the transitional layer, in different basins of the Eastern Mediterranean.

OXYGEN

Depth (m)	CRETAN SEA	NORTH AEGEAN SEA	OTRANTO STRAIT	SOUTH IONIAN SEA	CRETAN PASSAGE	NW LEVANTINE SEA
500	5.1	5.4	4.8	4.7	4.4	4.3
1000	5.3	5.2	5.4	4.3	4.2	4.2
2000	-	-	-	4.2	4.1	4.1

NUTRIENTS

Depth (m)	CRETAN SEA			NORTH AEGEAN SEA			OTRANTO STRAIT			SOUTH IONIAN SEA			CRETAN PASSAGE			NW LEVANTINE SEA		
	NO_3	PO_4	SiO_4	NO_3	PO_4	SiO_4	NO_3	PO_4	SiO_4	NO_3	PO_4	SiO_4	NO_3	PO_4	SiO_4	NO_3	PO_4	SiO_4
500	2.2	0.10	2.8	1.8	0.09	3.4	4.0	0.13	4.5	3.6	0.21	4.8	4.5	0.22	6.0	5.6	0.23	9.7
1000	1.7	0.07	1.4	2.4	0.11	4.5	2.7	0.06	3.4	4.7	0.23	8.7	4.6	0.25	9.7	5.8	0.27	11.6
2000	-	-	-	-	-	-	-	-	-	5.0	0.22	9.6	5.3	0.25	12.4	5.7	0.26	13.5

Still there are locally and temporary high planktonic biomasses in the cyclonic regions, where the nutrients ascend to the base of the euphotic surface water zone, making the phytoplankton biomass and primary production higher than in the anticyclonic regions where the layer of nutrients is situated at greater depths, limiting the nutrient input to the surface waters during the winter water mass mixing[30]. Other reasons for the relatively high production in some areas are: intensive convective water mass mixing during winter leading to vertical homogenization; the upwelling of waters from intermediate layers to the euphotic zone; and the nutrient enrichment in the river plume areas.

The Mediterranean waters, apart from their relative poverty in nutrients, are characterised by a nitrate to phosphate atomic ratio (N:P) different from that of the open ocean, in particular of the Atlantic Ocean. For the Eastern Mediterranean, the N:P ratio ranges between 20-28, which is much higher than that in the Atlantic Ocean (in conformity with the Redfield's ratio N:P = 16:1). It is interesting to note that the N:P ratio varies in different water masses of the Eastern Mediterranean. In the Eastern Ionian Sea near the Otranto Strait, the N:P ratio is estimated at 26.4, while south of 39°N it is 20.9, attributed to the different proportion of Adriatic Bottom Water (AdBW) and Levantine Intermediate Water (LIW) [31]. The N:P ratio in the Cretan Sea is estimated at about 22[32].

The N:P ratio in the water column also varies substantially with depth and it is somewhat constant below 400 m, ranging between 20 and 24. Some anomalously high values (N:P > 40) can be found at the top of the water layers of nutrients at both the Rhodes gyre and the Ierapetra anticyclone.

Dissolved oxygen concentration is an important oceanic parameter for the marine ecosystem functioning and services[33]. High concentrations of dissolved oxygen are observed in the surface water layers, particularly in coastal regions. In deep waters, oxygen gradually declines by biological respiration and is consumed by bacteria controlling organic matter decomposition. Nonetheless, climate warming is predicted to result in a further decline of the dissolved oxygen and in the intensification and expansion of low oxygen zones (LOZ) in deep layers for the following decades[33].

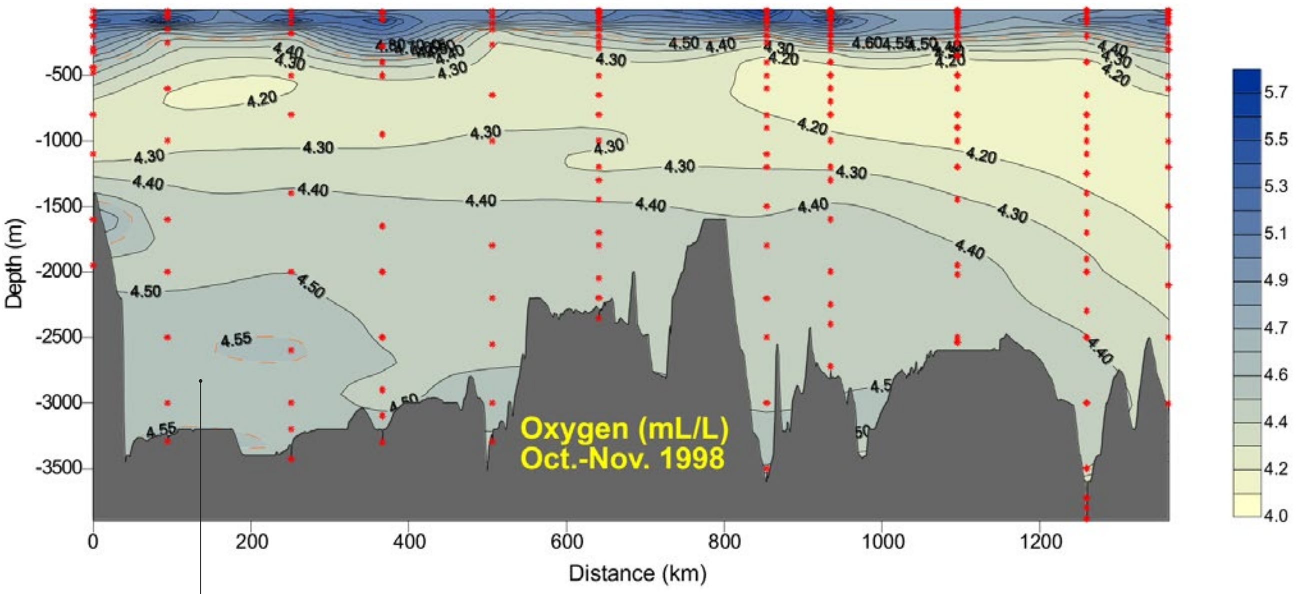
The typical Mediterranean structure of the dissolved oxygen is characterised by high oxygen concentrations for the upper and bottom water mass layers, separated by an oxygen minimum zone at intermediate layers[34].

Although an oxygen minimum zone is observed in both the Western and Eastern sub-basins, its vertical positions are different; in the Eastern Mediterranean it is between 600 and 1200 m deep and in the Western Mediterranean it is between 400 and 600 m [34].

The change in the thermohaline circulation of the Eastern Mediterranean at the end of the 1980s is known as **Eastern Mediterranean Transient (EMT).** This altered the thermohaline circulation of the Mediterranean Sea and has had a strong influence on the oxygen and nutrient concentrations in all major water masses of the Eastern Mediterranean Sea since then [58]. During the EMT event, the Aegean Sea acted as a new and more effective source of deep waters compared to the Adriatic Sea, which was commonly known as the main dense water source of the Eastern Mediterranean. Hence, waters with much higher dissolved oxygen concentration filled the deep and bottom layers of the Eastern Mediterranean. The newly formed deep waters of Aegean origin propagated through the Cretan Arc Straits and spread westward in the Ionian Sea and eastward in the Levantine Sea, following the deep depressions. Nonetheless, recent observations also indicate the presence of relatively well oxygenated and nutrient poor waters of an Adriatic origin in the Eastern Mediterranean, near the bottom in the northern Ionian Sea, providing evidence that the Adriatic Sea has once again started to form dense water (Fig. 1.5).

The **Eastern Mediterranean Transient (EMT)** event was also responsible for the advection of anomalously salty and warm Levantine Intermediate Water (LIW) through the Strait of Sicily, which in turn triggered the deep-water formation events in the Western Mediterranean during the following event known as the Western Mediterranean Transition (WMT) that occurred between 2004 and 2006[34,59].

Very few studies have been made on the long-term variability of dissolved oxygen and nutrients for specific subregions of the Mediterranean Sea and further investigations are needed to enhance the understanding of dense water formation processes and the dissolved oxygen and nutrients spatiotemporal variability as well as how they affect the ecosystems.



It shows the presence of the Eastern Mediterranean deep-water of Adriatic origin at depths of 2000-3500 m in the northern Ionian Sea with relatively richer oxygen concentrations and poorer amounts of nutrients than the overlying old Eastern deep water.

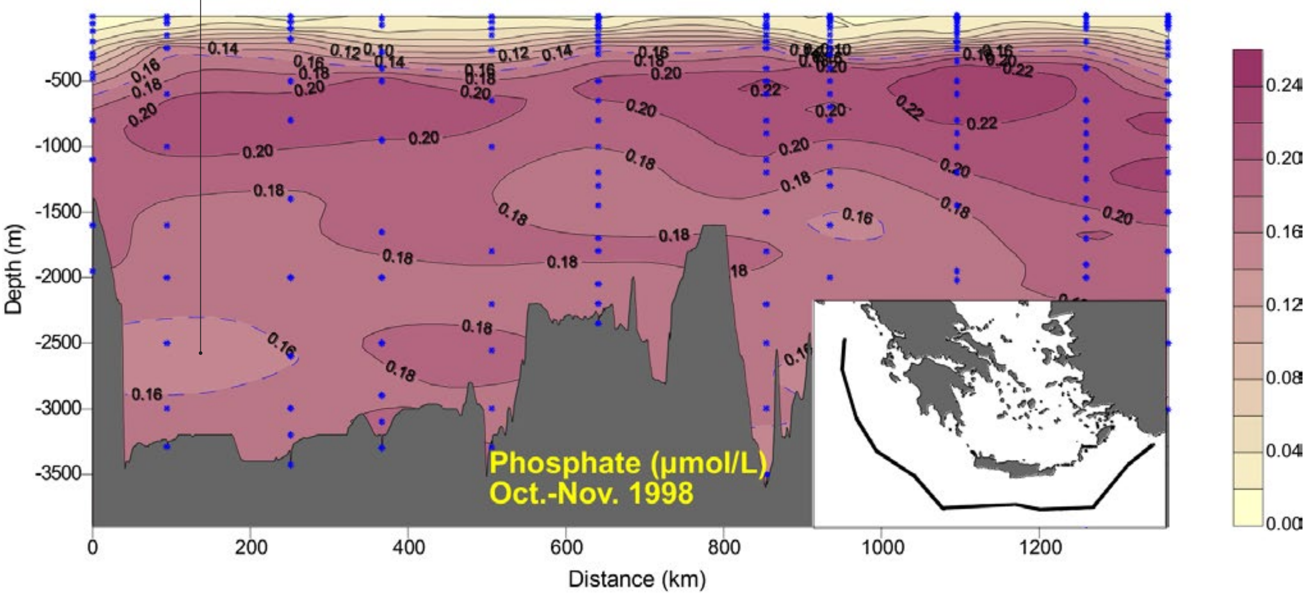


Fig. 1.5. Vertical distribution of oxygen (mL/L) and nutrients (phosphate µmol/L) along a transect from the NE Ionian – Cretan Passage – NW Levantine Sea during autumn 1998.

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BIOTIC ENVIRONMENT

Mytilineou Ch., Gerovasileiou V., Ali M., Farrag M., Stamouli C., Papadopoulou K.N., Smith C.J., Kallianiotis A., Stergiou K.I., Otero, M.

The present deep-sea fauna of the Mediterranean is characterized by a very low degree of endemism and a low diversity compared to the fauna of the adjacent Northeast Atlantic Ocean[35]. It is unique in the sense that it is relatively young, compared to the fauna of the outer Atlantic Ocean, mainly due to the Messinian salinity crisis event. As described before, the deep Eastern basin displays a number of characteristics that influence the environment for this fauna and separate it from most other deep-sea faunas in the world:

i) Extreme low nutrient regime with very low concentrations of potentially limiting organic nutrients (e.g. proteins and lipids) that sharply decline with increasing depth and distance from the coast.

ii) Low bacterial abundance with negligible inputs of primary organic matter into the deep areas. As a consequence, organic matter composed mostly of refractory compounds and "refractory" dissolved organic carbon, is thus "non-accessible" or "resistant" to rapid microbial degradation[36].

iii) Phytoplankton biomass subjected to strong grazing and thus its transport to deeper layers is kept low.

iv) Below 400 m in the Eastern basin, the water column is homothermic, with a salinity of 38.7-39.1% and a temperature of 13.5-15.0°C. It is also well oxygenated, permitting a higher decomposition rates of organic matter than in cold water areas and thus reducing the flux of organic matter to the deeper zones. Such hydrological conditions are in sharp contrast with conditions prevailing in the Atlantic with a salinity of 36.5% and a temperature decreasing gradually down to 2.5°C at 3000 m[34].

v) Generally, it is very deep, with more than 80% of the Ionian and Levantine Seas below 200 m. It is also characterized by trenches and abyssal plains around 3000 m deep.

ii) Formation of the **Intermediate Mediterranean Water** in the eastern basin (**Levantine intermediate water**) and its flows out towards the western basin limiting the vertical transport of organic matter to the deep-sea floor[26].

These conditions restrict the organic matter supply to the benthos affecting the life in deep waters and creating a decreasing abundance trend with depth, distance from the coast and food availability[13]. Despite these conditions, the deep-sea biodiversity of both Eastern and Western basins are considered similar[13] with relative isolation of deep-sea communities from the Atlantic influence and limited effect from the barriers produced by the shallow Sicily Channel between them both. This suggests that even if basin differences are evident and have to be considered, the whole Mediterranean Sea deep-sea should be considered as a wide-ranging species pool.

Throughout the continental Mediterranean slopes, a strong zonation of benthic megafauna can be observed, associated with a constant reduction in abundance, biomass and diversity, accentuated under 1200 m[1,37,38]. Below the 2600 and 2700 m isobaths, biomasses of megafauna are extremely low and population densities are reduced to minimum levels[39].

During the last 30 years, several scientific projects conducted with national, private or European funding focused more on the deep fauna of the Eastern Mediterranean providing important information. Nonetheless we still lack an approximate figure of the number of strictly deep-water species or eurybathic species (able to live at shallow and > 200 m depths) occurring in these waters. Many populations in the deep-sea are spatially fragmented, and will become more so with increasing resource exploitation.

Benthic species have complex life cycles that include a pelagic larval stage and sessile/sedentary adults and connectivity of these populations is achieved by the planktonic larval stage, and larval dispersal, which is in turn regulated by complex interactions between biological and oceanographic processes.

Some observations indicate that there is a clear and steep decline in species diversity in the Eastern Mediterranean from 1200 to 3000 m, although the presence of heterogeneous habitats can influence this biodiversity[40]. Little is known about the biodiversity of benthic prokaryotes in the deep sea. Deep Mediterranean sediments harbour an incredibly high and unique prokaryotic diversity, which is different from that described in other deep benthic environments. Significant longitudinal differences could be observed between the Western, Central, and Eastern Mediterranean, with a turnover diversity reaching 99%, indicating high regional variability[41]. In conclusion, the Mediterranean sediments can be considered to be ''bacterial hotspots''[13].

Similarly, foraminifera diversity and abundance have been found to be lower in the Eastern than in the Central and Western Mediterranean, with the lowest values in the Levantine Basin[42]. A peak in species richness has been reported between 200 m and 1000 m, below which richness decreases with depth[13]. Meiobenthos studies (focusing mostly on nematodes) also showed that the deep bottoms in the E. Mediterranean display one of the lowest meiofaunal standing stocks, which reflects the very low productivity of this area (See Chapter 5).

Studies on macrobenthos also revealed a decreasing number of taxa and density with increasing depth, that reflected the poor-nutrient status of the Eastern Mediterranean, especially in the mots eastern part[43]. The NW-SE gradient has been more or less confirmed by several studies on certain benthic groups such as decapods[44], prosobranch gastropods[45], molluscs[46], polychaetes[47] and sponges[48]. However, in trenches, like the Hellenic & Pliny Trench, hotspot abundances have been identified for macrobenthos[43]. In addition, the Aegean Sea, being the second major sea of the Eastern Mediterranean after the Levantine, does not seem to follow this general W-E declining trend.

To date, no published information exists on the presence of important fields of vulnerable deep-water sessile invertebrates in the Eastern Mediterranean, although many records of species such as the octocoral *Isidella elongata* have been reported in the Eastern Ionian and Aegean Seas[49,50], significant presence of the deep-sea sponge *Rizaxinella shikmonae* in the Levantine Sea[51] or fossils of cold water corals along the south margins of Crete, Karpathos and Rhodes Islands, suggesting the presence of important populations of frame-building corals during the Younger Dryas[52].

The most represented megafaunal groups in terms of abundance and diversity in deep Mediterranean waters are bony fishes (Actinopterygii) and decapod crustaceans[37]. This represents a major difference with the deep Atlantic seafloor[53,54] where holothurians seem to dominate[55]. Fish and crustacean species seem then to be completely adapted to bathyal conditions in the Mediterranean Sea and some studies indicated that the deepest bottoms shelter fish dominated by small-medium sized species where also some large fishes are widespread[56]. Fishing activities are worldwide recognized as producing disturbances on communities, habitat and ecosystem structure, diversity, and functioning. Fishing in deep waters, a highly sensitive ecosystem, should therefore be managed with great notion. In addition, the invasion of non-native species is a crucial factor that will continue to change the biodiversity of the Mediterranean, mainly in its Eastern basin that can spread rapidly northwards and westwards due to the warming of the Mediterranean Sea.

Overall, knowledge on the distribution of deep-sea organisms in the Mediterranean and its causes is still fragmented and systematic and molecular taxonomic revisions of a number of deep-sea fauna, including the major groups of benthic fauna, are still ongoing. Therefore, changes in the classification, as well as taxonomic revisions, are expected in the near future. •

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CHAPTER 1 /
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