WORLD SEAS

AN ENVIRONMENTAL EVALUATION

EDITED BY CHARLES SHEPPARD

SECOND EDITION

VOLUME I

EUROPE, THE AMERICAS AND WEST AFRICA

World Seas: An Environmental Evaluation

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Edited by

Charles Sheppard
Emeritus Professor, School of Life Sciences
University of Warwick, United Kingdom

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Chapter 11

Italian Seas

Roberto Danovaro[*,†], Ferdinando Boero[‡,§]
[*]Università Politecnica delle Marche, Ancona, Italy, [†]Stazione Zoologica Anton Dohrn di Napoli, Napoli, Italy, [‡]Università del Salento, CoNISMa, Lecce, Italy, [§]Istituto di Scienze Marine (ISMAR) CNR, Genova, Italy

11.1 THE ITALIAN SEAS

11.1.1 Geography, Topography, Geological Description

The Italian seas are part of the Mediterranean Sea. The sea as a whole contains about 3000 islands; its maximum depth exceeds 5000 m (in the Ionian Sea), and its average depth is about 1500 m. The Italian peninsula, together with Sicily, essentially divides the Mediterranean into Western and the Eastern subbasins, and the Italian seas contain most of the ecological conditions of both (Fig. 11.1).

The islands of Corsica, Sardinia, and Sicily, together with the Italian peninsula, define the Tyrrhenian Sea to the west. To the east lies the Adriatic, a semi-enclosed basin connected, through the Otranto Strait, to the Ionian Sea.

Every sea has its own identity and peculiarities. The northern coast has a varied assortment of landscapes characterized by long stretches of sand and equally long stretches of rock. Many rivers form deltas along the northern coast, the most important being the Po and the Rhone rivers. The Mediterranean Sea dried up during the Messinian Crisis (about 5.5 My ago) (CIESM, 2008), losing continuity with the Indo-Pacific Ocean, to which it was formerly connected. During the crisis, rivers indented the bottom of the dry marine basin, forming about 800 marine canyons, and later incoming water from Gibraltar generated the sea as we know today.

11.2 PHYSICAL OCEANOGRAPHY OF THE MEDITERRANEAN SEA

It is impossible to understand oceanographic features of the Italian Seas without understanding the dynamics of the whole Mediterranean Sea. The salinity of the Mediterranean Sea averages ca. 37‰ since riverine inputs do not compensate for evaporation, and sea level is maintained due to the connection with the Atlantic Ocean through the Gibraltar Strait. The Gibraltar current enters the Mediterranean along the surface and is compensated by a deep outflow of Mediterranean water wetwards through the Gibraltar sill. These currents renew the water of the Mediterranean Sea between the surface and 500 m depth. The renewal of waters deeper than 500 m requires a different process, involving deep water formation which happens in the so-called cold engines in the Gulf of Lions, the North Adriatic, and the North Aegean (Fig. 11.2).

Deep-water formation occurs when the surface temperature is relatively low and salinity is higher. These denser waters sink, in a process called cascading (Fig. 11.2 lower right inset). The sinking water pushes deep water up. This process sends oxygenated surface water to the deep, pushing up the nutrient-rich but oxygen-poor deep water, causing vertical mixing essential to deep-sea oxygen breathing organisms. Without these vertical exchanges, the deep Mediterranean waters would become anoxic. The cold engine of the western Mediterranean is on the north coast, especially in the Gulf of Lions, whereas that of the eastern Mediterranean is partly in the northern Adriatic.

The shape of the coast channels the Gibraltar current to generate horizontal currents that form more or less permanent gyres and eddies, the most peculiar one being the Ionian Bimodal Oscillating System (BIOS), running alternatively clock and counter clockwise (Civitarese, Gačić, Lipizer, & Eusebi Borzelli, 2010) (see Fig. 11.2). These horizontal currents intertwine with vertical ones, often connected with marine canyons, and the cold engine-generated cascading phenomena form downwellings through canyons and, where cascading does not occur, canyons intercept horizontal currents and drive them towards the coast in form of upwellings (Fig. 11.2 lower right inset). While the main currents are steady, the more local ones are far from constant and can go through seasonal and annual variations. The cold engines, for instance, operate mainly in

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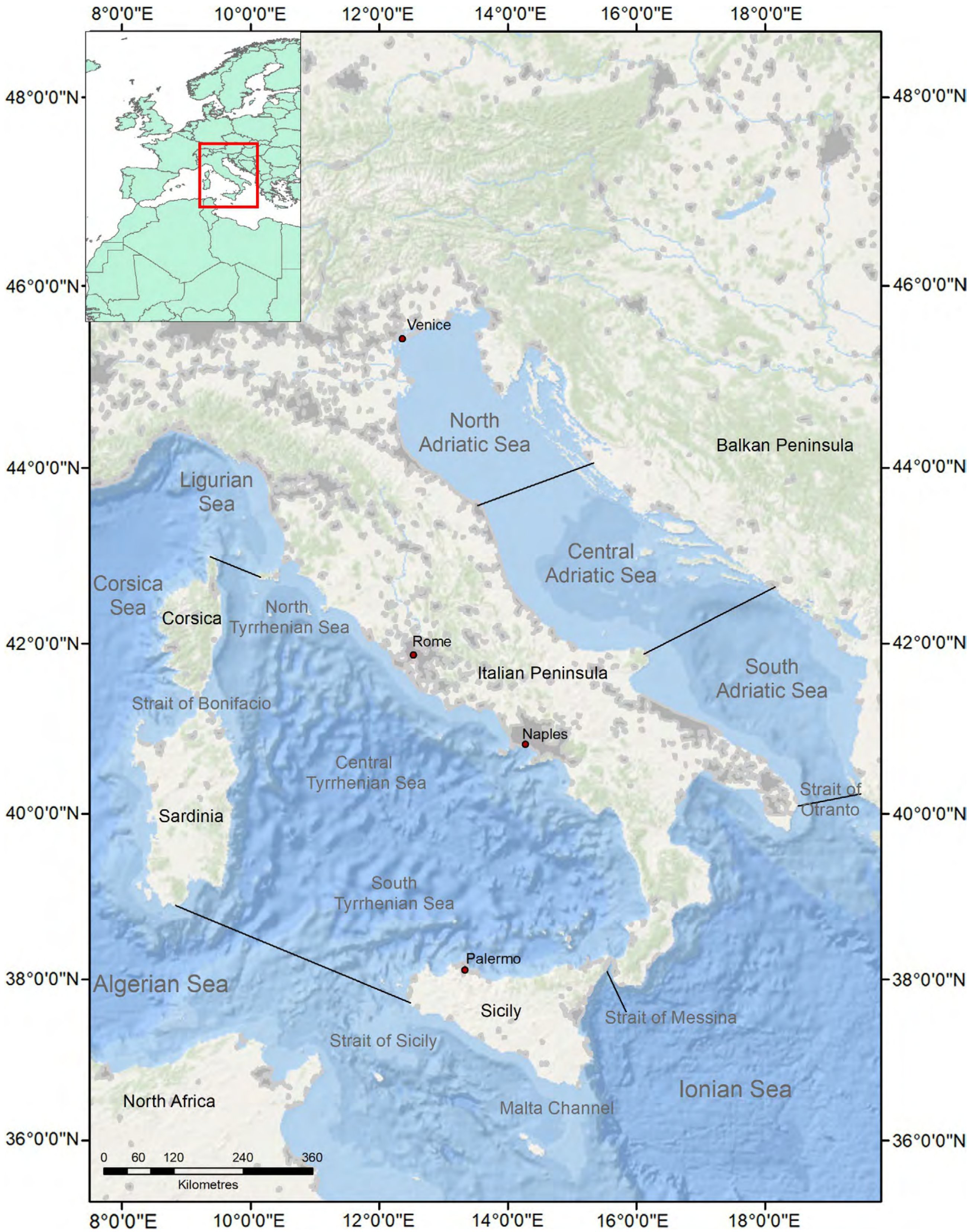

FIG. 11.1 The Italian Seas.

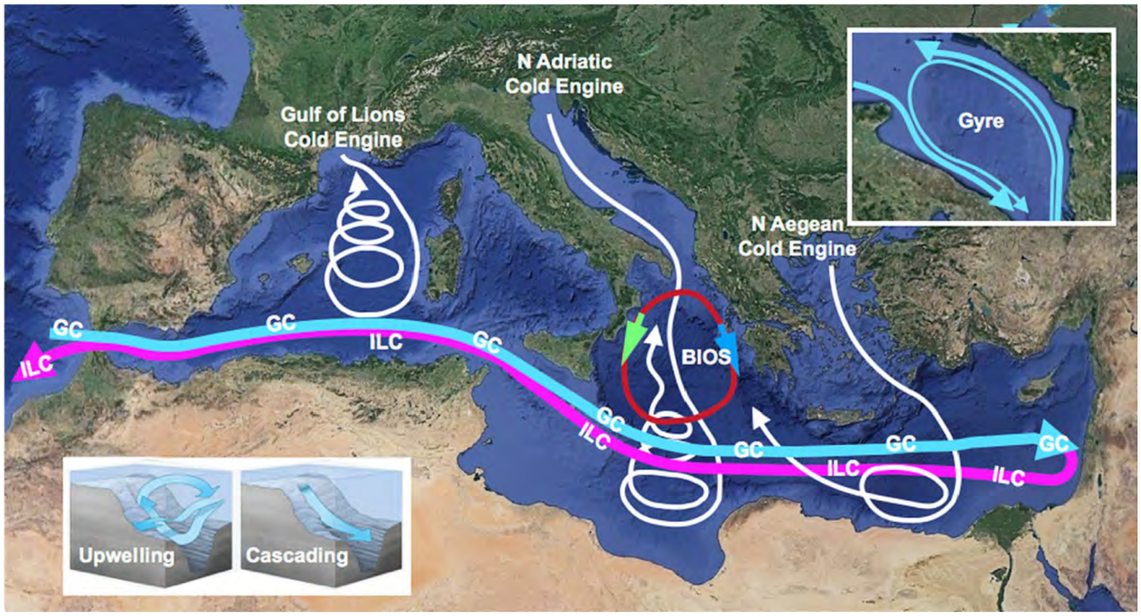

FIG. 11.2 The main horizontal and vertical currents of the Mediterranean Basin—*GC*, Gibraltar current; *ILC*, intermediate Levantine current; *BIOS*, Bimodal Oscillating System. *Modified after Boero, F., Foglini, F., Fraschetti, S., Goriup, P., Machpherson, E., Planes, S., Soukissian, T., CoCoNet Consortium. (2016). CoCoNet: Towards coast to coast networks of Marine Protected Areas (from the shore to the high and deep sea), coupled with sea-based wind energy potential. Scientific Research and Information Technology 6 (Suppl.), 1–95.*

the winter. Regime shifts can occur when the northern Adriatic cold engine failed. In such a period of rapid change sudden regime shifts are to be expected and even the sophisticated models that describe the circulation of the Mediterranean Sea can fail to predict them.

11.2.1 The Adriatic Sea

The Adriatic Sea is over 800 km long and around 150–200 km wide, with a surface of about 138,600 km^2 and a volume of roughly 35,000 km^3 (McKinney, 2007). The major axis is NW-SE oriented, and the Adriatic continental shelf is the most extensive one in the central Mediterranean Sea. The basin can be divided into three sections, with increasing depth from north to south, each with different characteristics, different widths, and topographic gradients. The northern Adriatic comprises 5% of the basin, with a maximum depth of 75 m and occupies the flooded seaward extension of the Po Plain and reaches an average depth of about 35 m. It gently down to about 100 m depth to a line between Pescara and Sibenik, where a slope leads to the central basin at depths of 140–150 m. The central Adriatic is 15% of the basin, up to 220 km wide, with an average depth of 130–150 m, but is also characterized by the 270 m deep Pomo Depression, forming the "Meso-Adriatic Trench." The southern Adriatic is 80% of the total volume, with an area of 57,000 km^2, an average depth of 450 m, and a maximum depth of 1233 m (Fig. 11.3) and contains a comparatively large bathyal basin with shelf surfaces of varying width; the continental shelf is limited in the Strait of Otranto, 750 m deep and 72 km wide, where important water exchanges with the Ionian Sea take place (Trincardi, Cattaneo, Asioli, Correggiari, & Langone, 1996). The western part of the Adriatic (i.e., the Italian coast) is low, with sediment-loaded beaches, which originate from strong Pleistocene to Holocene river discharge. The eastern Adriatic coast is rugged and rocky; at the northernmost point of the Adriatic, Monfalcone marks the abrupt change between the Italian coast to the southwest and the Balkan one southeast. The Adriatic seabed sediments are predominantly sandy-muddy, while the main clastic sources are located along the western side. Contrary to the rest of the Mediterranean Sea, where tides are negligible, tides can be particularly relevant in the northern Adriatic.

11.2.1.1 Oceanography

The Adriatic Sea takes in up to one-third of the freshwater flow received by the entire Mediterranean. The Adriatic's entire volume is exchanged into the Mediterranean Sea through the Strait of Otranto every 3–4 years, a very short period, likely due to the combined contribution of rivers and submarine groundwater discharge. Drifting particles have been estimated to reside in the Adriatic Sea for just 150–168 days (Poulain & Hariri, 2013). The general circulation is cyclonic with a northwest flow along the eastern coast and a return southeast flow along the western coast. The mean circulation shows seasonal variability according to changing winds and thermal fluxes during the year. Local cyclonic gyres characterize the general

FIG. 11.3 The main currents of the three portions of the Adriatic Sea (graphics: F. Boero).

circulation in the three regions: the southern gyre tends to persist throughout the year, the middle gyre is more pronounced in summer and autumn, and in the northern region a cyclonic gyre is evident during the autumn in front of the Po River mouth (Fig. 11.3).

A thermohaline current flows southwards across the continental shelf and along the Italian coast to cascade through the Bari Canyon into the Ionian Sea, to the depths of the Taranto Canyon. To balance this outflow, an incoming current enters the Adriatic Sea from the eastern coast of the basin, and reaches the Gulf of Trieste. The presence of headlands such as those at Istria, Conero, and Gargano leads to the formation of a northern, a central, and a southern gyre, with horizontal currents that connect the western and the eastern coasts of the basin, along which the currents flow in opposite directions. In this way, the Adriatic Sea has three coherent oceanographic cells (Boero et al., 2016). Both intensity and location of the costal currents (western Adriatic and eastern Adriatic current) and of the gyres above the middle and south Adriatic Pits have significant seasonal variations. The typical winds Bora and Sirocco blow along the eastern coast of the Adriatic Sea, especially during cold months, regulating the circulation of water masses. Annual winds are generally NNW-SSE in the South Adriatic Basin. During the warmer season, sea and land breezes are frequent. The circulation of Adriatic surface water (ASW) is affected by the inflow of freshwater particularly from the Po River, the inflow of Mediterranean water through the Otranto Strait and wind shear. The Adriatic Sea is the major source of the densest water in the eastern Mediterranean and the eastern Mediterranean deep water. Four water masses circulate through the southern Otranto Strait: ASW, the Ionian surface water (ISW), the Levantine intermediate water (LIW) from the eastern Mediterranean (LIW—a warm and highly saline current on the eastern slope of the Otranto Strait from 250 to 500 m depth), and the Adriatic deep water (ADW—a high density, low temperature and low salinity current on the western slope) (McKinney, 2007).

11.2.2 Tyrrhenian Sea

The Tyrrhenian Sea has a surface of 275,000 km^2, a mean depth of 2000 m and has a complex bathymetry, reaching 3780 m. The basin is almost triangular, and the island of Elba marks the boundary between the Tyrrhenian and the Ligurian Seas, even though, for some geographers, the Tyrrhenian Sea comprises the whole coast of Tuscany, reaching the border of Ligury, where high and rocky coasts start. The Strait of Bonifacio, between Corsica and Sardinia, connects the Tyrrhenian Sea with the Sardinian Sea. A line between Cape Lilibeo (Sicily) and Cape Teulada (Sardinia) separates the Tyrrhenian Sea from the Algerian Sea. The Strait of Messina connects the Tyrrhenian Sea with the Ionia Sea. The northern Tyrrhenian Sea between Corsica and the Tuscany coast of Italy is shallower than the central and south Tyrrhenian Sea.

11.2.2.1 Oceanography

The Tyrrhenian Sea has four openings (see Fig. 11.1). The Sea's large-scale circulation (Astraldi & Gasparini, 1994; Krivosheya, 1983; Millot, 1999) is that of a mainly wind-driven circulation, with some quasi-permanent features in the western part of the basin: a wide cyclonic area to the southeast of Sardinia, and a cyclonic center east of Corsica (the Bonifacio gyre) having an anticyclonic companion to the south. Two broad regions can be defined on the basis of prevailing dynamic conditions. The northern and central parts are mostly influenced by the wind blowing year-round eastward from the Strait of Bonifacio. This jet-like force excites important quasi-stationary counter-rotating gyres that enhance the vertical mixing, also renewing the deep waters with a cascading process. In contrast, the southern part of the basin appears to be under the influence of forces conveyed through the southern opening, where the seasonal intrusions of the modified Atlantic water (MAW) play a major role. In winter, the surface flow along the eastern Tyrrhenian coast as far as the Corsica Channel provides a strong link in the circulation of the two basins. In summer the MAW does not leave the Tyrrhenian northward. While its circulation involves the whole basin, the inflow/outflow is, for the most part, throughout the southern opening. Since it mixes with both the surface water and the deep water, the LIW plays an essential role on the vertical exchanges inside the basins. The Tyrrhenian water column is a three-layer system: a surface layer filled by waters of Atlantic origin, an intermediate layer containing the LIW, and a bottom layer of resident Tyrrhenian deep water, the latter resulting from the western Mediterranean deep water and the transitional eastern Mediterranean deep water (Astraldi, Gasparini, Sparnocchia, Moretti, & Sansone, 1996; Sparnocchia, Gasparinia, Astraldi, Borghini, & Pistek, 1999) (Fig. 11.4).

The Tyrrhenian Sea differs from the rest of the Mediterranean Sea in the sense that the Gulf of Lions cold engine does not renew its deep waters where, however, life thrives. The MAW and LIW that flow into the basin from between Sardinia

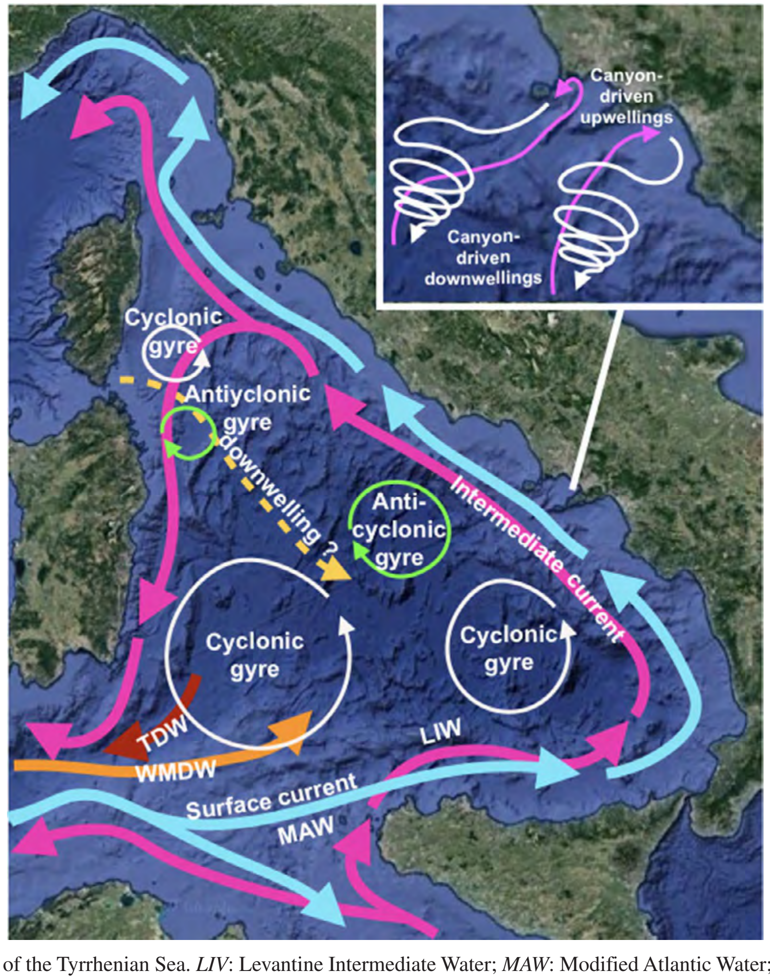

FIG. 11.4 The main currents of the Tyrrhenian Sea. *LIV*: Levantine Intermediate Water; *MAW*: Modified Atlantic Water; *TDW*: Tyrrhenian Deep Water; *WMDW*: Western Mediterranean Deep Water. Inset: Canyon-driven up- and down-welling (From various sources, graphics: F. Boero).

and Sicily, run along the northern coast of Sicily and then go northwards along Calabria, Campania, Latium, and Tuscany, to then flow south of the Island of Elba towards Sardinia, along whose eastern coast the current proceeds southwards, where it outflows from the basin. Canyons indent the whole continental shelf and generate upwellings when there is no stratification, which generate offshore downwellings towards the center of the basin, a pattern supported by the distribution patterns of jellyfish (Benedetti-Cecchi et al., 2015; Canepa et al., 2014; Guglielmo et al., 2017). This mix of horizontal and vertical currents is still poorly studied as a whole.

11.3 NATURAL ENVIRONMENTAL VARIABLES, SEASONALITY

11.3.1 Climate, Freshwater Discharges

The warm season usually occurs from June to September, with short intermediate seasons, in May and October, whereas the cold season spans from November to April. The temperatures range from 12°C to13°C in the cold season, when the basin is homeothermic, and 26°C to 28°C in the warm season, when a sharp stratification occurs. Temperatures are fairly constant under the mixed layer, between 12°C and 13°C. Along northern shores, winter temperatures reach well below 12°C and surface waters can even freeze in the Gulf of Trieste (northern Adriatic). In the last decades, however, climate change has rapidly altered this situation: thermal anomalies are increasingly frequent, and the sea surface temperatures often exceed 30°C throughout the basin causing extensive mass mortalities of organisms that usually remain below the summer stratification, causing stress to stenothermic organisms, such as sea fans (Rivetti, Fraschetti, Lionello, Zambianchi, & Boero, 2014). During recent decades the temperatures of both the Adriatic and the Tyrrhenian and Ligurian Seas have significantly increased (Bianchi & Morri, 2000) which is having huge consequences on the biotas of both basins in terms of dramatic changes in biodiversity composition due to either tropicalization (the establishment of tropical species) and meridionalization (the northward expansion of species that thrived in the southern Mediterranean) (Boero, 2015).

Climate change has been invoked to explain the eastern Mediterranean transient (1991–1992 and 1992–1993) when the northern Adriatic cold engine failed to send oxygenated water in the deepest portions of the eastern Mediterranean (Danovaro, Dell'Anno, Fabiano, Pusceddu, & Tselepides, 2001).

Rivers flow into the Mediterranean mainly on the northern shore (with the exception of the Nile). The Ebro in Spain, the Rhône in France, and the Po in Italy are the most remarkable ones. Riverine waters from these and several smaller ones are widely used for agriculture, hydroelectric power generation, and for the cooling of industrial plants, and bring many domestic and industrial pollutants. Climate change is affecting fresh water inputs, with increasingly long dry seasons, when rivers almost dry up, followed by sudden bursts of precipitation. The overall freshwater balance remains stable, but extreme events increase. In general, summers tend to be warmer, longer, and dryer than before, whereas winters are shorter, usually warmer, and very wet, and extremely low temperatures are not infrequent. River management has often been unwise in respect with coastal erosion. Rivers used to bring huge sediment loads during winter, replenishing beaches and compensating for wave erosion. The construction of dams and the mining of river sand for construction have greatly limited the transport of sediments, enhancing coastal erosion. Almost invariably, the problem has been tackled by building coastal defenses made either of rocks or of concrete tetrapods. This practice has transformed long stretches of sandy shores into hard-bottom shores (e.g., the central and northern Adriatic Italian coast).

Besides these general phenomena, common to both the Tyrrhenian and the Adriatic Seas, the numerous rivers discharging into the Adriatic Sea, plus underground freshwater seeping into the sea along the eastern coast, affect both sedimentation and coastal circulation. This effect is particularly evident in the northern part of the Adriatic Sea, highly influenced by the Po River discharge (and that from nearby minor rivers) and by meteorological events. The Po River is the largest contributor of sediments to the Adriatic Basin, and supplies over 11% of the total freshwater flow into the Mediterranean, 28% into the Adriatic Sea, and 50% into its northern part (Degobbis, Gilmartin, & Revelante, 1986). This drives lower salinities in the whole basin and induces elevated primary production that leads to the high abundance of fish; the resulting system is thus a highly exploited fishing zone (Cataudella & Spagnolo, 2011; Fortibuoni, Libralato, Raicevich, Giovanardi, & Solidoro, 2010). Total input and evaporation results in an excess of water of 90–150 km^3 per year that is exported in the Mediterranean Basin through the Otranto Strait (McKinney, 2007). The Po river terrigenous supply is turbid, but the littoral environment is highly energetic and does not allow much sedimentation of fine matter, so the area is characterized by the presence of coarse terrigenous sand. The Po Plain and the northern Adriatic Sea is a single-flooded sedimentary plain that permits large lateral movement of the coastline (McKinney, 2007). The inputs coming from the river create gyres that move the sediments and produce deposits and sink zones that determine the local conditions. The influence of the river input spreads along the whole basin.

11.4 MAJOR COASTAL AND SHALLOW HABITATS

The biodiversity of Mediterranean marine ecosystems is high, and the species contingent of the warm season is very different from that of the cold season. Seasonality drives radical shifts in species composition in the mixed layer where temperatures range from 13°C to 28–30°C. The cold season biodiversity is of boreal affinity, whereas the warm season biodiversity is of tropical affinity. Below the mixed layer, where temperatures are more stable, seasonality is less evident. The biodiversity comprises ca. 17,000 species (Coll et al., 2010) but it has not been thoroughly explored and new species are continuously found both in the deep sea (Danovaro et al., 2010) and in coastal areas, where new species of relatively large size are still described (e.g., Piraino et al., 2014; Scorrano, Aglieri, Boero, Dawson, & Piraino, 2017). In contrast to what happens in less seasonal seas, the biomass of the Mediterranean Sea is divided between a large number of species, none of which form huge populations. This is very evident in the yields of local fisheries, where there are no major species in terms of quantities.

Benthic habitats can be classified according to the level on the shore and the type of substrate (Fraschetti, Terlizzi, & Boero, 2008). Many species are habitat formers, especially on hard bottoms. Habitat formers can be seasonal in occurrence, as is the case of many algae, the most remarkable ones being those of the speciose genus *Cystoseira* that form dense canopies. Bioconstructors are also habitat formers, and their bodies and constructions can be conspicuous.

11.4.1 Main Habitats

11.4.1.1 Posidonia *Meadows*

The seagrass *Posidonia oceanica* (Fig. 11.5) is endemic to the Mediterranean Sea and is the trademark habitat of the whole basin.

Posidonia meadows are present throughout a large part of the Mediterranean but in some areas they have almost disappeared, especially along the middle and northern Adriatic, whereas they thrive in the southern Adriatic. The European Union (EU) recognizes *Posidonia* meadows as a habitat of community importance, listed in the EU Habitats Directive. *Posidonia* can grow on both rocky and sandy substrates, from the surface to more than 50 m depth, depending on light penetration. The rhizomes have rootlets and each rhizome bears a shoot of leaves. Old leaves are shed seasonally and accumulate on the shore, forming dense masses. New rhizomes grow on old and dead ones, raising the sea bottom and forming a particular bioconstruction made of dead rhizomes. Under particular conditions, the rhizomes can reach the surface, with the leaves exposed to air, so forming real reefs with inner lagoons. The ecological role of *Posidonia* meadows

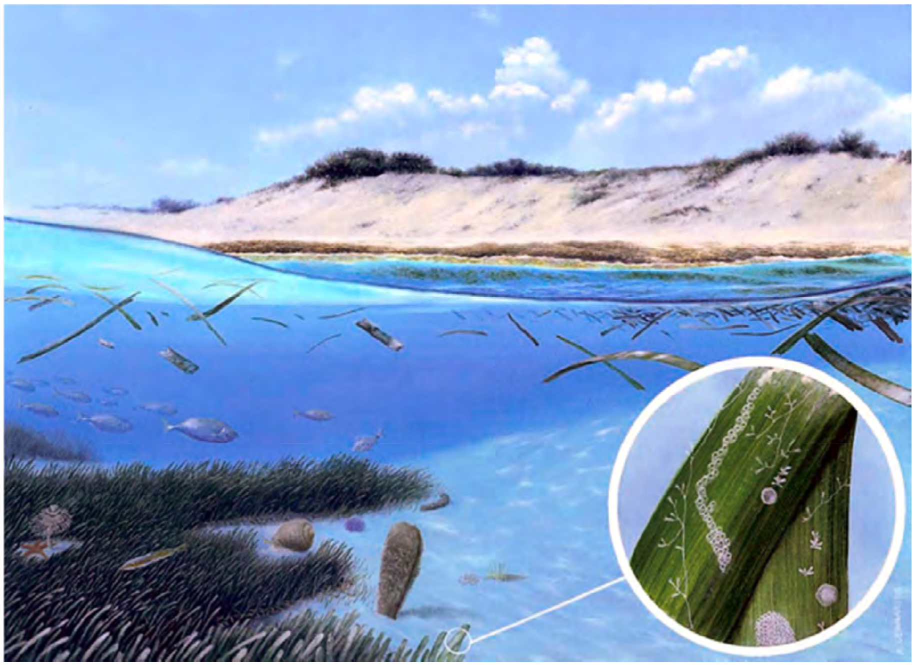

FIG. 11.5 Posidonia meadows (concepts: F. Boero; art: Alberto Gennari).

is analogous to that of coral reefs in tropical areas. They are an important sink of CO_2 and an equally important source of O_2, and they are habitat for numerous species, some of commercial importance and some living exclusively in association with the meadows. The rhizomes stabilize the sea bottom, and the leaves buffer wave action, so preventing coastal erosion (Boudouresque et al., 2017). The dead leaves that accumulate on the coast further prevent coastal erosion. These essential ecosystem services, and the widespread distribution of the meadows, are the reason for considering *Posidonia oceanica* to be the most important species of the whole basin. These reasons justify its strict protection from human activities, the most important ones being direct destruction due to coastal development, trawling, anchoring, and sedimentation increase including material from cage mariculture. Most Sites of Community Importance in Mediterranean EU waters have been crated due to the presence of *Posidonia* meadows. Before the 1980s, sexual reproduction of *Posidonia* was extremely rare in the northern Mediterranean shore, being more frequent on the southern shore, where temperatures are higher. Since the beginning of the 1980s, however, the flowers of *Posidonia* have been increasingly recorded, at first not leading to fruit formation. In subsequent years, fruits have been reported, but not seedlings. More recently, seedlings have been observed too. It seems that global warming is enhancing the reproductive success of the plant. Other sea grasses (*Zostera*, *Cymodocea*) are not equally important but can be locally relevant.

11.4.1.2 Algal Forests

Cystoseira is the most important habitat forming algal genus in the Mediterranean, with numerous species. *Cystoseira amentacea* forms extensive fringes on rocky shores (Fig. 11.6), and other species can reach much deeper levels.

The most important species are *Cystoseira zosteroides*, *C. usneoides*, *C. dubia*, and *C. corniculata*. Other important canopies are formed by *Sargassum* spp., *Laminaria ochroleuca*, and *Rodriguezella strafforelli*. Especially at shallow depths, algal forests are seasonal, present in spring and summer, and spend the other seasons as resting thalli. Algal forests are habitat for many benthic and nektonic species and are important elements of submarine landscapes. *Fucus virsoides*, endemic to the North Adriatic, is the only representative of the genus in the whole Mediterranean and is probably suffering the impact of global warming.

11.4.1.3 Bioconstructions

These are in “reef” habitat type of the Habitats Directive and are thus of community importance, even though they have not been given the same importance of *Posidonia* meadows, at least in terms of declaration of Sites of Community Importance. However, some Mediterranean bioconstructions, especially coralligenous formations, are scenic and have played a key role in the choice of marine protected areas (MPAs). Coralligenous formations are varied. Their name originates from the presence of the precious coral *Corallium rubrum* but, in general, they are characterized by the presence of coralline algae that are overgrown by other algae and invertebrates. A vast array of skeletonized invertebrates, from sponges to cnidarians,

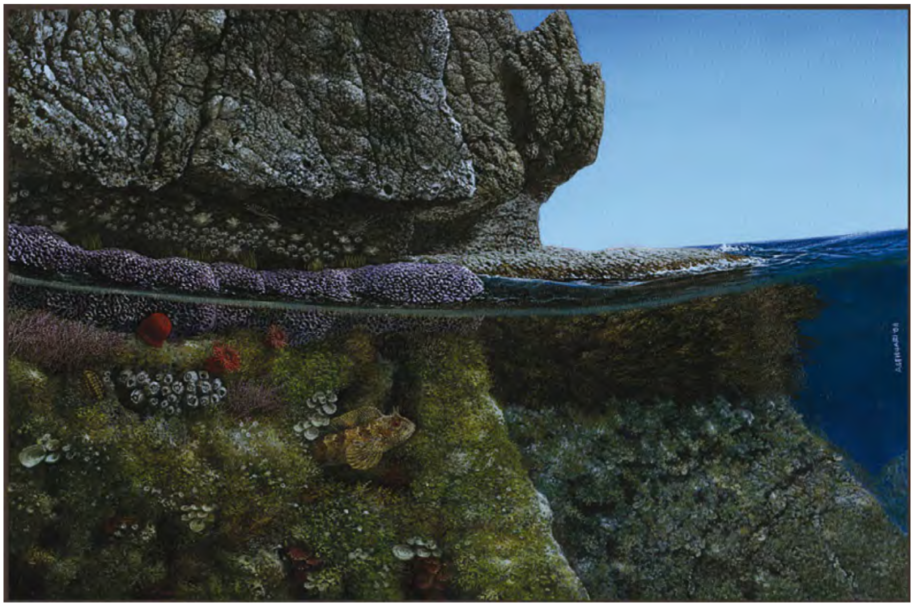

FIG. 11.6 Lithophyllum “trottoir” and the *Cystoseira amentacea* fringe (concepts: F. Boero; art: Alberto Gennari).

bryozoans, molluscs, and annelids adds to the coralline. The living part of these formations, therefore, is made of algae and invertebrates but, once they die, their skeletons are kept together by a matrix of probable bacterial origin, some sort of stromatolite. Bioconstructions of coralline algae (mainly *Lithophyllum* spp.) (see Fig. 11.5) are present in the intertidal zone of exposed rocky shores, where they form the so-called "sidewalks." Other coralligenous formations thrive on cliffs, below the zone dominated by brown and green algae. They are absent in the central and northern Adriatic, but are quite common both in the Ligurian, Tyrrhenian, Ionian, and southern Adriatic Seas. Coralligenous formations are dominated by sea fans of the genera *Eunicella* and *Paramuricea* that can form extensive forests attractive for SCUBA divers. Besides gorgonaceans, other conspicuous invertebrates range from sponges, madreporarians, hydrozoans, bryozoans, ascidians, and large bivalve mollusks and annelids. The colors and the three-dimensional structure of these habitats are comparable to those of tropical coral reefs.

Where MPAs are successfully enforced, fish populations are very abundant and diverse, including many sparids, groupers, and other species of high commercial value. Coralligenous formations can also occur on horizontal substrates and, in this case, they are called platforms or mounds, according to their shape (Fig. 11.7). Recently, in the marine caves of Apulia, a new type of bioconstruction has been found, namely, the biostalactites. These are made of a core of annelid tubes that become incorporated into a bacterial matrix. They hang from the roofs of marine caves and have no algal component (Belmonte et al., 2009). Other locally important bioconstructions are made of vermetid molluscs and sabellarid polychaetes. These "reefs" occur in shallow waters. Maerl formations are produced by coralline algae that grow into rolling shapes that accumulate on horizontal bottoms, and are increasingly found along Mediterranean coasts. In the northern Adriatic, the "Tegnue" are a special type of bioconstruction that is presently attracting much attention, due to its originality.

11.4.1.4 Marine Caves

Marine Caves (Fig. 11.8) are habitat type, listed in the EU Habitats Directive.

They are particularly abundant along Mediterranean rocky coasts where karst processes are prominent. In the Tyrrhenian Sea they are frequent in the Gulf of Naples. In the Adriatic Sea caves are mostly present in the South. Marine caves replicate horizontally, in a few meters, the vertical zonation that can be observed from the surface to several 100-m depths. Algae are present at the very entrance, to be replaced by animals throughout the cave. The deepest caves can be inhabited by species that usually thrive in deep waters. Some species, such as carnivorous sponges, are known to live in marine caves only. Anchialine caves harbor a unique biodiversity; these caves contain marine waters but have scant or no communication with the open sea. Some species are known to live exclusively in one or in just a few caves (Pesce, 2001).

FIG. 11.7 Coralligenous formation (concepts: F. Boero; art: Alberto Gennari).

FIG. 11.8 A Mediterranean marine cave (concepts: F. Boero; art: Alberto Gennari).

11.4.1.5 *Animal Forests*

In the winter, many algae-dominated habitats undergo a change in physiognomy. In some cases, large hydroids replace algal canopies and form extensive animal forests. The species of the genus *Eudendrium* are the most remarkable. From 50 to 200 m depth, extensive forests of black corals such as *Leiopathes glaberrima* and the zoanthid *Savalia savaglia*, and also sponges, hydrozoans, bryozoans, and tunicates, play important habitat formers. They inhabit both hard and soft substrates, as does the hydrozoan *Lythocarpia myriophillum* and the sea fan *Isidella elongata*. At even deeper depths, the cold corals *Madrepora oculata*, *Lophelia pertusa*, and *Desmophyllum dianthus* play important roles (Fig. 11.9). These animal forests are present in the whole Ligurian and Tyrrhenian Seas, in the southern portion of the Adriatic Sea and in the Ionian Sea. *Corallium rubrum*, the precious red coral, has been collected for centuries and its populations are declining due to over harvesting. These animal forests are now receiving due consideration, thanks to the use of remotely operated vehicles (Fig. 11.9).

11.4.1.6 *Barrens and Trophic Downgrading*

The sea urchins *Arbacia lixula* and *Paracentrotus lividus* are abundant in shallow rocky habitats. *Paracentrotus* are also common in *Posidonia* meadows. Predators such as the sparids keep sea urchin populations under control but, when overfishing dramatically reduces their numbers, or where date mussel fisheries leads to the desertification of hard substrates (Fanelli, Piraino, Belmonte, Geraci, & Boero, 1994), sea urchins increase in numbers and greatly impact algal forests, leading to barrens where only encrusting coralline algae and turfs persist, especially in crevices where the grazing of the urchins is restricted (Guidetti & Dulčić, 2007) (Fig. 11.10).

The establishment of large populations of two species of *Siganus* in the eastern Basin is equally leading to barrens since these fish, which entered from the Suez Canal, are powerful grazers, able to reduce algal forests to bare substrates. The native herbivorous species *Sarpa salpa* exerts similar impacts when its populations become too large, often due to lack of higher predators. This impoverishment of the phytobenthos is probably the result of trophic downgrading. Fish populations, in fact, are being overexploited and the top predators are suffering the impact of fisheries the most (Britten et al., 2014). The reduction of shark populations (with the exception of the plankton feeder basking shark *Cetorhinus maximus*) has been followed by the decreasing abundance of other carnivorous fish. This led to the release from predation of herbivorous fish that are not as palatable as carnivorous ones and, hence, not equally fished due to their low commercial value. The increase in aquaculture practices, mainly of carnivorous species, requires extensive use of smaller fish to feed the cultured ones (Thiede et al., 2016). The impoverishment of top down control of herbivores due to the decreasing abundances of their predators is having dramatic impacts on habitat structure, resulting in the increase in barrens.

FIG. 11.9 A remotely Operated vehicle explores a cold-coral formation (concepts: F. Boero; art: Alberto Gennari).

FIG. 11.10 A sea urchin barren (concepts: F. Boero; art: Alberto Gennari).

11.4.1.7 Soft Bottoms

Soft bottoms are characterized mostly by their infauna, with the exception of sea grass meadows that are a distinct habitat themselves. The infauna is made of burrowers, and interstitial fauna that lives between the sediment grains (Fig. 11.11).

The interstitial fauna is defined by the size of the organisms, the meiofauna being usually smaller than 1 mm and organisms larger than 1 mm being macrofauna. The macrofauna is mostly composed of molluscs, crustaceans, echinoderms, and polychaetes. The meiofauna includes several phyla, such as Gnathostomulids, Kinorhinchs, Loriciferans, Gastrotrichs, and Tardigrades, but is also made of small representatives of most phyla. The epifauna of soft bottoms is mostly fish and crustaceans, and is heavily fished by trawling. Soft bottoms are also inhabited by colonies of Cnidarians, such as Pennatulaceans,

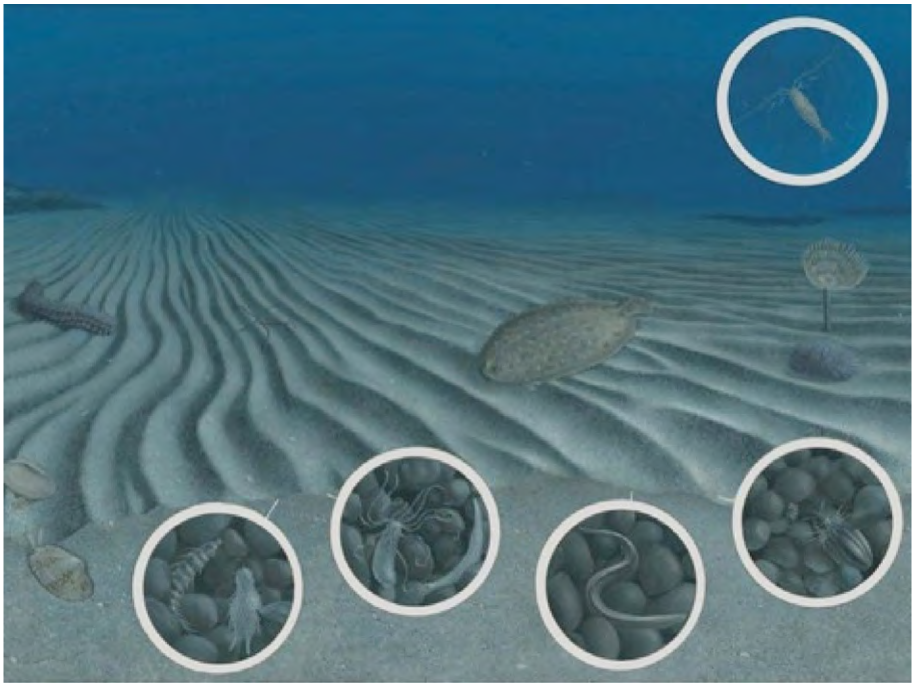

FIG. 11.11 Soft-bottom communities, with macro and meiofauna (concepts: F. Boero; art: Alberto Gennari).

Alcyonarians, Gorgonaceans, and Hydroids, and by individual Actinians and Cerianthids. In the deep sea soft bottoms are dominant, but they often include islands of hard substrates, with a mixture of soft and hard bottom habitats. The soft bottoms of the north and central Adriatic Sea, and indeed all the soft substrates of the Italian Sea, are heavily overfished.

11.4.1.8 Transitional Waters

Coastal lagoon, deltas, and estuaries represent a transition between freshwater systems and marine ones (Fig. 11.12).

FIG. 11.12 Transitional waters. *Aphanius fasciatus*, in the forefront, and Liza sp. near the surface (concepts: F. Boero; art: Alberto Gennari).

They are quite common along sandy shores, their salinity is lower than that of marine waters and are very productive. The diversity of transitional waters is lower than that of marine ones, but is quantitatively rich. They have been used for extensive aquaculture since ancient times, as is the case of the Comacchio Lagoon, in the northern Adriatic Basin, where eels are traditionally raised.

11.5 OFFSHORE SYSTEMS

11.5.1 Pelagic Domain

Due to the size of its inhabitants, the pelagic domains appear as a desert compared with benthic systems, the main plants and grazers being phyto and zooplankton. The only visible organisms are the gelatinous macrozooplankton and representatives of the nekton, mostly vertebrates (sharks, fish, sea turtles, cetaceans, and seals). Most fished resources come from the pelagic domain and most ecological processes take place there. Currents connect the various parts of the marine realm. In spite of its apparent homogeneity, pelagic systems are highly diverse due to different oceanographic features and to the peculiarities of the sea bottom. Marine canyons can channel deep waters towards the coast, generating upwellings that are also reinforced by wind energy. These bring nutrient rich deep waters towards the coast, enhancing primary production and, from this, secondary and tertiary production. In this respect, the two realms are functionally connected. Furthermore, the shape of the Mediterranean coasts generates gyres and eddies that connect wide portions of the various subbasin (see Figs 11.1–11.3). The intertwining of vertical and horizontal currents determines conditions that are far from being homogeneous. These are the "habitats" of the pelagic domain. They are not as defined as benthic ones, and habitat mapping there is not as precise as it is in the benthic realm. The currents, furthermore, are often seasonal so that conditions change throughout the year. These systems function in pulses: phytoplankton blooms are followed by herbivorous zooplankton blooms, followed by blooms of carnivores (including fish larvae and juveniles), and these sustain the nekton. The phytoplankton blooms, followed by zooplankton blooms typically occur in late winter-early spring (Fig. 11.13A) when solar energy increases and storms and riverine run-offs make nutrients available. The abundance of plankton decreases in the summer

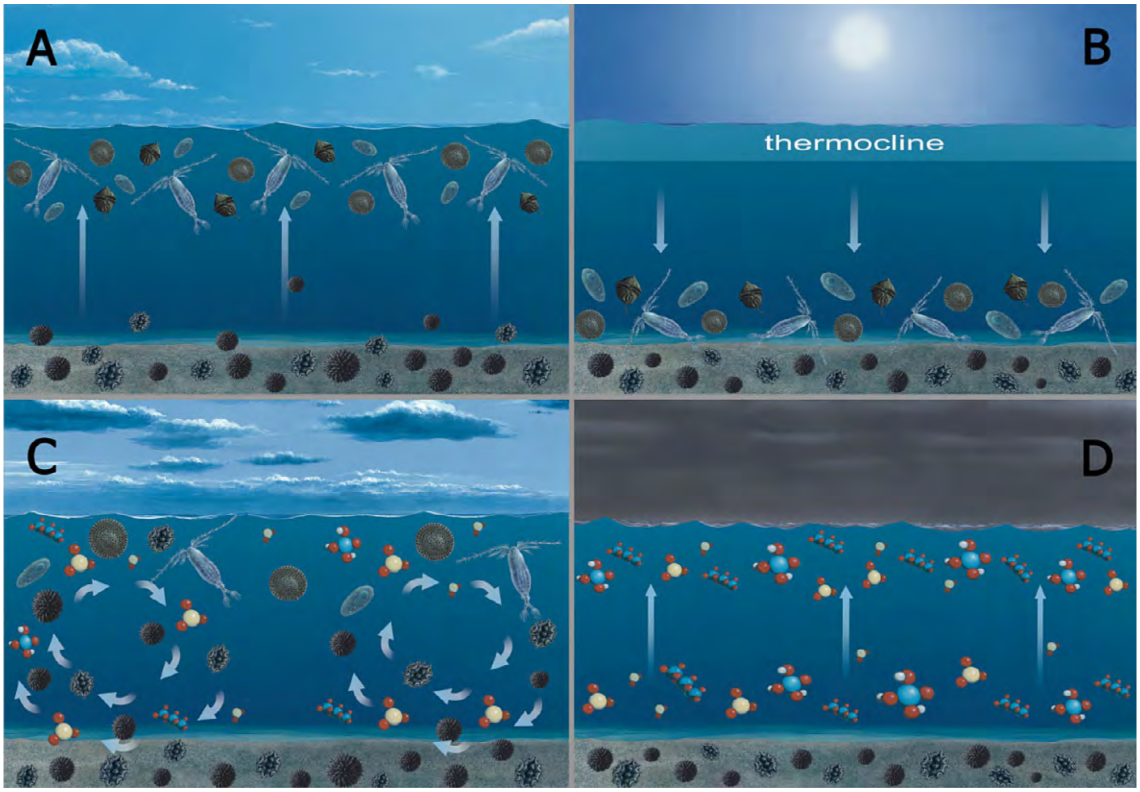

FIG. 11.13 The seasons and plankton production, with active stages in the water column and resting stages in the sediments. Reported are (A) blooms of phyto and zooplankton in spring with re-activation of quiescent cystes and resting stages. (B) Summer thermocline, nutrient depletion and death of phyto and zooplankton and production of new resting stages. (C) Resuspension of sediment and resting stages in fall. (D) Winter full water circulation, resuspension of cystes and resting stages (concepts: F. Boero; art: Alberto Gennari).

when stratification is strong (Fig. 11.13B), and a further bloom occurs in the autumn (Fig. 11.13C), whereas winter storms resuspend nutrients and resting stages (Fig. 11.13D) (Boero, Belmonte, Fanelli, Piraino, & Rubino, 1996). These phenomena are not homogenously distributed in the Mediterranean Sea and in the rest of the whole ocean. Many species of both zoo and phytoplankton, especially in coastal areas, spend adverse seasons as resting stages that are deposited in the sediments.

The Adriatic Sea can be divided into three large cells, corresponding to the north, the central, and the southern gyres. In the last decades, the Adriatic ecosystems have been subjected to severe changes. Before the 1980s it was the most productive basin of the whole Mediterranean, in terms of fisheries yields, but this changed when the mauve jellyfish *Pelagia noctiluca* dominated the whole basin for several years. The Adriatic ecosystems went through a series of phase shifts that, after jellyfish, involved the dominance of dinoflagellates (red tides), followed by mucilages, leading to a present-day situation of lower production (Boero & Bonsdorff, 2007).

11.5.1.1 Deep-Sea Ecosystems

The deep sea contains a number of potential "hot spots" of biodiversity, such as: (a) highly heterogeneous seafloor of open continental slope systems, (b) submarine canyons, (c) seamounts, pockmarks, and volcanic ridges, (d) deep-water coral reefs and other biogenic reefs (see Fig. 11.9), (e) hydrothermal vents, (f) cold seeps and related structures, (g) gas hydrates, (h) volcano fields affected by brines, (i) abyssal plain deep, and (j) hypersaline anoxic basins (Danovaro et al., 2009; Danovaro et al., 2010; WWF/IUCN, 2004).

The Mediterranean Basin has a complex network of more than 800 canyons, a large portion of which are in Italian waters; these play a key role as ocean-continental shelf exchanges, as major pathways for the transport and burial of organic carbon, corridors for material transported from the land to the deep sea, and temporary buffers for sediment and carbon storage (Canals, Company, Martin, Sanchez-Vidal, & Ramirez-Llodra, 2013). Their complex circulation supports increased biological production and they are considered ecological "hot spots" because of their diversity and abundance of pelagic life. Canyon upwellings attract a variety of migratory top pelagic predators such as tunas, swordfishes, sharks, turtles, and cetaceans. The high concentration of food and abundance of prey, trapped within the canyon walls, make the submarine canyon ecosystems attractive for top-predators but also to large filtering organisms such as finback whales. Submarine canyons influence also benthonic and nektonic organisms during their active and passive daily migratory movements between shallow and deeper water (Benedetti-Cecchi et al., 2015; Canepa et al., 2014; Guglielmo et al., 2017; Paull et al., 2008). Canyons play an important role in structuring the populations and life cycles of planktonic fauna, as well as benthic fauna associated with them. Canyons are also important habitats for commercial species, such as hake (*Merluccius merluccius*) and the rose shrimp (*Aristeus antennatus)*. These areas can play the role of "spawning refugia" (Caddy, 1993), refuges where a portion of a heavily exploited stock can annually sustain recruitment (Company et al., 2008; Sardà et al., 2004).

In the Mediterranean, over 242 seamounts, banks rises, highs, hills, spurs, and other kind of seafloor elevations have been identified (Würtz & Rovere, 2015), and in the western Mediterranean, the Tyrrhenian bathyal plain contains the highest concentration of seamounts of the entire basin. Volcanic bodies are either associated with north–south-oriented crustal faults (Magnaghi, Vavilov, and Marsili seamounts) or with crescent-shaped bathymetric ridges (e.g., Vercelli and Cassinis). The eastern Mediterranean Basin is characterized by a higher topographic heterogeneity than the western sector, with a large number of seamounts, including the impressive the Eratosthenes Seamount. Available knowledge about biodiversity on seamounts has been mainly focused on benthic habitats and less on the pelagic life. Suspension feeders, particularly deep-sea corals and sponges, usually dominate the hard-bottom habitats, and here the most important habitat-forming cnidarian taxa usually found are alcyonaceans (sea fans and soft corals and, at least for soft bottoms, sea pens), antipatharians (also called black corals forming large forests up to 500 m depth), and scleractinians (such as *Dendrophyllia cornigera*, *Desmophyllum dianthus*, and the white reef-forming corals *Madrepora oculata* and *Lophelia pertusa*) (Bo et al., 2011; Danovaro, Bianchelli, Gambi, Mea, & Zeppilli, 2009; Pusceddu, Gambi, Zeppilli, & Bianchelli, 2009; Robinson et al., 2014).

Deep-water coral banks form locally elevated secondary hard substrates associated with strong bottom currents that enhance food supply and impede the settlement of silt. These corals are important refuge or nursery habitats for a rich associated fauna, some of commercial interest (Mastrototaro et al., 2010). These habitats are distributed in several provinces around the central Mediterranean Sea

Mediterranean deep-water corals are associated with temperatures ranging from 4°C to 13°C; salinities from 38.4 to 38.9, and dissolved oxygen from 3.75 to 4.54 $mL\,L^{-1}$ (Freiwald, Beuck, Ruggerberg, Taviani, & Hebblen, 2009; Naumann, Orejas, & Ferrier-Pages, 2013). The temperatures in the deep Mediterranean are close to the upper limit for many bathyal cold-water corals (Freiwald, Fossa, Grehan, Koslow, & Roberts, 2004). However, the recent discovery from the Levantine area adds a new temperature record, as the populations of *D. ramea* develop at up to 155 m depth in temperatures of 17°C. At present, some deep-water coral areas have been recorded in Italian waters, but only a few of them have been examined by means of remotely operated vehicles (ROV); our knowledge of Mediterranean deep-water corals comes largely from scientific cruises and fishing dredge and trawl hauls. The bathymetric distribution of cold-water coral communities is very wide, as in the province of Santa Maria di Leuca (northern Ionian Sea) where the corals occur from 194 m to 1100 m. Cephalopods, crustaceans, and fish are attracted by the structural complexity of the deep-water corals, which may act as essential feeding and spawning habitats. These deep-water corals are a spawning area for the rockfish *Helicolenus dactylopterus* and a nursery for the deep-water sharks (*Etmopterus spinax*) and several other deep-water fish species. Large portions of coral banks have been damaged, mostly by fishing gears, and are characterized by low presence of living colonies and the presence of dead coral framework as well as broken coral fragments (coral rubble). Coral habitats also support many large bivalves (*Acesta excavata*) and giant oysters (*Neopycnodonte zibrowii*) (Taviani et al., 2011).

Reef-building sponges create habitat for other organisms and provide refuge for adult redfish and nursery habitat for juveniles. Three species of sponges (*Bubaris sarayi*, *Sarcotragus cf. muscarum*, and *Ircinia cf. retidermata*) have been found by Ilan, Ben-Eliahu, and Galil (1994) at 830 m depth off the Israeli Mediterranean coast, in whose cavities live a wide variety of organisms such as polychaetes and snapping shrimps. In the western Mediterranean Sea are monospecific reef-like aggregations built by the lithistid demosponge *Leiodermatium pfeifferae*, on a 760-m-deep seamount, (Maldonado et al., 2015), that hosts a wide variety of benthic organisms such as hydroids, alcyonaceans, and scleractinians.

Deep hydrothermal vents occur in volcanically active areas where mineral-rich, hot water reaching 400°C flows into the surrounding waters. Here specialized bacteria convert the reduced form of sulfur, hydrogen or iron and CO_2 or methane into food and energy. Most Mediterranean hydrothermal vents are known from depths of less than 100 m (Dando, Stuben, & Varnavas, 1999), but deeper vents exist at 300 m depth and likely much deeper in the Tyrrhenian Sea. Massive sulfide deposits of hydrothermal origin, consisting of pyrite, hematite, sphalerite, galena and baryte, are present at the Palinuro seamount (Tyrrhenian Sea), together with manganese crusts of hydrothermal origin (Eckhardt, Glasby, Puchelt, & Berner, 1997), with Siboglinidae tubeworm clusters and bacterial mats surrounding hot vents at 600 m on the top of the seamount (Carey et al., 2012). The deep-sea vents have also been documented in the Marsili Seamount (Tyrrhenian Basin) at about 450-m depth (Lupton et al., 2011) in which, for the first time, a dual symbiosis of beard worms Siboglinidae has been reported associated with the vents (Zimmermann et al., 2014). These systems very likely show significant differences with respect to the typical high-temperature deep-sea vents in the Atlantic and Pacific mid-ocean ridge and are likely closer to other back-arc or volcanic hydrothermal systems such as in the western Pacific, due to the nature and intensity of the seepage (i.e. the slow escape of a liquid or gas through porous material or small holes), the depth of the vents [much shallower in the Mediterranean Sea than on most mid-ocean ridge vent fields (Beaulieu, Baker, German, & Maffei, 2013, InterRidge database)], and the characteristics of the associated fauna.

Cold seeps are marine seafloor ecosystems that form around hydrocarbon emission pathways. Supply of hydrocarbons from deep subsurface reservoirs varies in space and time. Hence, cold seeps have a highly fragmented distribution along continental margins. Cold seeps are characterized by chemosynthetic communities fuelled by chemical energy originated from microbial utilization of methane and other hydrocarbons (Levin & Sibuet, 2012). Cold seeps (i.e., hydrogen sulfide, methane, and other hydrocarbon-rich fluid seepage) in the deep Mediterranean are present in the Gela Basin (Strait of Sicily, central Mediterranean). Among cold seeps, mud volcanoes are abundant. They have been typically found in two geodynamic settings: (1) along the Africa-Eurasia subduction zone, particularly in the central and eastern Mediterranean Basins and its western most boundary in the Gulf of Cadiz and (2) along the continental margins that border Africa from eastern Tunisia to the Levantine coasts, and in some areas of the southeastern Tyrrhenian margin of Calabria (Mascle et al., 2014).

The deep Mediterranean includes either bathyal or abyssal plains. In the western basin, the 2600/2700 m isobaths have been used as the upper limit of the abyssal plain, which has a maximum depth of about 3050 m. The Tyrrhenian Plain has been defined as bathyal although the deepest part of the Basin exceeds 3600 m. These plains cover an overall area of about 240,000 km^2. With water temperatures at 4000 m of about 14°C (rather than 4°C or colder as other deep oceanic basins), the entire benthic environment is as hot as the water around many diffuse hydrothermal vents. Typical deep-sea plain fauna, include crustaceans, echinoderms, glass sponges, and macroscopic foraminifera, while other groups (i.e., fishes, decapod crustaceans, mysids, and gastropods) appear much less abundant in the deep Mediterranean than in the northeastern Atlantic plains.

11.5.2 Ecosystem Functioning

Trophic networks imply that the species living in a habitat often take resources from other habitats. Connectivity is not only linked to life cycles and life histories, but also to trophic networks and to biogeochemical cycles.

The recent concept of cell of ecosystem functioning (CEF) (Boero et al., 2016) links patterns and processes and defines spatially a volume of water comprising both the sea bottom and the water column where connections are statistically tighter than in nearby volumes. The Mediterranean Sea, under this respect, is a large mega-CEF whose functioning is driven by the Gibraltar current. The western Mediterranean is a smaller CEF that depends on the Gulf of Lions cold engine. The Tyrrhenian Sea, is also a distinct CEF, is the eastern Mediterranean Basin that depends on the northern Adriatic and the northern Aegean cold engines. At smaller levels, CEFs are identified based on the presence of upwellings, connecting the deep sea with the surface, and downwellings connecting the surface with the deep sea. Horizontal currents, such as fronts, gyres, and eddies, interact with up and downwellings, forming a mosaic of processes that link the various habitats. The links can be seasonal, such as the cascading that occurs only in the cold season, as also happens for the upwellings, and these crucial phenomena can occur in restricted, but very important, time windows. Linking patterns and processes into a holistic framework is the basis of integrative management of marine environments and of their resources. The identification of CEFs is in its infancy, and breaking the artificial compartments into which the marine environment has been divided is a major challenge. The Mediterranean Sea is an ideal arena for setting up these principles, as done by Boero et al. (2016).

11.6 CLIMATE CHANGE IMPACTS

11.6.1 Sea-Level Rise, Temperature Rise, pH Changes, Storms, Ice Melt

The Mediterranean Sea is among the most sensitive seas to global warming, and Italian seas, and particularly the northern Adriatic are the most sensitive and vulnerable areas of the Mediterranean Basin. During the summer, the increased SST warms up the surface layer and it is presumed that the greater the temperature increases the greater will be the depth that the warm layer will be (Fig. 11.14).

In the winter, surface and deep sea temperatures are equal, and it is in this period that up and downwellings occur, triggering phytoplankton production in coastal areas, and oxygenating the deep sea. During the summer, stratification prevents such flows. Under the mixed layer, conditions are more constant in terms of temperatures, and large populations of stenothermic organisms thrive. The deepening of the mixed layer, due to global warming, has caused extensive mass mortalities of benthic organisms that usually live below the mixed layer. This has been happening since the 1980s (Rivetti et al., 2014).

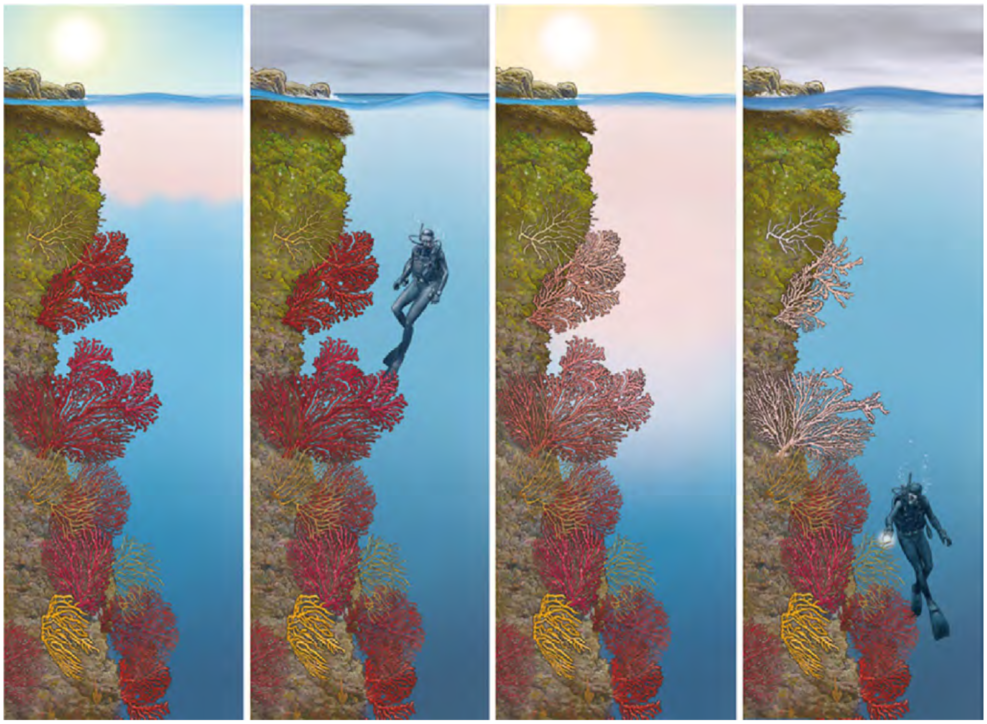

FIG. 11.14 Cold-water species, such as sea fans, live below the warm layer of the summer (*left* and *central left*), global warming leads to the deepening of the warm layer, causing mass mortalities (*central right* and *right*) (concepts: F. Boero; art: Alberto Gennari).

If temperature increases have put cold-water species at a disadvantage, they favored the establishment of tropical species that started to replace indigenous ones. Hundreds of tropical species have entered the Mediterranean from the Suez Canal and many of them have taken great advantage of the new thermal regimes of the basin. The change became evident in the eastern Basin first, but then expanded towards the West. This "tropicalization," or "Meridionalization," is one of the most evident effects of global warming. Species that usually thrived in southern parts of the Mediterranean (meridional species) spread northwards, where they find suitable conditions that, in the past, were not available. This is pushing cold-water species northwards and into deeper waters. The effects of global warming are probably influencing the functioning of the cold engines, and the eastern Mediterranean transient has been a preview of a possible future (Rivetti et al., 2014). The northern Adriatic cold engine stopped and was replaced by the northern Aegean one in bringing surface oxygenated waters to revive the deep sea. If the cold engines stop or change their functioning, there will be serious problems in deep-sea communities and habitats, where it is even possible that large anoxic phenomena will take place. Global change, furthermore, is causing an increase in the intensity of several phenomena. Summer droughts can be followed by extremely intensive precipitations, so that salinity initially increases and then decrease suddenly. These phenomena are happening with temporal mismatches with ecological processes linked to primary and secondary production, so leading to anomalous thermohaline conditions that, in their turn, lead to anomalies in ecosystem functioning.

These changes are interacting with a trend towards acidification, even though the effects of pH decreases are still far from be completely understood. The presence of hydrothermal vents with lower pH than the surrounding waters is allowing for the study of the effects of pH gradients and, if the trend is, there will be changes in biodiversity composition and also in the biology of species. There are however signs of physiological adaptations to pH changes, and the Mediterranean Sea is a very promising arena to study the phenomenon. The usually limited tide ranges make the perception of sea-level rises even greater in this basin than in most areas of the world. Both sea-level change and the increase in extreme events such as storms are impacting heavily on Mediterranean shores, where effects on coastal erosion are dramatic.

In the North Adriatic Sea, the ecosystem of the Venice lagoon as well as infrastructures and local communities are vulnerable to sea-level rise and storm events, with natural and human-induced vulnerability increased by climate changes. Venice is not only threatened by high tides, but is sinking through subsidence, at the same time as the Adriatic Sea is rising. The surrounding marshes, which used to break the waves coming into the city, have gradually disappeared, and industrial development on the mainland has added to the increased subsidence and pollution. Venice and the Venetian lagoon are vulnerable to both extreme weather events and "normal" flooding, which now occurs up to 10 times in 1 year. Long-term patterns of rising sea level have been clearly established here due to both global changes in sea level and land subsidence, particularly in deltaic areas. This is exacerbated by water surges due to storms and by particularly strong winds typical of the Adriatic Basin such as the Bora (cold, dry, northeastern wind) and Sirocco (southeastern wind). The combination of these factors has increased the frequency and intensity of floods in the northern Adriatic coastal areas. The Adriatic coast are introduced with new species that include aliens (from aquaculture activities and shipping) and thermophilic species from other Mediterranean subregions that are extending their geographic range (Pecarevic, Mikus, Cetinic, Dulcic, & Calic, 2013). These dynamics are enhanced by frequent massive mortality episodes (Di Camillo et al., 2013). The incoming of nonindigenous species (NIS) such as the toxic benthic microalga *Ostreopsis ovata* is affecting benthic communities, including bivalves, gastropods, cirripeds, echinoderms, and fishes, causing diseases or mass mortalities where massive *Ostreopsis* blooms occur (Gorbi et al., 2013).

11.7 DIRECT ANTHROPOGENIC IMPACTS

Increased human activities and coastal development are quickly affecting the Adriatic and Tyrrhenian biodiversity. The northern Adriatic Sea is densely urbanized and polluted (Cozzi et al., 2012; Lotze et al., 2006), and the areas around the Po River, the Venice Lagoon, and in the Gulf of Trieste bear the highest pressure. Along the coastline, untreated waste water and solid waste can cause fecal coliforms contamination in adjacent waters, fertilizer run-off from agricultural activities, invasive species from ballast waters, and pollution from oil and gas exploration further worsen the situation. The southern Tyrrhenian coasts have similar problems although the presence of deeper waters contribute to dispersion of contaminants and products released by untreated sewage.

Climatic stressors, demersal fishing, hypoxia, and pollution from land-based activities are major contributors to high cumulative impacts to the Adriatic Sea and in the southern Tyrrhenian and Sicily Channel (Micheli et al., 2013). Coastal erosion is evident along 90% of the Italian coasts. Coasts are eroded by changes in sediment deposition, removal of material, and offshore structures and alterations of rivers through dams and diversions. Changes in sediment deposits result from changes in water flow due to construction of dams on upstream rivers and watersheds, removal of natural coastal habitats (i.e., wetlands), the construction of coastal structures and defenses, and the construction of offshore structures.

11.7.1 Contamination

Coastal pollution from excessive nutrient inflow, typically from agricultural and municipal runoff has been one of the main factors affecting the Adriatic Waters, leading in many cases to fish kills, algal blooms, and low-oxygen conditions, particularly in the northern region of the sea.

In the Tyrrhenian Sea the most relevant impacts are related to industrial activities, illegal dumping, and untreated sewage. Solid waste is often identified as the priority pollution source, particularly in the eastern Adriatic and southern Tyrrhenian. Illegal dumping of toxic waste through ship sinkings provides significant contamination in the southern Adriatic. The phenomenon seems to be particularly diffused along the coast of the Puglia Region, while up to 30 sunk ships possibly containing toxic compounds are mostly concentrated in the coasts of southern Italy (Apulia, Calabria, Campania, Sicily). Oil spills are also a major concern. Another concern comes from seismic activities, drilling, and rig construction and operation.

Maritime transportation represents another important pressure responsible for acoustic pollution, water pollution, marine litter production (including plastics), and air pollution (Carić, 2010). Marine traffic also increases the introduction of invasive species. The Arno River drains a wide inland area, transporting Al, Fe, Hg, and other elements at high concentrations towards the sea (Fabiano, Danovaro, Magi, & Mazzucotelli, 1994). The coastal area of Livorno has Europe's largest chloride-alkali plant, which is responsible for Hg pollution (Seritti, Petrosino, Morelli, Ferrara, & Barghigiani, 1982). Significant pollution from both the Ombrone and Albegna effluents is significant (Corsi, Mariottini, Sensini, Lancini, & Focardi, 2003). The central part of Tuscany is characterized by cinnabar (HgS) deposits of Mount Amiata, an inactive volcano, where mining and smelting began during the Etruscan period (eighth to first centuries BC) and stopped in 1980 (Scerbo, Ristori, Stefanini, De Ranieri, & Barghigiani, 2005). High levels of trace elements were recorded in sediments from the island of Elba to Monte Argentario (Storelli, Storelli, & Marcotrigiano, 2001). In addition, three large coastal towns, Pisa, Livorno, and Cecina, located in the northern Tyrrhenian Sea, discharge partially treated effluent into rivers. The whole Italian coast also experiences summer tourism, which leads to a substantial increase in inhabitants. As a consequence, municipal wastewater treatment plants show effluents characterized by worsened water quality and an increase in the nutrient concentration of marine water (Renzi et al., 2010).

11.8 RESOURCES

11.8.1 Fisheries, Artisanal, and Industrial

The fisheries sector in the Adriatic is diverse, largely made up of small-scale fisheries. Highest catches are recorded from Italian vessels, followed by Croatia, Albania, and Slovenia. The current state of heavy exploitation of Adriatic fishery resources is evident and although some stocks may be recovering, for others the situation remains critical. Future changes in the sector will also strongly depend on the population dynamics of commercial species in the region. Conflicts may also arise with the recreational and the artisanal fishery sectors (especially between different types of gears). Fisheries have always played an important role as a source of livelihood for the local populations. Until 1990, the subregion was the second most significant for fishing and economic importance of the 10 fishing areas in the Mediterranean. The Adriatic Sea is one of the largest and the best-defined areas of shared fish stocks in the Mediterranean, which makes shared management of fisheries an essential requirement in order to ensure sustainability of the sector.

Due to its moderate slope and soft sea bottom, it is particularly suitable for trawling and dredging for clams. The bottom trawl fishery takes place over the entire Adriatic continental shelf and on some parts of the continental slope in the southern Adriatic. It mostly targets the red mullet (*Mullus barbatus*), European hake (*Merluccius merluccius*), and Norway lobster (*Nephrops norvegicus*).

The south and central Tyrrhenian Seas fleet is composed of around 2800 boats and contributes to approximately 12% of national production (Irepa Onlus, 2010). The relatively narrow continental shelf has clearly favored artisanal fishing systems (trammel nets, gillnets, combined nets, long lines, hand lines, pots, harpoons, and "menaide" nets), which are used by 84% of the boats, while 9% use trawl nets and 4% seine nets. In regard to catches (Irepa Onlus, 2010), pelagic species are the most abundant: anchovy account for around 24.5% of production, sardine 9.3%, and swordfish 6.3%. European hake (*Merluccius merluccius*), which ranks fifth among the most captured species after the group category "other fish," accounts for 5%, while deep-water rose shrimp accounts for 1.5%. These, together with red shrimps, red mullet, and octopus, are the most highly valued species in economic terms. The biomass and density indices for the European hake (*Merluccius merluccius*), one of the most exploited species in Italian Seas, do not show significant temporal differences in spite of wide fluctuations (Cataudella & Spagnolo, 2011). The indications from stock assessment nevertheless recommend the need for a more prudent management of this important resource, safeguarding in particular the areas of high concentrations of juveniles, which are mainly captured by trawling, but also by reducing the fishing pressure on the parental stock, which is mainly caught by other fishing gear (e.g., gill nets). Red mullets show wide variations in density indices since 2002, but do not display a corresponding variation in biomass indices. This result is abundant catches of juveniles recorded in 2002, 2005, and 2007, years in which the trawl surveys were carried out in mid and late summer, when the species shows massive recruitment in shallow waters. The noticeable temporal reduction in both biomass and density indices for horned octopus seems to indicate a state of distress for this species. It is known that cephalopods have relatively short life cycles (1–2 years) and their abundance is strongly influenced by the successful recruitment, which in turn is affected by environmental parameters (Cataudella & Spagnolo, 2011).

Overfishing has been leading to trophic downgrading since the 1970s (Britten et al., 2014), with a widespread regime shift from fish to jellyfish and, possibly, jellyfish eaters (Fig. 11.15) (Boero, 2013).

11.8.1.1 Aquaculture

Since the 1970s, Mediterranean marine aquaculture has been developing rapidly, with a regional growth rate of 70% between 1997 and 2007. The aquaculture sector in the Adriatic Sea has also followed similar trends and it is expected to continue developing and diversifying in parallel to the decline of wild stocks and the increasing demand for fish products. Italy is the Adriatic country with the most developed aquaculture sector, while other Adriatic riparian countries (Croatia, Albania, and Montenegro) have relatively small aquaculture industries with particularly high growth potential. Although estimates suggest that the Mediterranean aquaculture sector may show more than 100% growth by 2030 in terms of production and value, it is unlikely that such growth will occur in the Adriatic Sea, where the lack of suitable areas for the installation of new farms is a major constraint, together with the potentially increasing conflicts with the tourism and fisheries sectors. According to FishStat Data (Policy Research Corporation, 2011) the Adriatic fish aquaculture production, including marine and brackish waters species, accounts for 3% of the total production in the Mediterranean Sea and it is approximately 31,000 tons. The most cultured species are sea bream and sea bass. Italy and Croatia are the two leading Adriatic countries in terms of aquaculture production. Italy produces 70% of aquaculture products in the region and is the largest producer of shellfish, particularly in its northern and central Adriatic Regions. Croatia follows with 21% of the total Adriatic aquaculture production.

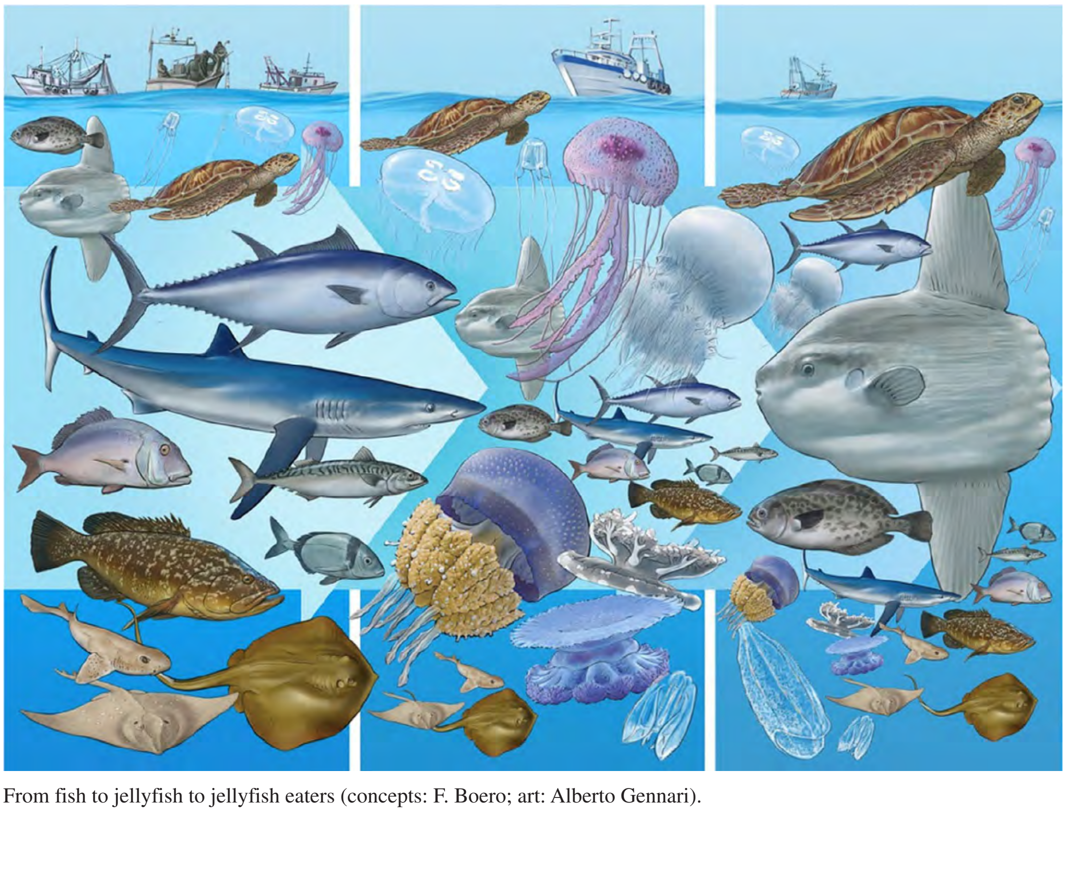

FIG. 11.15 From fish to jellyfish to jellyfish eaters (concepts: F. Boero; art: Alberto Gennari).

During the 1980s, there was a shift from the fixed-pole farming system, typical of a small number of lagoon areas or coastal and sheltered sea stretches, to floating systems. It was possible to develop mussel farming in open sea areas in the Adriatic and in the Tyrrhenian Sea (areas of Campania, Lazio, and Liguria). Farms are concentrated along the coastal areas of the Ionian and Tyrrhenian Seas, including the Pozzuoli area and the Gulf of Gaeta.

11.8.1.2 Oil, Gas, Minerals

The continental margins are the main site of oil and gas exploration and production. The oil, gas, and prospects of the Tyrrhenian Sea are under evaluation although no exploratory drilling has been performed to date. Due to unfavorable geological, geophysical, and oceanographic conditions, gas hydrates in the Adriatic and Tyrrhenian Seas are poor. The Adriatic Sea has a high concentration of oil and gas activities, and Italy has over 140 offshore active fields, Croatia has only 3 although the sector is expected to grow considerably in the near future as the country is initiating a large-scale process of exploration and production that involves 29 new concessions. Italy is also planning to develop further new drilling projects, and similarly exploration and production activities are likely to occur in Montenegro and Albania. Italy has 67 active concessions for extraction, for a total area of 9025 km^2, and has drilled a total of 335 gas wells and 61 oil wells, the majority of which are in the Adriatic, with over 100 platforms located in the Emilia Romagna Region. The Tyrrhenian Sea and its seamounts are potentially important sites of precious minerals, but no authorization has been sought so far.

11.8.1.3 Tourism

The Adriatic Sea is among the top touristic destinations in the Mediterranean Sea. Italy and Croatia host most tourists, with 71% (>40 million arrivals with over 90 million overnight stays) and 18% (>10 million arrivals with over 50 million overnight stays) of the total tourist arrivals (WTTC, 2014). Tourism is strongly seasonal and generally peaks in July and August. Touristic activities in the region can be divided in three main categories: coastal tourism, cruise tourism, and nautical tourism. The Adriatic Sea has also registered an increase of cruising. This is particularly evident in relation to the share of the entire Mediterranean cruise sector as Adriatic cruise passenger movements in 2013 represented the 22.3% of overall traffic in the Mediterranean Sea, recording over 5.2 M cruise passengers (including transit and embarking/ disembarking operations) in the 20 main cruise ports. The Adriatic is one of the top nautical tourism destinations and therefore pressures from this subsector are significant. Data from 2013 show that there are 350 structures dedicated to this form of tourism that can host up to 80,000 boats. In Italy there are 253 Marinas, while there are 81 in Croatia with over 16,000 moorings at sea. There are over 4700 charter boats registered in Croatia and the number of arrivals of charter guests has been steadily increasing. "Marine" tourists are mostly attracted to areas with different categories of protection as they have a high natural value and biodiversity. MPAs are particularly attractive.

The blue tourism in the Tyrrhenian Sea is equally relevant and concentrated along all coasts. Also cruising and maritime transportation are extremely important with >6 million arrivals in the Port of Naples alone, every year.

11.8.2 Protection and Conservation Measures, Legal Protective Instruments

Legal instruments. The United Nations Convention on the Law of the Sea (UNCLOS) provides an international framework for protection and preservation of the marine environment, with general obligations to protect and preserve the marine environment, to address pollution damage and contingency planning and to carry out environmental monitoring and impact assessment, also in relation to the intentional or accidental introduction of alien species.

Convention on Biological Diversity (CBD)—Under the mandate of the CBD for marine environment protection, the Aichi Biodiversity Target 11 specifically gives particular emphasis to protect critical ecosystems requesting that *by 2020, at least 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through protected areas and other effective area-based conservation measures.*

Aichi Biodiversity Target 6. It is on sustainable management of marine living resources, and it mentions that *by 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches.*

Barcelona Convention—states that "to prevent, abate, combat and to the fullest extent possible eliminate pollution of the Mediterranean Sea Area" and "to protect and enhance the marine environment in that area so as to contribute towards its sustainable development." The Convention provides indications for the creation, protection, and management of specially protected areas (SPAs) and the establishment of specially protected areas of Mediterranean importance (SPAMIs).

ACCOBAMS. ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area) is a cooperative tool for the conservation of marine biodiversity, with a special focus on cetaceans, in the Mediterranean and Black Seas.

General Fisheries Commission for the Mediterranean (GFCM) of FAO—GFCM is a Regional Fisheries Management Organization (RFMO) promoting the development, conservation, rational management, and best utilization of living marine resources as well as the sustainable development of aquaculture in the Mediterranean, the Black Sea, and connecting waters.

The Marine Strategy Framework Directive (MSFD 2008/56/EC). It represents the tool of the EU's Integrated Maritime Policy to achieve Good Environmental Status of marine waters by 2020. The MSFD applies to the area of marine waters over which a Member state exercises jurisdictional rights in accordance with the UNCLOS.

The Habitats Directive. It is aimed at halting biodiversity loss through the conservation of habitats and species in European territory (European Habitats Directive, 1992). The Directive has the aim of setting up a coherent network of special areas of conservation (SACs) hosting the habitats and species of conservation priority listed (forming part of the Natura 2000 network).

Marine Protected Areas. The number of MPAs and marine reserves has increased worldwide (Kelleher, Bleakly, & Wells, 1995) and in the Mediterranean Sea, with an annual growth of 5.2%, the percentage of MPAs under national jurisdiction is 1.5 (Boero, et al., 2016). In the Mediterranean Sea there has been a rush in recent years to establish MPAs and reserves (Lubchenco, Palumbi, Gaines, & Andelman, 2003) and more than 1000 MPAs have been identified (Boero et al., 2016). The zonation of Mediterranean MPAs usually consists of two or three levels, with the distinction of relatively small no-take areas (also called no-entry), where all human activities are prohibited, except for the mandatory interventions of managers and scientific research, surrounded by buffer areas, where some activities are forbidden (e.g., spearfishing, scuba diving, amateur line fishing), or exposed to limitations and surveillance. Small-scale professional fishing is usually allowed in buffer zones. In some MPAs there is also a third peripheral zone with less restricted regulation of activities (CEE Directive n. 76/160, 2000).

In Italy there are currently 29 MPAs, ranging in size from 120 to more than 50,000 ha. Italian MPAs are multiple-use protected areas with different protection levels and include one or more no-take/no-entry zones ('A zones' according to Italian law), surrounded by buffer zones (defined as 'B and C zones,' where there are less restrictions to human uses, including fishing). The EU project *CoCoNet* (Boero et al., 2016) provided guidelines to the institution of networks of MPAs in the Mediterranean and the Black Seas, with a core area in the southern Adriatic.

11.8.3 Clean-up, Habitat Restoration or Success Stories

The EU project "Marine Ecosystem Restoration in Changing European Seas" (MERCES) is (i) assessing the outcomes of different solutions for marine restoration across habitats; (ii) determining their effectiveness along with a socioeconomic cost-benefit analysis; (iii) define legal, policy, and governance frameworks of the proposed actions. MERCES has identified one area in the central Adriatic and in the Tyrrhenian Sea to active practice of active restoration either in shallow soft-bottoms habitats based on the bivalve *Pinna nobilis* and the seagrass *Posidonia oceanica*. Transplant experiments of the seagrass *Zostera marina*, *Z. noltii*, and *Cymodocea nodosa* have been conducted in the last 15 years with some success (Danovaro unpublished data). Additional experiments are planned or are being conducted in the Tyrrhenian Sea, both in coastal shallow hard bottoms and mesophotic habitats, based on transplantation experiments of the sponges *Axinella cannabina*, *A. polypoides*, *Spongia officinalis*, *Hippospongia communi*, and the macroalgae *Cystoseira* spp. (except *C. compressa*), the gorgonian *Corallium rubrum*, and the sea urchin *Paracentrotus lividus*. In the Gulf of Naples, the project ABBACO is testing innovative actions aimed at environmental and ecological recovery of the Bagnoli-Coroglio area, a highly contaminated area deriving from the decommissioning of the industrial activities (started in late "800 early" 900), which were responsible for the presence of xenobiotics, determining acute and chronic impacts on biodiversity and ecological functioning of the marine communities. The restoration will include the removal of contaminated sediments and the adoption of biotechnological tools (bioremediation) to clean up all of the remaining contaminants, representing the largest effort of decontamination of marine areas at EU level.

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