“

In deep-sea environments, meiofauna support an abundant and complex food web. As human pressures in these environments are increasing, these species can be used to monitor changes and play a vital role in developing conservation and monitoring programmes.”

CHAPTER 5/

Deep-sea meiofauna diversity

Lampadariou N., Sevastou K.

The deep sea supports a very high biodiversity, composed mainly of macrofauna and meiofauna. Meiofauna is a collective name that represents one of the most diversified communities of the marine realm, including small organisms, unicellular protists and multicellular metazoans (size < 1 mm) that live in aquatic sediments (Fig.5.1). Owing to their high abundance and diversity - especially in ecosystems where other metazoans are practically absent - their effects on benthic ecosystems through bioturbation and grazing activities, and their role in stimulating microbial activity and linking prokaryotic and detrital resources to higher trophic levels, meiofaunal organisms are believed to be important contributors to deep-sea ecosystem processes and functions, including nutrient cycling and degradation of organic pollutants[1,2]. In extreme environments, such as hydrothermal vents, brines or deep-sea plains, meiofauna organisms are an important part of the communities present. The dynamic responses of different meiofauna groups (taxa), such as some foraminiferans, nematodes and copepods, may also reveal important information on how the communities respond to changes and provide a warning signal of anthropogenic impacts. Given the ongoing and future developments regarding oil exploration and pipeline installations in the deep sea, information regarding these organisms could serve as a valuable reference point regarding the prevailing environmental and ecological conditions before and after the onset of anthropogenic disturbances.

As regards the Mediterranean deep sea, substantial work has been carried out over the last three decades expanding the knowledge of meiofauna distribution patterns[3,4,5]; nevertheless, the understanding of how their community functions is still largely unknown. In the Eastern Mediterranean, deep-sea meiofauna studies have traditionally focused on basin ecosystems. More recently, studies from other habitats, such as open slopes and cold seeps, have also started to emerge, while those from canyons and seamounts are still rare.

Fig. 5.1. Some representative meiobenthic animals from the eastern Mediterranean.
(a) a harpacticoid copepod, (b) a gastrotrich, (c) the head end of a nematode and (d) a tardigrade.

Here, we present an overview summary of all the available published and unpublished information on meiofauna from different deep-sea habitats and regions in the Eastern Mediterranean. It is focused on showing the variations in abundance, community structure and diversity of meiofauna and their relation to the environmental conditions in each of the regions. The detailed analysis[1] and data are derived from a number of multidisciplinary collaborations (e.g., projects, cruises etc.), in the course of which benthic samples were collected at different depths (Table 5.1) and habitats (deep-sea basins and slopes, canyons, seamounts, brine lakes and mud volcanoes), with most of them concerning two habitats, deep-sea basins and open slopes.

1 The data that support the findings of this analysis are available from the corresponding authors on request.

Table 5.1. Overview of projects, surveys and investigated areas from canyons, seamounts, brine lakes, mud volcanoes, deep-sea basins and slopes of the eastern Mediterranean.

Area	Habitat	Project	Expedition	Research Vessel	Date	No of Stations	Depth range (m)
Ionian Sea (Area 1)	Basin	ADIOS	Cruise 2	AEGAEO	Oct-2001	9	2765-2840
		BIODEEP	Cruise 1	AEGAEO	Aug-2001	14	3078-3424
		BIOFUN	TRANS-MED	SARMIENTO DE GAMBOA	Jun-2009	3	3335-3335
		MATER	TransMediterranean	AEGAEO	Jun-1999	2	3200-3200
		REDECO	REDECO Cruise 1	AEGAEO	May-2010	3	3302-3315
	Brine	BIODEEP	Cruise 1	AEGAEO	Aug-2001	11	3179-3521
	Slope	BIOFUN	TRANS-MED	SARMIENTO DE GAMBOA	Jun-2009	2	2011-2012
		REDECO	REDECO Cruise 1	AEGAEO	May-2010	3	2960-2980
North Aegean Sea (Area 2)	Basin	MATER	MATER Cruise 1	AEGAEO	Mar-1997	2	798-805
			MATER Cruise 2	AEGAEO	Sep-1997	8	115-1300
		MITTELMEER 1997/98	METEOR 40/3	METEOR	Dec-1997	9	1244-1271
	Slope	MATER	MATER Cruise 2	AEGAEO	Sep-1997	6	145-340
			MATER Cruise 3	AEGAEO	Mar-1998	3	650-650
South Aegean Sea (Area 3)	Basin	MATER	MATER Cruise 1	AEGAEO	Mar-1997	3	914-914
			MATER Cruise 2	AEGAEO	Sep-1997	15	1190-2280
		MITTELMEER 1997/98	METEOR 40/3	METEOR	Dec-1997	5	1875-1876
	Slope	REDECO	REDECO Cruise 1	AEGAEO	May-2010	2	1049-1619
Libyan Sea (Area 4)	Basin	BIOFUN	TRANS-MED	SARMIENTO DE GAMBOA	Jun-2009	1	2845-2845
		HERMES	HERMES3 (HCMR)	AEGAEO	May-2006	4	2670-3603
		MATER	TransMediterranean	AEGAEO	Jun-1999	3	2950-3870
		MITTELMEER 1997/98	METEOR 40/3	METEOR	Dec-1997	9	4282-4392
		REDECO	REDECO Cruise 1	AEGAEO	May-2010	3	2707-3607
			REDECO Cruise 2	AEGAEO	May-2011	1	3564-3564
	Canyon	HERMES	HERMES3 (HCMR)	AEGAEO	May-2006	2	1220-2420
	Mud volcano	HERMES	MEDECO Leg 2	POURQUOI PAS ?	Nov-2007	9	1941-1943
	Slope	BIOFUN	TRANS-MED	SARMIENTO DE GAMBOA	Jun-2009	2	1204-2015
		HERMES	HERMES3 (HCMR)	AEGAEO	May-2006	6	508-1910
Levantine Sea (Area 5)	Basin	HERMES	MEDECO Leg 2	POURQUOI PAS ?	Nov-2007	1	2152-2152
		ZOOTOP	MSM 14/1	MARIA S. MERIAN	Jan-2010	1	2419-2419
	Mud volcano	HERMES	MEDECO Leg 2	POURQUOI PAS ?	Nov-2007	7	2024-2029
	Seamount	ZOOTOP	MSM 14/1	MARIA S. MERIAN	Jan-2010	12	874-2239

1

EASTERN IONIAN SEA

For the Eastern Ionian Sea, quantitative information on the abundance and biomass of meiofauna is available from three different habitats: deep-sea basins (2765-3424 m depth), open slopes (2011-2980 m depth) and the deep hypersaline anoxic basins (3179-3521 m depth) of the south-eastern and central Ionian Sea (Fig. 5.2).

The number of major meiofauna taxa reported from the Ionian Sea (Table 5.2), 17 in total, falls within the range of observations in other Mediterranean areas[4], with nematodes, copepods, polychaetes and ostracods most commonly found in all three habitats. Other meiofauna taxa have also been encountered but in low numbers; priapulids and sipunculids were only found in deep-sea basins and gastropods only in the brine lakes. In the deep-sea basins and slopes, nematodes dominated the communities ranging on average from 60 to 88%, while harpacticoid copepods and tardigrades represented on average 3-8% and 4-6% of the total abundance, respectively. However, the meiofauna community structure differed considerably in brine sediments, with different taxa, namely copepods, molluscs and ostracods dominating at various brine lakes[6].

The available studies also show that meiofaunal density in the Ionian Sea is low, which is typical throughout the Eastern Mediterranean, and tends to decrease with depth.

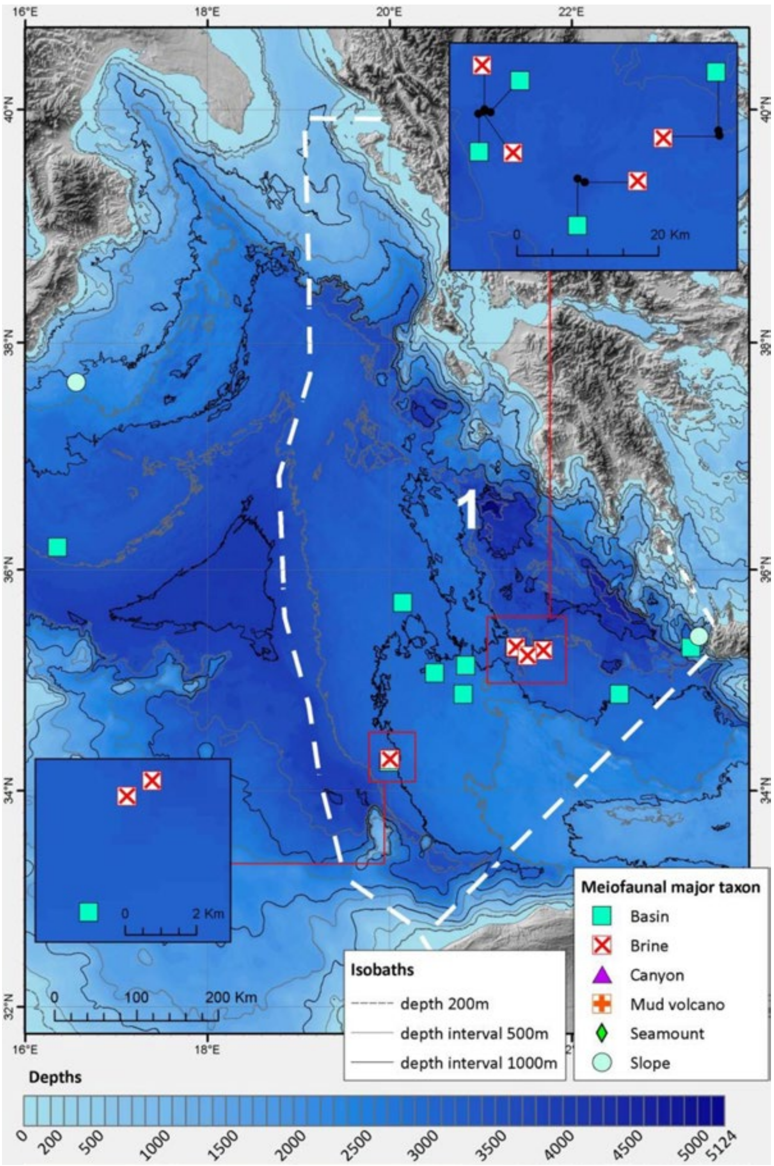

Fig. 5.2.
Map showing the locations of stations from the Ionian Sea with symbols representing different habitat types.

deep-sea basins; open slopes; Brines (deep hypersaline anoxic basins). Data campaigns from 1999 and 2010.

Table 5.2. Presence/absence data of meiofaunal taxa found at the five different areas and habitat types (Bas: Basin; Bri: Brine; Slo: Slope; MV: Mud volcano; SM: Seamount; Can: Canyon).

	Eastern Ionian Sea			Levantine Sea			Libyan Sea				North Aegean Sea		South Aegean Sea	
Taxon	**Bas**	**Bri**	**Slo**	**Bas**	**MV**	**SM**	**Bas**	**Can**	**MV**	**Slo**	**Bas**	**Slo**	**Bas**	**Slo**
Amphipoda					+	+	+				+	+		+
Annelida incertae sedis				+				+						
Aplacophora											+		+	
Bivalvia	+	+			+	+	+		+	+	+	+	+	
Caudofoveata				+	+				+					
Cnidaria						+								
Copepoda	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Crustacea		+									+		+	+
Cumacea					+						+		+	
Echinodermata							+				+			
Gastropoda		+			+						+	+		
Gastrotricha				+	+	+	+		+	+		+		+
Halacaroidea	+		+	+	+	+	+		+	+	+	+	+	+
Isopoda					+	+			+		+	+	+	+
Kinorhyncha	+		+	+	+	+	+			+	+	+	+	+
Loricifera						+	+			+				+
Mollusca							+				+		+	
Nematoda	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Nemertina							+			+	+	+	+	
Oligochaeta				+	+	+	+		+		+	+	+	
Ostracoda	+	+	+	+	+	+	+		+	+	+	+	+	+
Other	+				+	+	+	+	+	+	+	+	+	
Polychaeta	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Priapulida	+			+	+	+	+		+	+	+	+	+	
Rotifera	+		+	+	+	+	+		+	+				+
Scaphopoda											+			
Sipuncula	+			+	+	+	+		+		+	+	+	
Soft bodied	+	+					+				+		+	
Tanaidacea	+				+	+	+		+	+	+	+	+	+
Tardigrada	+		+	+		+	+	+		+	+	+	+	+
Turbellaria	+	+		+	+	+	+	+	+	+	+	+	+	

Deep-sea basins appear to be the most diverse habitat exhibiting much higher taxon richness than brines and open slopes (Fig. 5.3). In addition, brines appear to be very different from open slopes and basins in terms of community structure due to the presence in high densities of a number of taxa that have been adapted to the anoxic conditions of the brines, such as bivalve and gastropod juveniles, and which are absent from the basins and slopes.

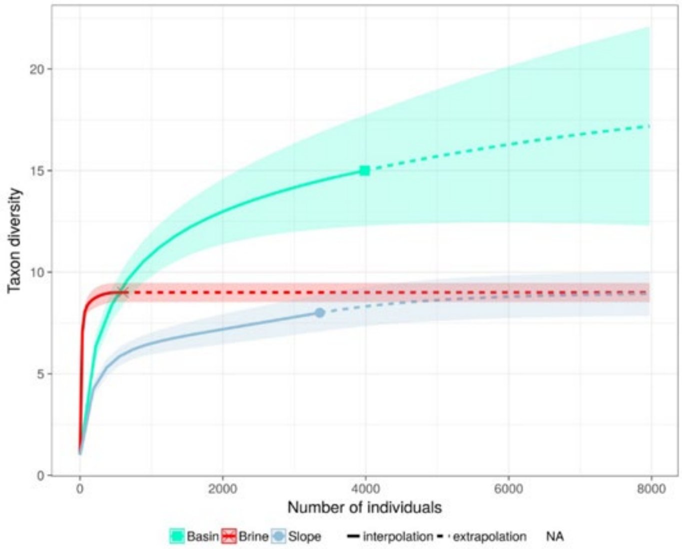

Fig. 5.3.
Comparison of meiofaunal major taxon diversity from three different habitats in the Ionian Sea.

(Solid line: actual data; dashed line: extrapolated data; colour-shaded regions: 95% confidence intervals).

2 NORTH AEGEAN SEA

For the North Aegean Sea, information on meiofauna communities is only available for two habitats: deep-sea basins (115-1271 m) and slopes (153-675 m) (Fig. 5.4).

Overall, 26 meiofaunal taxa have been encountered in all studied areas and habitats in this region. Similar to the Ionian Sea, diversity, expressed as the number of meiofauna taxa, is higher in deep-sea basins (25 taxa) as compared to slopes, (19 taxa) with gastrotrichs being the only taxon missing from the basin habitat. The difference in diversity between these two habitats high-

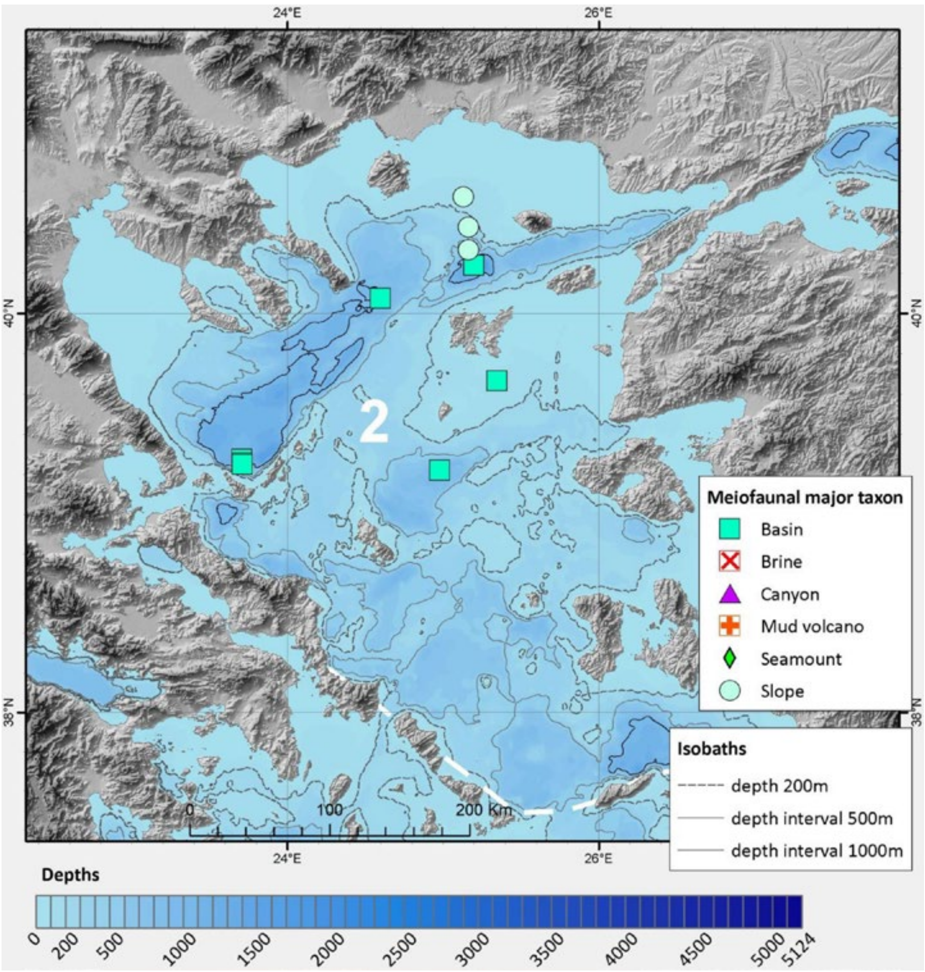

Fig. 5.4.
Map showing the locations of stations from the North Aegean Sea with symbols representing different habitat types.
deep-sea basins;
slopes. Data source from 1997.

lights the importance of each habitat for estimating global deep-sea biodiversity (Fig. 5.5).

Total metazoan meiofaunal density in the North Aegean ranged on average from 531 ind/10 cm^2 in the basin habitat to 996 ind/10 cm^2 in open slopes. These values are relatively high compared to other bathyal and abyssal areas of the Eastern Mediterranean and are directly related to the overall higher primary productivity of the North Aegean Sea, mainly due to riverine outflows and the influx of nutrient-rich Black Sea surface waters entering through the Dardanelles Straits[7]. Depth had no effect on the densities of total meiobenthos or individual groups in this area, and they remained practically constant in both habitats. This can be partly explained by the enhanced vertical flux of organic matter into the deeper parts of the basins[7].

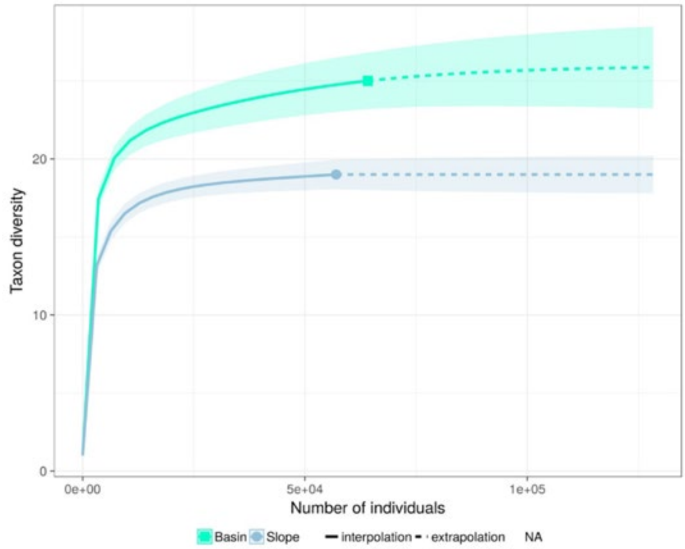

Fig. 5.5. Comparison of meiofaunal major taxon diversity from two different habitats in the North Aegean Sea.

(Solid line: actual data; dashed line: extrapolated data; colour-shaded regions: 95% confidence intervals).

3 SOUTH AEGEAN SEA

Available studies designed to compare meiofaunal assemblages inhabiting the South Aegean Sea were only available from a few investigations in open slopes and deep-sea basins between 914-2273 m (Fig. 5.6). The community structure of meiofauna in the South Aegean Sea was similar to the north Aegean and was dominated by nematodes (73-81%) followed by harpacticoid copepods (5%). In contrast to the North Aegean, meiofaunal abundance progressively decreased with increasing water depth, from 216 ind./10 cm^2 at 914 m to 26 ind./10 cm^2 at 2273 m depth. Such a decrease in meiofaunal densities with depth is a common feature in most marine systems and has been reported in other bathymetric studies of the Mediterranean Sea[8,9,10].

The South Aegean is one of the most oligotrophic (low nutrients) regions of the Mediterranean Sea, characterised by extremely low productivity rates, high temperatures, strong summer stratification of the water column and minimal quantities of organic matter in bathyal sediments[11,12]. These, in turn, result in lower meiofaunal abundances and diversity compared to the northern region.

The number of major meiofauna taxa reported in studies from the South Aegean Sea (Table 5.2, Fig. 5.7) was 25 in total, 21 in the deep-sea basins (914-2273 m) and 14 in the open slopes (1049-1619 m). Significant differences have also been observed in terms of meiofaunal structure, either comparing different habitats or depths. Common taxa from muddy sediments such as Turbellaria or other soft bodied taxa (e.g., Gnathostomulida) as well as Nemertina, Sipuncula and Priapulida were absent from open slopes in the South Aegean (Table 5.2).

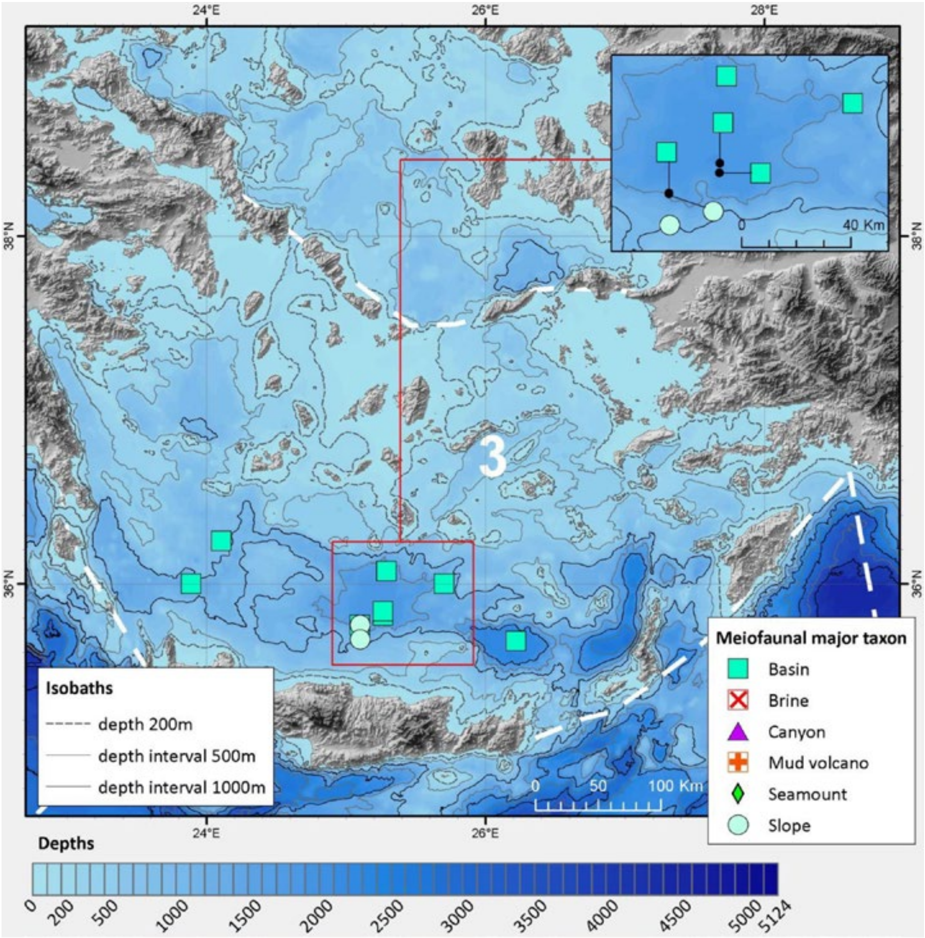

Fig. 5.6.
Map showing the locations of stations from the South Aegean Sea with symbols representing different habitat types.

deep-sea basins;
slopes.
Data from 1997 - 2010.

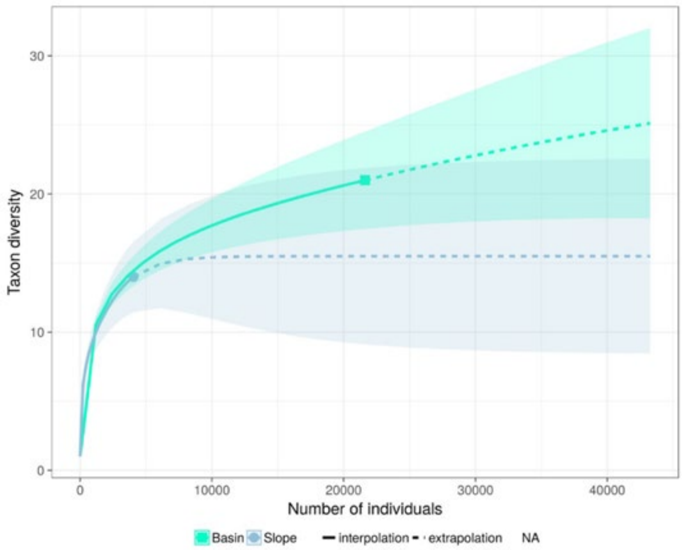

Fig. 5.7.
Comparison of meiofaunal major taxon diversity from two different habitats in the South Aegean Sea.

(Solid line: actual data; dashed line: extrapolated data; colour-shaded regions: 95% confidence intervals).

4 LIBYAN SEA

For the Libyan Sea, the available information is derived from expeditions carried out between 1997-2010 across four habitats (basins, slopes, canyons and mud volcanoes) located south of the island of Crete at depths ranging between 508-4261 m (Fig. 5.8).

The available studies suggest that meiofauna richness is greater at deep basins (2670-4261 m depth, 22 taxa). In both open slope (508-2015 m depth) and mud volcano (1941-1943 m depth) habitats, 16 taxa were encountered, whereas in the canyons (Samaria submarine canyon) at depths ranging between 1220-2420 m only 7 taxa were recorded (Fig. 5.9). The severe physical disturbance and instability of canyon systems along with the limited sampling effort in these types of habitat might explain the low diversity observed in these environments[13]. In contrast to these three habitats, mud volcanoes seem to host a remarkable abundance of rarely found meiofaunal taxa (e.g., acarians, cumaceans, tanaids and cladocerans), which are specifically associated with volcanic structures and are absent in open slope and basin sediments (Table 5.2).

Meiofauna abundance values south of Crete were highest at the Napoli mud volcano (585 ind/10 cm^2) and generally declined with water depth. This is consistent with information from other sites of similar depths in the Eastern Mediterranean, particularly deep-sea basins[4,7,14,15].

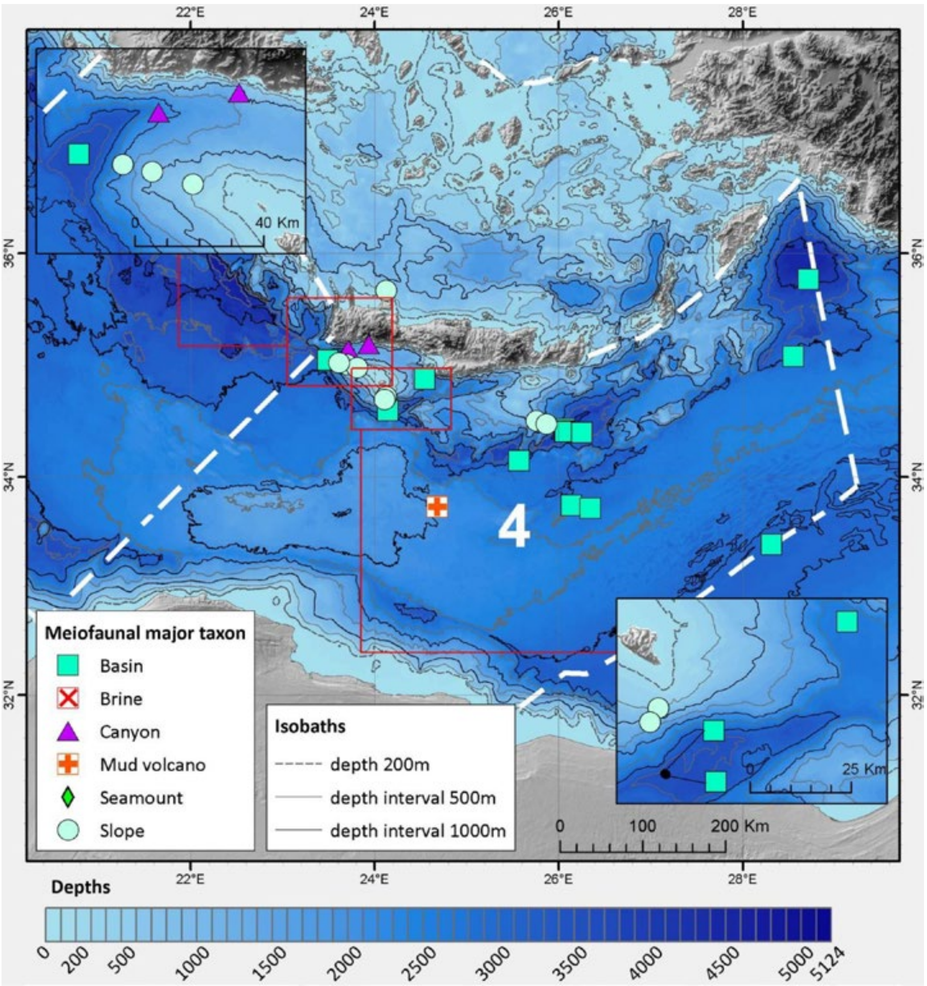

Fig. 5.8. Map showing the locations of stations from the Libyan Sea with symbols representing different habitat types

deep-sea basins; slopes; canyons; mud volcanoes.

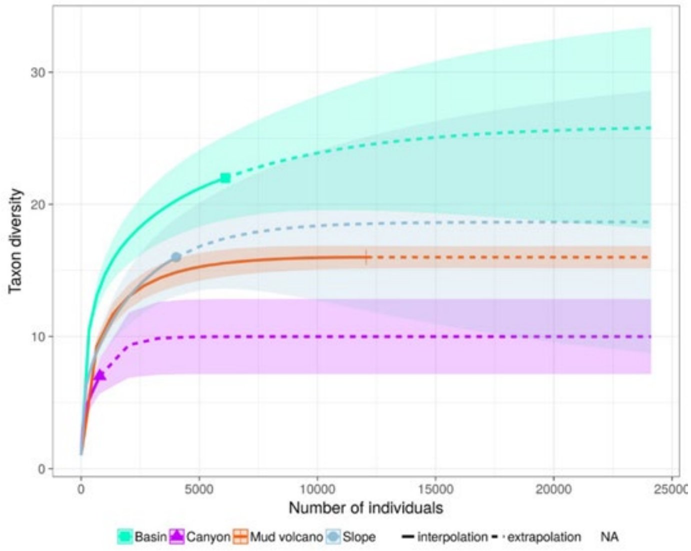

Fig. 5.9.
Comparison of meiofaunal major taxon diversity from four different habitats in the Libyan Sea.

(Solid line: actual data; dashed line: extrapolated data; colour-shaded regions: 95% confidence intervals).

5 LEVANTINE SEA

Meiofaunal abundance, community structure and biodiversity from the Levantine Sea have been investigated at depths ranging between 874-2419 m at two deep-sea sites, the Eratosthenis seamount and the Amsterdam mud volcano (Fig. 5.10).

In total, 24 taxa were encountered (Table 5.2), 15 of which were found in basin stations (2025-2419 m) surrounding the two sites, while the Eratosthenis seamount (874-2239 m) and Amsterdam mud volcano (2024-2152 m) had 20 taxa each. Despite having the same number of taxa, meiofaunal composition differed between the seamount and mud volcano, with more molluscan taxa, such as Caudofoveata and Gastropoda, found in the latter (Table 5.2).

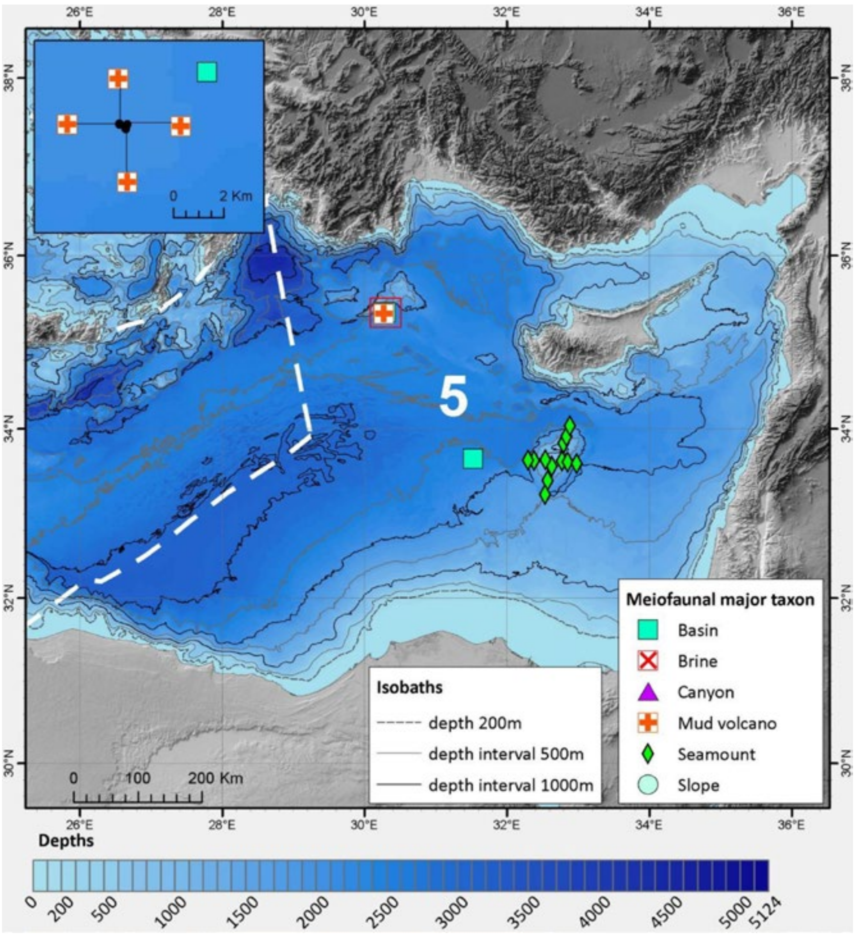

Fig. 5.10.
Map showing the locations of stations from the Levantine Sea with symbols representing different habitat types.
deep-sea basins;
seamounts;
mud volcanoes.
Data between 2007 - 2010.

The very low values of meiofaunal abundance in this area are typical for the Eastern Mediterranean deep sea. However, the values reported from the Eratosthenes Seamount are lower compared to values from other seamount areas[16]. In contrast, higher meiofaunal densities were found at the mud volcano. This observation along with the unique community structure of this habitat indicate a positive effect as a result of higher food availability or habitat complexity of these ecosystems that may provide a higher number of niches and possibly refuge from predators[17,18]. Nevertheless, diversity analysis suggests that the three habitats do not show any significant differences in taxon richness (Fig. 5.11).

Meiofaunal abundance in the Levantine Sea did not show any apparent bathymetric pattern, since densities remained practically constant, with the exception of the mud volcano stations, where values were relatively high. Densities were on average 63 ind./10 cm^2 at a depth of approximately 1000 m and remained low (approximately 38 ind./10 cm^2) at 2500 m. The mud volcano stations had on average 772 ind./10 cm^2 at a water depth of 2024 m.

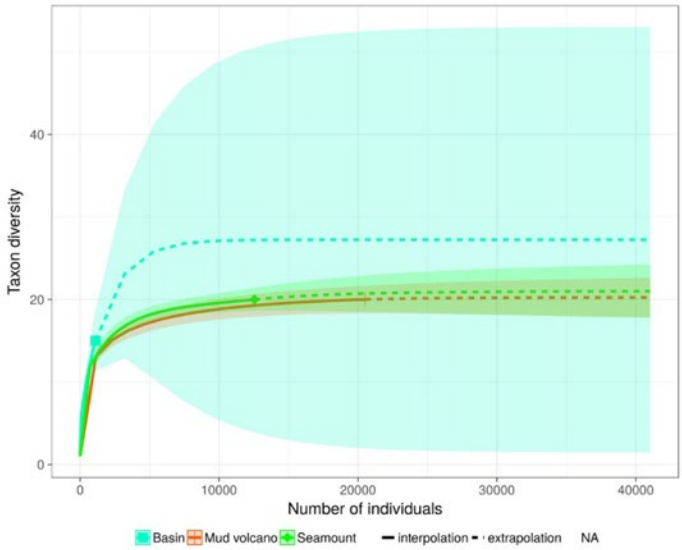

Fig. 5.11.
Comparison of meiofaunal major taxon diversity from three different habitats in the Levantine Sea. (Solid line: actual data; dashed line: extrapolated data; colour-shaded regions: 95% confidence intervals).

General Remarks

The different deep-sea habitats in the Eastern Mediterranean harbour specific meiofauna assemblages, which contribute significantly to the regional diversity and support the idea of the deep sea being a highly diverse environment making its protection highly significant for conservation. Meiofauna communities in mud volcanoes, seamounts and canyons show significant shifts in density and the relative proportions of the dominant taxa, separating them from slopes and basins. In addition, meiofauna abundance follow a general decreasing trend with depth, although some notable exceptions, such as the highly productive North Aegean Sea, exist.

Evidently, with many areas and habitats remaining still unexplored, we need more information in order to understand the unique community structure, ecosystem functioning patterns, and possible anthropogenic impacts on these very different deep-sea habitats. For the Eastern Mediterranean in particular, the focus should perhaps rely more on canyons, seamounts and cold seeps, since these environments are potential hotspots of benthic biodiversity but, so far, there have been only limited studies. •

CHAPTER 5 /

REFERENCES

1. Giere O. (2009). ***Meiobenthology: the microscopic motile fauna of aquatic sediments***. Springer Verlag, 548 pp.

2. Schratzberger M., and Ingels J. (2017). ***Meiofauna matters: the roles of meiofauna in benthic ecosystems***. Journal of Experimental Marine Biology and Ecology,502: 12–15.

3. Danovaro R., Company J.B., Corinaldesi C., D'Onghia G., Galil B., Gambi C., Gooday A., Lampadariou N., Marco Luna G., Morigi C., Olu K., Polymenakou P., Ramirez- Llorda E., Sabbatini A., Sardà F., Silbuet M., and Tselepides A. (2010). ***Deep–sea biodiversity in the Mediterranean Sea: the known, the unknown and the unknowable***. PLoS One,5(8): e11832.

4. Gambi C., Lampadariou N., and Danovaro R. (2010). ***Latitudinal, longitudinal and bathymetric patterns of abundance, biomass of metazoan meiofauna: importance of the rare taxa and anomalies in the deep Mediterranean Sea***. Advances in Oceanography and Limnology,1: 167–197.

5. Sevastou K., and Lampadariou N. (2021). ***Benthic Meiofauna in the Aegean Sea.***. ***In***: ***The Handbook of Environmental Chemistry.*** Springer.Berlin, Heidelberg.

6. Lampadariou N., Hatziyanni E., and Tselepides, A. (2003). ***Community structure of meiofauna and macrofauna in Mediterranean deep-hyper-saline anoxic basins.*** CIESM Workshop Monographs,23: 55.

7. Lampadariou N. and Tselepides A. (2006). ***Spatial variability of meiofaunal communities at areas of contrasting depth and productivity in the Aegean Sea (NE Mediterranean)***. Progress in Oceanography,69: 19–36.

8. Danovaro R., Tselepides A.,Otegui A., and Della Croce N. (2000). ***Dynamics of meiofaunal assemblages on the continental shelf and deep-sea sediments of the Cretan Sea (NE Mediterranean): relationships with seasonal changes in food supply***. Progress in Oceanography,46: 367–400.

9. Tselepides A. and Lampadariou N. (2004). ***Deep-sea meiofaunal community structure in the Eastern Mediterranean: are trenches benthic hotspots?*** Deep-Sea Research I,51: 833–847.

10. Sevastou K., Lampadariou N., Polymenakou P.N., and Tselepides A. (2013). ***Benthic communities in the deep Mediterranean Sea: exploring microbial and meiofaunal patterns in slope and basin ecosystems***. Biogeosciences,10: 4861–4878.

11. Psarra S., Tselepides A., and Ignatiades L. (2000). ***Primary productivity in the oligotrophic Cretan Sea (NE Mediterranean): seasonal and interannual variability.*** Progress in Oceanography,46: 187–204.

12. Tselepides A., Papadopoulou K.-N., Podaras D., Plaiti W., K.D. (2000). ***Macrobenthic community structure over the continental margin of Crete (South Aegean Sea, NE Mediterranean)***. Progress in Oceanography,46: 401–428.

13. Zeppilli D., Leduc D., Fontanier C., Fontaneto D., Fuchs S., Gooday A.J., Goineau A., Ingels J., Ivanenko V.N., Kristensen R.M., Neves R.C., Sanchez N., Sandulli R., Sarrazin J., Sørensen M.V., Tasiemski A., Vanreusel A., Autret M., Bourdonnay L., Claireaux M., Toomey L. and Fernandes D. (2018). ***Characteristics of meiofauna in extreme marine ecosystems: a review***. Marine Biodiversity,48: 5–71.

14. Lampadariou N., Tselepides A., H.E. (2009). ***Deep-sea meiofaunal and foraminiferal communities along a gradient of primary productivity in the eastern Mediterranean Sea***. Scientia Marina,73: 337–345.

15. Sevastou K., Lampadariou N., Mouriki D., Tselepides A., and Martínez Arbizu P. (2020). ***Meiofaunal distribution in the Levantine Basen (Eastern Mediterranean): Spatial variability at different scales, depths and distance-to-coast.*** Deep Sea Research Part II: Tropical Studies in Oceanography,171: 104635.

16. Zeppilli D., Bongiorni L., Cattaneo A., Danovaro R., and Santos R.S. (2013). ***Meiofauna assemblages of the Condor Seamount (North-East Atlantic Ocean) and adjacent deep-sea sediments***. Deep Sea Research Part II: Topical Studies in Oceanography,98: 87–100.

17. Levin L.A., Mendoza G.F., Gonzalez J.P., Turber A.R., and Cordes E.E. (2010). ***Diversity of bathyal macrofauna on the northeastern Pacific margin: the influence of methane seeps and oxygen minimum zones***. Marine Ecology,31: 94–110.

18. Vanreusel A., Fonseca G., Danovaro R., da Silva M.C., Esteves A.M., Ferrero T., Gad G., Galtsova V., Gambi C., da Fonsêca Genevois V., Ingels J., Ingole B., Lampadariou N., Merckx B., Miljutin D., Miljutina M., Muthumbi A., Netto S., Portnova D., Radziejewska T., Raes M., *et al.* (2010). ***The contribution of deep-sea macrohabitat heterogeneity to global nematode diversity***. Marine Ecology,31: 6–20.