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Editors

The Mediterranean Sea

Its history and present challenges

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Future Trends of Mediterranean Biodiversity

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Abstract

This chapter focuses on analysing the current biodiversity of the Mediterranean Sea and the changes that are taking place on a human time scale (decades). Some of the changes observed may be sometimes interpreted as natural changes (cyclical, episodic or catastrophic), but most of them are of human origin. Each of the main anthropogenic impacts (habitat fragmentation and loss, overfishing and exploitation of living resources, pollution, species introductions and others) are analysed separately, although it is noted that predictions of how all the impacts interact synergistically are necessary. Furthermore, the effects of the so called "global change" (including both global warming and ocean acidification) on Mediterranean biodiversity are highlighted. It also deals about some episodic events (mass mortalities, jellyfish blooms, noxious algal blooms, proliferation of mucilages) caused by a combination of different impacts. Finally, some predictions are done about the near future of marine biodiversity in the Mediterranean Sea and some suggestions to address the problem are given.

Keywords

Mediterranean Sea • Biodiversity • Natural changes • Anthropogenic impacts • Global change • Episodic events

Changing Mediterranean Marine Biodiversity

Change is the rule in biodiversity. Biodiversity, at all its levels, is a changing entity at very different time-scales, from evolutionary to seasonal, or even daily. Nevertheless, global biodiversity is changing nowadays at an unprecedented rate as a complex response to several human-induced changes in global environment. This chapter focuses on analysing the current biodiversity of the Mediterranean Sea and the changes that are taking place on a human time scale (decades). The changes caused by each of the identified impacts (both natural and anthropogenic) are analysed separately, but cause and effect may not be so simple, and often all the links in the chain of ecological consequences can be traced only by painstaking detective work. Ecology continuously teaches us that ecosystems rarely operate in a simple, linear fashion with causes leading to obvious effects. Threats do not operate alone, therefore predictions of how all the different impacts interact synergistically are necessary. Furthermore, the wide range of processes that are affected by climate change make it difficult to predict the magnitude and rate of its effects. Only an extensive knowledge of how the ecosystem operates will allow us to understand, interpret and predict the consequences of the whole set of impacts that are affecting the marine biodiversity of the Mediterranean Sea. Nevertheless, some predictions about the near future (focusing in decadal scale) of marine biodiversity in the Mediterranean Sea are advanced and some possible ways to address the problem are commented on.

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To place recent rapid changes into context, it is necessary to know both past (long-term) and present (short-term) changes to elucidate the dominant scales of variation and what current biodiversity trends are different from historical trends. We have to retrieve the past and, from the past, we can estimate the future. To make inferences about the future of biodiversty in the coming decades, we basically need to know what has happened over the past decades, but a historical perspective is necessary to compare rates of change across evolutionary and ecological time-scales in the absence of human disturbance.

The Mediterranean Fauna and Flora have evolved over millions of years into a unique mixture of temperate and subtropical elements, with a large proportion of endemic species. From its complex history, the high species richness of the Mediterranean is largely due to both its long evolutionary history through the Tertiary and the post Pliocene diversity pump from the Atlantic (Bianchi 2007). The Mediterranean Sea has been subjected to extensive changes in configuration and climate since the Miocene. A historical review (Taviani 2002) shows that tropical biota survived in the Mediterranean till the beginning of the Pleistocene. Shift from the middle Miocene to Quaternary temperate-glacial conditions brought about radical biological changes in the Mediterranean basin. The combination of events such as the opening/closure of the Strait of Gibraltar, ice cycles and changes in temperature, salinity and current patterns, has apparently made this area a notable generator of diversity. The alternation of the ice ages with the warm interglacials resulted in different immigration waves of Atlantic fauna of boreal or subtropical origin, respectively. Because of reduced opportunities for north–south migration in response to changing sea temperatures, the species present within the Mediterranean were subjected to higher evolutionary pressure.

The Mediterranean Sea is a remnant of the once extensive Tethys Ocean, an open equatorial water body that bit into Pangea during the Triasic. In the Cretaceous, after the opening of the Atlantic Ocean, Tethys connected the newly born ocean to the older Indo-Pacific Ocean through this equatorial water-body. The circum-tropical Tethys ceased to exist when the Mediterranean basin lost contact with the nascent Indian Ocean about 16 mya (Vermeij 2012), but its biota continued to be tropical and highly diverse, roughly comparable to that to be found today in the tropical Indo-Pacific. At the end of the Miocene, during the Messinian (about 6 mya), the connection with the Atlantic also closed, and the Mediterranean become an isolated sea. The progressive desiccation of this basin due to its negative water balance during the so-called "Messinian Salinity Crisis" (MSC) caused a mass extinction of the Tethyan biota. At the dawn of the Miocene (5.3 mya), the Strait of Gibraltar re-opened and the Mediterranean was repopulated by species of Atlantic Origin, that were prevalently of (sub)tropical affinity (Bianchi 2007).

The first phases of the Pliocene (the Zancladian and the Piazenzian) were warm, especially during the so-called Pliocene Climate Optimum (between 3.6 and 2.6 mya), with a temperature 5 °C warmer than today and high sea levels of +20 to +35 m (Por 2009). Therefore, the Mediterranean biota preserved its tropical character. At the beginning of the Pleistocene (the Gelasian) the glacial cycles started, with a sudden cooling about 2.6 mya (the Artic Glaciation) causing the end of the tropical biota of the Mediterranean, because most of Early Pliocene marine species became extinct.

During the Pliocene the shallow-water marine fauna of southern Europe and West Africa, including the Mediterranean basin, constituted a more or less unified biogeographical entity extending from northwestern France to southern Angola (Vermeij 2012). Nevertheless, due to the low sea water temperatures of glacial periods, the Mediterranean was invaded by cold water species from the northeastern Atlantic. On the other hand, the tropical post-Pliocene biota that lived along the West African coast and the Cape Verde islands was isolated from the Gibraltar portal by the cold Saharan upwelling and the Canaries current, and still is separated to some extent, constituting the so-called Senegalese biota. Furthermore, the west–east gradient of increasing temperatures within the Mediterranean was steeper during the glacial period than today. While the winter temperature fell as low as 7 °C (Thunell 1979) in the western basin, in the Levant basin the winter temperature was never lower than 16 °C. Today the gradient between west and east is only of about 13–18 °C of minimum surface temperature. So, the Levant basin functioned as a "cul de sac" of warm water, which was out of reach for the cold-water species entering the Mediterranean.

During the last interglacial (the Eemian Interglacial), between 125,000 and 110,000 ya, with global temperatures 2–3 °C higher than today, the West African fauna succeeded in overcoming the Saharan upwelling and the temperature gradient in the Mediterranean to reach the Levant. Thus, the input of the Senegalese biota through the Gibraltar portal has been the only possible tropical input during the Pleistocene. After this warm period, and especially during the Last Glacial Maximum (20,000 ya), the Mediterranean was invaded by cold-adapted North Atlantic species. In recent decades, the ongoing global increase in temperature is noticeable all over the Mediterranean.

Recent Mediterranean Biodiversity

According to a recent review of Mediterranean biodiversity (Coll et al. 2010), the number of macroscopic living species at present inventoried in this sea can be estimated at about 13.200 species (nearly 11,600 metazoans and 1,600 macrophytes). This is a very high figure, if we consider that the Mediterranean only represents less than 0.8 % of the overall world ocean area, while the number of species that inhabit it represents about 5 % of total known recent marine species.

The present-day extraordinarily rich biota of the Mediterranean Sea is due to the outcome of the above dramatic events, which subjected the biota to high evolutionary pressures and may have been the cause of frequent phenomena of extinction and speciation. On the other hand, the complex topography of its coastline, with a number of islands and archipelagos of different sizes and fairly isolated subbasins subject to a great variety of climatic and hydrological conditions, also promotes a high species diversity. Lejeusne et al. (2010) defined the Mediterranean as a factory designed to produce endemics; in fact, about a quarter of Mediterranean marine species are endemic. These endemics live together with species deriving from several waves of colonization of either temperate or tropical organisms.

Although the Mediterranean Sea is recognized as one of the most diverse regions on Earth, its depths are quite species-poor. Less than 10 % of Mediterranean animal species are present below a depth of 1,000 m, and less than 3 % below 2,000 m (Boudouresque 2004). The Mediterranean deep waters are homothermic at about 13 °C and this limits the establishment of truly abyssal groups, which are typically adapted to colder waters (Emig and Geistdoerfer 2004). The low diversity of the Mediterranean deep fauna may also be due to the Gibraltar sill (less than 350 m depth) acting as a physical barrier to the colonization from the richer Atlantic deep fauna (Bouchet and Taviani 1992).

Most of the present-day Mediterranean species are of Atlantic origin that entered after the MSC, and therefore the Mediterranean biota presents a strong similarity to that of the northeastern Atlantic (European and African coasts). This caused the biogeographic physiognomy of the Mediterranean Sea to become that of an Atlantic province (Briggs 1974).

Recently, the man-made contact through the Suez Canal, opened in 1869, started to give access to hundreds of Indo-Pacific species to the Mediterranean. On the other hand, an increasing settlement by tropical Atlantic newcomers occurs entering the Mediterranean through the strait of Gibraltar. According to Por (2009), the congruence of these two events, the warming of the sea and the influx of the Indo-Pacific and tropical West African biota, led to the present re-establishment of the Tethyan biota in the Mediterranean. It should be noted here that thousands of alien species have been introduced by man in recent times, most of them lessepsian immigrants.

The main characteristics of the present-day Mediterranean Sea and its biota can be summarized as follow:

- Quasi-enclosed sea characterized by rich and complex physical dynamics with distinctive traits, especially in regard to the thermohaline circulation.
- Warm, salty, nutrient-poor water (widespread P deficit).
- Irradiance about 20 % greater than the mean irradiance incident at similar latitudes in the Atlantic Ocean.
- Seasonal thermocline from May–June to September–October.
- Homogeneous deep-water layers down 250–300 m that do not get colder than 12–13 ºC.
- Late winter phytoplankton boom.
- High diversity of habitats.
- High species richness and low abundance. High number of rare species.
- Mainly species of Atlantic origin with less abundant populations and generally smaller individual sizes.
- High rate of endemism (more than one-quarter of the species).
- Shallow-water rocky bottoms dominated by frondose algae, mainly fucales of the genus *Cystoseira*.
- Lush meadows of the seagrass *Posidonia oceanica*, which cover large areas between 0 and 40 m deep and are a key ecosystem.
- Proliferation of long-lived organisms within scyaphilous benthic communities.
- Low primary production, low fish production, and poor development of higher levels of the food chain (low pressures from top predators).
- Overall, the open waters are largely dominated by small autotrophs, microheterotrophs and egg-carrying copepod species.
- Low levels of herbivory and low levels of chemical defences.

In short, the Mediterranean is an oligotrophic sea (rich in oxygen and poor in nutrients). Nutrient concentration decreases along both the west–east and the north–south directions, resulting in variations in the structure of the pelagic food web. In the same way, the general pattern of species richness decreases from west to east. The Siculo-Tunisian sill (400 m deep) separates two distinct basins, the western and eastern basins, and has been traditionally considered as a geographical and hydrological barrier.

The Mediterranean also contains a high diversity of habitats. A description of the great variety of marine Mediterranean habitats and communities was first given by Pérès and Picard (1958), and later amended by Augier (1982), Bellan-Santini et al. (1994), (RAC/SPA 2006), among others. The basic scheme of classification, coming from these authors and widely adopted, is based on substrate and sediment type, depth, irradiance, hydrodynamic, and plant distribution. Recently Fraschetti et al. (2008) reviewed existing marine habitat classification systems in Europe and proposed a reduced habitat classification for the Mediterranean. This list contains 94 habitats that follow a hierarchical structure and refers to the level on the shore, the primary geological substrate, and common biological assemblages and foundation taxa.

Compared with the Atlantic, the Mediterranean marine communities generally have more species, with smaller individuals having a shorter life cycle (Bellan-Santini et al. 1994).

Rocky reefs, *Posidonia oceanica* meadows and coralligenous assemblages are among the most productive habitats, sustaining high biodiversity due to their heterogeneity and three-dimensional complexity. They supply food resources, nurseries and shelters for a variety of organisms.

Loss of Mediterranean Marine Biodiversity in Recent Times

Present day biodiversity is undergoing rapid alteration under the combined pressure of both global change and human impact. There is a growing evidence that human activities are directly or indirectly resulting in the extensive loss of biodiversity and in an impoverishment of the Mediterranean marine biota. Human-dominated Mediterranean ecosystems are experiencing accelerating loss of populations and species, and significant changes in food webs due to anthropogenic disturbances and global change are evident.

Many biologists or divers who have observed marine communities over a period of time have noted local disappearance of some species or significant declines of their populations, but regrettably they do not have accurate data to confirm or refute these personal impressions. No species are known to have totally disappeared from the Mediterranean in recent years, but many species may have disappeared unnoticed. A possible example may be the hydroid *Tricyclusa singularis*, that has never been recorded after its original description (Boero and Bonsdorff 2007), and several species of elasmobranch have virtually disappeared from some areas of the Mediterranean (Ferretti et al. 2008) In any case, it is very difficult to confirm the disappearance of a species in the marine environment. But, of course, extinction of an entire species in merely the end point of an incremental process of extinction of individual populations. As a species loses its component populations it also slowly loses its ability to adapt, its role in the ecosystem and, ultimately, its ability to survive. Local depletion of some species has been pointed out in some places. As an example, in the case of the Venice lagoons, where 141 algal species were found in 1938, only 104 were found in 1962, and 95 in 1987 (Zenetos et al. 2002). In the same way, 9 of 14 species of canopy-forming algae have disappeared since the 1930s from rocky shores of the northwestern Mediterranean, most of the genera *Cystoseira* and *Sargassum* (Thibaut et al. 2005).

Nevertheless, global or regional loss of species are only the last steps of marine biodiversity decrease (Sala and Knowlton 2006), but ecological (or functional) extinction occurs long before species completely disappear. Population declines precede ecological extinction, that occurs when a species is so rare that it no longer fulfills its natural ecosystem function and, hence, becomes ecologically irrelevant. Furthermore, size/density population declines involve genetic diversity loss, that will likely affect all levels of biodiversity, since genetic diversity is the first level of biodiversity. Low genetic diversity may enhance lower resistance to disturbance.

Natural Changes (Cyclical, Episodic or Catastrophic)

Nature is subject to continuous changes, which not always happen gradually over the long-term. Some of them are cyclical or respond to episodic disturbances. Causal events may be unusual in a human scale, but common in an evolutionary time-scale. Fluctuations or pulses in populations and ecosystems are part of the natural dynamics of ecological systems. In the Mediterranean marine climate is characterized by oscillatory variation with a periodicity of ca. 22-year (Duarte et al. 1999). Changes in biota may also occur in cycles of variable duration (Southward 1995).

Many species show episodic recruitment pulses. After long periods of steady growth of the populations of some species, they may experience mass mortality events. These high mortality events can lead to episodes of high recruitment that result in the recovery of populations and ultimately regulate their dynamics and structure (Navarro et al. 2011). Cyclical or episodic mortality events may serve to renew populations, to maintain diversity preventing aggressive species from outcompeting other species, and to allow the persistence of a mosaic of successional stages (Cerrano et al. 2000). The study of catastrophic episodic events may contribute to the understanding of life history patterns of many long-lived organisms (Boero 1996; Navarro et al. 2011). Otherwise, episodic disturbances may act synergistically with punctual small-scale anthropogenic disturbances to put at the brink of disappearance highly complex and species-rich benthic communities.

Natural disturbances, such as extreme storms, diseases or herbivore outbreaks, are well known and there are numerous examples in the literature. Recurrent diseases have been noted in species of some groups, such as bivalves (*Spondylus gaederopus* and some arcids), sea urchins (*Paracentrotus lividus, Arbacia lixula, Sphaerechinus granulatus*), or large corneous demosponges (Cerrano and Bavestrello 2009). By contrast, outbreaks of common sea urchins can completely remove erect algae and other organisms, producing barren grounds. On the other hand, severe storm events cause massive mortalities of benthic organisms by direct wave action, or as a consequence of sediment and boulder displacement (García Rubiés et al. 2009). Such extreme severe storms normally occur every 40–50 years, but their frequency and/or intensity may be more sensitive to global warming. Aumann et al. (2008) pointed out that frequency of exceptional storms increases globally at the rate of 6 % per decade, whereas Jiménez et al. (2012) noted that storm-induced damaged has increased at a rate of about 40 % per decade in the NW Mediterranean since the 1950s.

Tu sum up, when analyzing the changes caused by human activities it should be taken into account that some of the observed changes could be just natural episodic or cyclical changes.

Main Anthropogenic Impacts

Human activities are now the strongest driver of change in marine biodiversity at all levels of organization; hence, future trends will depend largely on human-related threats (Sala and Knowlton 2006). Most human activities have local impacts, but some and, above all, the overall total acting synergistically may have global impact through cumulative processes. The building of the Aswan High Dam in 1968 may not only have deleteriously influenced the productivity, biochemistry and food web structure in the Nile delta and Eastern Mediterranean, but also the hydrological functioning and structure of the whole of the Mediterranean, which itself will influence the chemical and biological characteristics in a feedback loop (Turley 1999). Likewise, the man made Suez Canal (in 1869) has allowed the entry of hundreds of exotic species into the eastern Mediterranean, many of which have already spread over the entire basin.

The most widespread human activities causing impacts on biodiversity are coastal development, overfishing and exploitation of living resources, pollution and introduction of exotic species, which are commented below.

Coastal Development

Habitat modification, fragmentation, degradation and loss are widely considered some of the most serious threats to all components of diversity, structure and functioning of marine coastal ecosystems and to the goods and services they provide (Claudet and Fraschetti 2010). Fragmentation of natural habitats is itself a major cause of local species extinction, even if the surviving patches of habitat still look healthy. Coastal development, along with pollution and sediment loading have notably reduced the extension of important habitats for marine diversity, such as seagrass meadows. The loss of habitat structure generally leads to a decline in species richness and to reductions in overall abundance and biomass. This raises the question of a significant loss of biodiversity, the impoverishment of many species and the fragmentation and decline of their populations. Ultimately, it results in a large-scale degradation, simplification and homogenization of marine communities. In the transition from complex native habitats to simplified habitats, many resident and characteristic species are replaced by fewer opportunistic species with generalistic and/or invader traits (Airoldi et al. 2008).

Due to loss and fragmentation of habitats, connectivity between populations of the same species (genetic flux) is interrupted or reduced. Connectivity is increasingly recognized as a key conservation objective because of its importance for species replenishment (Saenz-Agudelo et al. 2011). Moreover, when the population density of many species decreases, their reproductive success is also considerably reduced, especially in the case of broadcasting invertebrates ("Allee effect") (Courchamp et al. 2008). This has important impacts on population stability and community dynamics. Populations become more isolated and decrease in size and abundance due to fragmentation of habitats, and there is a strong relationship between population size/density and fitness. Changes in fertilization success, larval supply and recruitment play a major role in future population dynamics, and in long-term viability of species.

Recruitment patterns govern the establishment of new populations and hinder the extinction of local populations. If there are no suitable habitats for recruitment, larvae of many species will die without having found an appropriate place to settle. The decrease in available habitats for a species leads to a reduction in the number of both donors and potential recipient populations. Furthermore, the local extinction of species without dispersal ability prevents their recovery. The role of marine protected areas (MPAs) as exporters of larvae has been highlighted often, but this is not much use if the larvae that are exported do not find suitable places to settle outside of MPAs. At the same time, populations within MPAs will suffer a progressive genetic impoverishment if they only act as donors but do not import larvae from surrounding areas.

Overfishing and Exploitation of Living Resources

The most important negative consequence of fishing activities is the degradation of marine ecosystems by removal of target or non-target species and by physical disturbance inflicted by some fishing gear. Most of the major impacts of fishing on the ecosystems recorded around the world severely affect the Mediterranean. They vary from local effects on the sea bottom caused by trawler gear to large-scale impacts on cetacean populations driven by driftnet bycatch. The huge diversity of fishing gear and practices, the very high intensity of fishing, and the presence of a vast array of large vulnerable species (that include emblematic sharks, turtles, whales and seals) make the Mediterranean an area especially sensitive to the effects of fishing (Tudela 2004). Fisheries in the Mediterranean are diverse, catches are usually low and sometimes show marked seasonal differences.

In short, fishing has resulted in the overexploitation of several fish stocks and has notably increased in the past decades, but the depletion of species is also evident on historical time scales. As for particular fishing gear, bottom trawling, longlining and driftnets appear as those with most impact on marine ecosystems over the whole Mediterranean region. Bottom trawling causes continuous alteration and destruction of continental shelf benthic communities and produces large amounts of discards of benthic invertebrates, accounting for up to 80 % of the catch. Additionally, it can be responsible for the alteration of the benthic biogeochemical cycles (Pusceddu et al. 2005).

Evidence shows that the effects of fishing in the Mediterranean go far beyond the isolated impacts on overfished target species, vulnerable non-commercial groups or sensitive habitats. The effects of fishing are also conspicuous at the systemic level, and constitute the major factor causing changes in the food webs in the Mediterranean (Sala 2004; Coll et al. 2008). A holistic approach should therefore be adopted if the overall changes to the structure and the functioning of marine ecosystems caused by fishing are to be remedied (Tudela 2004), but multispecies catch hinders the implementation of appropriate management actions.

On the other hand, overexploitation by intensive and long time harvesting has led to a serious decline in some benthic invertebrates, such as the red coral *Corallium rubrum* (Santangelo et al. 1993), date-mussel *Lithophaga lithophaga* (Fanelli et al. 1994), large demosponges (Pronzato and Marconi 2008) or many shellfish (Volulsiadou et al. 2009). Some aggressive practices affect rocky bottoms, such as dynamite fishing for coral and date mussels.

Pollution

Eutrophication and pollution arise from agriculture, industrial activity, tourism and human population growth that have become serious problems in most of the densely populated and industrialized regions of the world. Hydrocarbon spills, heavy metal contamination, and their biological effects cause increasing concern in the Mediterranean Sea. Furthermore, special attention is now being paid to the "new pollution" processes, that is the introduction of novel substances with biological activity that might have synergic effects with "classical pollutants" (Danovaro 2003). The immunosuppressive effects of contaminants arising from agriculture, industrial activity and human population growth may have contributed to the severity of mass mortalities among marine mammals, and the additional chronic effects of organochlorines could hinder, or even prevent, recovery of individuals from pathogenic disease. All this leads to an impoverishment of species diversity, an increase in bioproductivity, and the intensification of potentially toxic cyanobacterial blooms. Furthermore, the presence of macro- and micropollutants may have a strong impact on microbial-loop functioning and cause the increase of viral infection (Danovaro et al. 2003).

On the other hand, water transparency shows a declining trend of -0.1 m year^{-1} in the NW Mediterranean (Marbà and Duarte 1997), that provides further evidence for deterioration of water quality along the Mediterranean littoral. The increase of water turbidity in the last decades can be the result of an increase in suspended sediment in the water, an increase in suspended particulate organic matter, or both. The decreasing water transparency has important consequences for the ecosystems, mainly in their vegetal components. Many algal species, but also *Posidonia oceanica*, are sensitive to a reduction in water transparency due to pollution and turbidity. The decline or loss of some deep-water species, mainly fucales, such as *Cystoseira spinosa* and *C. zosteroides*, has been detected in recent decades (Thibaut et al. 2005) accompanied by a tendency to shift their deeper distribution limits to an upper level.

Species Introduction

Current changes and human activities are favouring the increasing introduction of non-indigenous species ("alien species"). In the last decades, enhanced mainly by the opening of the Suez Canal, aquaculture and ship transport, hundreds of alien species reached and established themselves in the Mediterranean. Most of the species introduced to the basin are thermophilic originating in the tropical Indo-Pacific (Lessepsian migration). Arrival of alien species can be taken as natural when considering the Atlantic newcomers from the newly active Gibraltar Portal, but anthropogenic when considering Lessepsian migration from the Red Sea through the artificial Suez Canal, or the many species actively or passively introduced by humans. The list of exotic species that have invaded the Mediterranean Sea is continuously increasing, particularly in the eastern basin. A growing bulk of literature on the subject has been published in recent years, with subsequent revisions. Today more than 600 alien species have been reported in the Mediterranean (Galil 2008), or nearly 1,000 if we consider newcomers of Atlantic origin (Zenetos et al. 2010). Their number has nearly doubled every 20 years since the beginning of the twentieth century (Galil 2008, 2009). Most alien species are lessepsian migrants coming from the Red Sea, with an additional set of species from other tropical areas. Therefore, the bulk of the introduced species are of tropical origin and they have been confined for long to the easternmost Levantine shores, but the general warming of the Mediterranean favours their spread (Occhipinti-Ambrogi 2007).

The lack of evidence of species extinction coupled with the establishment of alien species is apparently leading to an increased species richness of the Mediterranean. Therefore, a biodiversity increase might be perceived as a positive consequence of alien arrival and establishment, especially in the eastern basin, where some thermophilic species have now attained commercial relevance (Galil 2007). Nevertheless, the spread of these species may lead to biotic homogenization, increasing risk of local extinction of native species, reduction of genetic diversity, loss of ecosystem functions, and alteration of both habitat structure and ecosystem processes (Boero et al. 2008). According to Zenetos et al. (2010) at least 134 alien species are or may be invasive in the Mediterranean, i.e. with a negative effect on native species and communities.

Other Minor or Local Impacts

A number of other minor or local impacts (beach replenishment programmes, marine farms, diving, anchoring, hypersaline brine discharges from desalination plants, …) do not cause significant damage on their own, but the sum of them all acting synergistically prevents the recovery of the entire marine ecosystem. Cumulative human impacts and synergistic interactions between multiple stressors can exacerbate nonlinear responses of ecosystems to human impacts and limit their adaptive capacity. To this should be added a number of other sporadic or accidental anthropogenic impacts, such as oil spills, accidental polluting, or occasional effluents.

Global Change

Impacts of Global Warming ("Tropicalization"?)

Global warming in now recognised as the predominant threat to biodiversity in many parts of the world. The global warming observed since the end of the nineteenth century has been caused not only by natural climate changes on the decades-centuries scale but also by the impact of human activities on the Earth's climate system. The enclosed Mediterranean basin is a miniature ocean where the effects of climate change are likely to be more apparent earlier than in other more open seas and oceans (Coll et al. 2010). In the Mediterranean, a positive trend in temperatures is clearly seen after the mid 1970s (0.040 °C/year for surface water and 0.025 °C/year at 80 m depth since 1975), and the number of days that the temperature was >18 °C shows an increasing trend of 1.25 days/year since the mid 1970s (Coma et al. 2009). According to Marbá and Duarte (2010), the average annual maximum temperature for the first decade of the present century was 1 °C above temperatures recorded for the last decade of the last century. In addition, over this general trend, cyclical oscillations are overlayed, and thermal anomaly events are increasingly frequent in recent years (Coma et al. 2009; Garrabou et al. 2009; Crisci et al. 2011). At least three well-documented heat waves impacted the NW Mediterranean in the summers of 1999, 2003 and 2006. The occurrence of heat waves, rather than a gradual, smooth elevation of the temperature also reduces the opportunities for adaptive changes. Furthermore, the frecuency of other extreme events (severe storms, droughts, floods) has increased in recent decades and is likely to further increase in the future (Calvo et al. 2011).

Rapid warming of the Mediterranean and heat waves threaten marine biodiversity and, particularly, marine ecosystems already stressed by other impacts, such as *Posidonia oceanica* meadows. A clear relationship between increasing seagrass shoot mortality rates and increased warming has been highlighted by Marbà and Duarte (2010), even in pristine meadows, which provides evidence that warning alone has the potential to cause abrupt mortality in *Posidonia* meadows. According to these authors, a pronounced *P. oceanica* shoot mortality occurs when seawater exceeds 28 °C associated with the occurrence of heat waves. Thus, they observed that those heat waves recorded in 2003 and 2006 lead to a mortality of 13 % of the *Posidonia* shoots population the subsequent year at Cabrera Island (a protected marine area in the Balearic Islands).

As a result of warming, one expectation could be a homogenisation of the Mediterranean biota, disrupting present biogeographical entities (Lejeusne et al. 2010). Climate change is causing shifts in the geographical distribution of species to keep within their thermal regime, associated with local extinction and contraction/expansion of their distribution ranges. Therefore, the most evident phenomenon correlated with global warming is the successful geographical spread of species of warm water affinity (Boero et al. 2008). These distributional changes are clearly evident for highly mobile species (mainly fish), but also for some benthic invertebrates (Fig. 28.1). Coinciding with the recent change of temperature, many native thermophilic species appeared or became common in northern sectors, where they were formerly absent or rare (Bianchi and Morri 1993; Francour et al. 1994; Despalatović et al. 2008; Puce et al. 2009). More than 30 warm-water indigenous fish species have now been reported north of their last geographical distribution (Boero et al. 2008). However, northward displacement in the Mediterranean Sea is limited due to the physical presence of the European continent. Concurrently, cold water species have practically disappeared from many areas of the Mediterranean. Besides, the warming of the Mediterranean waters could also modify the migration pattern of some species, such as bluefin tunna *Thunnus thynnus* and the amberjack *Seriola dumerili*, which have lengthened their stay in northern and central Mediterranean waters before migrating towards their winter areas (Bombace 2001).

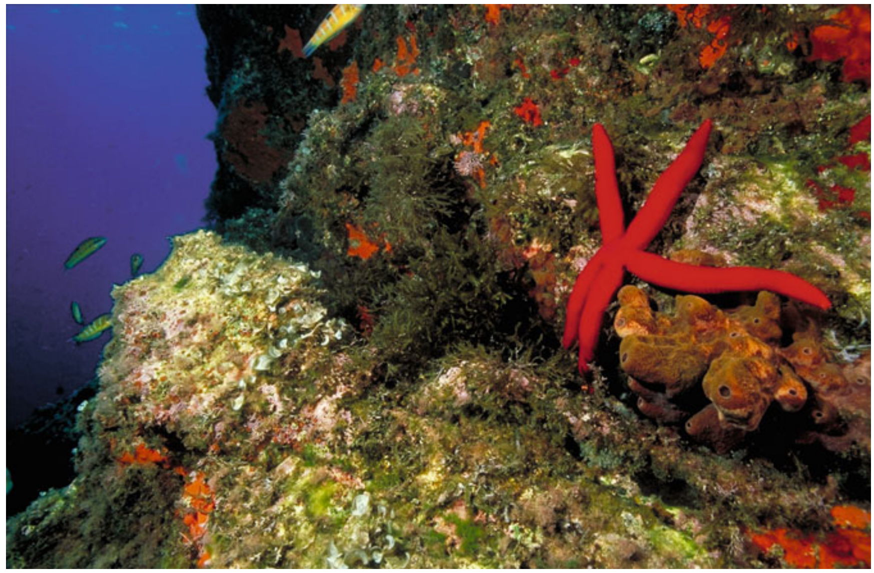

Fig. 28.1 Many species of warm water affinity, such as the sea star *Ophidiaster ophidianus*, are spreading to the northern sectors of the Mediterranean Sea (Author: J.C. Calvín)

In the Mediterranean Sea climate change combines with Atlantic influx, lessepsian migration and the introduction of exotic species by humans lead to the establishment of tropical marine biota (Bianchi 2007). The Suez Canal serves as a gateway for natural migration but also facilitates the expansion of ship-borne fouling biota. There are thousands of species that settle in the Mediterranean coming from the Red Sea in a stepwise ("Lessepsian migration") or as one-jump noxious immigrants ("Erythrean alien") (Galil 2006). There is also an increasing settlement by tropical Atlantic newcomers entering the Mediterranean through the Strait of Gibraltar. In this sense, Ben Rais Lasram and Mouillot (2009) pointed out that the currently warmer Mediterranean is acting increasingly as a "catchment basin" for southern species. They recorded 127 thermophilic fish species that supplemented in the last decades the Mediterranean fauna, 65 lessepsian species and 62 coming from the Atlantic. Initial northward and westward expansion of the range of Atlantic and Levantine species, respectively, has also been detected (Bianchi and Morri 1993; Guidetti and Boero 2001; Azzurro 2008; Relini 2009). Furthermore, several tropical invaders have already reached the northernmost sectors of the Mediterranean Sea (e.g. Dulčić et al. 2008; Francour and Mouine 2008; Kružić 2008; Daniel et al. 2009; Katsanevakis et al. 2011).

A warming Mediterranean is becoming more receptive also to species arriving accidentally with ship ballast and other artificial ways, adding to the number of successful establishment cases. This influx of thousands of tropical species into the Mediterranean is one of the most remarkable biogeographic phenomena of today. Observed changes due to climate change involve both indigenous species subjected to a process named "meridionalization" and non-indigenous species, subjected to a process defined as "tropicalization" (Boero et al. 2008). Such changes are causing a progressive homogeneization of Mediterranean marine biotas (Philippart et al. 2011). Some authors consider the use of the term "tropicalization" to be exaggerated (Lejeusne et al. 2010) and suggest that "meridionalization" is a more realistic term to refer to the increase of the proportion of thermophilic species.

On the other hand, if the Mediterranean Sea is becoming 'tropical' those species of boreo-Atlantic origin that entered the Mediterranean during glacial periods and established themselves in the northern colder areas of the basin cannot migrate further northward due to the geographic configuration of the Mediterranean. Therefore there is the risk of extinction of these cold-water species from the Mediterranean. Rarefaction or even disappearance of cold-water species from their refuges in the Gulf of Lion-Ligurian Sea and the northern Adriatic has already been recorded (Chevaldonné and Lejeusne 2003; Boero and Bonsdorff 2007; Ben Rais Lasram et al. 2010). On the other hand, the colder and less saline western basin of the Mediterranean Sea, will become more similar to the eastern basin, allowing exotic and native warm-water species to spread and thrive in the northern areas. As a result, sub-regional peculiarities in biodiversity might eventually disappear, leading to a taxonomic, genetic and functional homogenization (Boero et al. 2008).

Climate warming can also affect competitive interactions between native species of different thermal affinity (Chevaldonné and Lejeusne 2003). For example, the increase of *Sardinella aurita* in the western Mediterranean might have contributed to the decrease of both the anchovy *Engraulis encrasicolus* and the sardine *Sardina pilchardus* (Sabatés et al. 2006). An illustration of cascading effects caused by global warming is exemplified by the competitive interactions between the common native sea urchins *Paracentrotus lividus* and *Arbacia lixula* and their effects on the invasive coral *Oculina patagonica*. In the Mediterranean Sea both urchins coexist in rocky shallow waters and are considered the main controlling factors of the dynamics, structure and composition of infralittoral macroalgal assemblages. *Arbacia lixula*, a thermophilic species, seems to exert a major role in barren areas formation and maintenance. The two species have a clearly different thermal optimum at the larval stage: *A. lixula* showed higher larval survival at higher temperature than *P. lividus* (Privitera et al. 2011). This allows us to predict a potential decline of *P. lividus* populations, while *A. lixula* should benefit from higher temperatures, as indicated by higher recruitment after particularly hot summers. In turn, this leads us to expect an increase of the barren areas. Furthermore, Coma et al. (2011) found evidence that barren areas facilitate the recruitment and proliferation of the alien coral *Oculina patagonica*, which shows the synergistic effects of global warming on the dynamics of invasion of exotic species.

Even populations in protected areas are susceptible to global changes, because of the pervasive effects of temperature shifts. Therefore, habitat protection alone may not be enough to ensure persistence of a population and so the conservation and harvesting management of species requires the development of objective criteria to assess species' vulnerability to climate change (Lo Brutto et al. 2011).

Impacts of Acidification

Around half of all extra CO_2 produced so far by human activities has dissolved in the oceans. The anthropogenic increase in the concentration of atmospheric carbon dioxide is reducing the pH of seawater on a global scale (a process termed "ocean acidification"), changing the chemistry and biogeochemical cycling of carbon and carbonate. A growing number of studies have demonstrated adverse impacts of acidification on marine organisms. The combination of elevated temperature and acidification has been shown to be detrimental to the calcification process, hence marine organisms with calcareous skeletons, shells or plates will experience problems. These include major bioconstructing organisms, such as scleractinian corals, bryozoans or red coralline algae, but also molluscs, crustaceans, echinoderms, foraminifera and some calcifying phytoplankton (mainly coccolithophorides) as well as zooplancton (Pteropods and larvae of many groups). Ocean acidification reduces the abundance of carbonate ions, which are an essential component of the mineral calcium carbonate that these organisms use to build their protective shells and skeletons. An update of the impacts of acidification on biological, chemical and physical systems in the Mediterranean and Black sea was published by CIESM (2008). Recently an estimation of a pH decrease of up to 0.14 units has been identified in the western Mediterranean Sea since preindustrial times, which is of higher magnitude than the global surface ocean decrease of about 0.1 units over this time period (Calvo et al. 2011).

Ocean acidification is also predicted to reduce the absorption of low frequency sound, leading to a noisier environments for marine mammals (Hester et al. 2008). On the other hand, recent studies suggested that jellyfish increase in abundance as pH declines, probably due to the negative impact of more acidic conditions on calcifying plankton, opening up an ecological space for gelatinous plankton (Attrill et al. 2007).

Episodic Events

Mass Mortalities

Temperature anomalies and higher sea surface temperatures have severely impacted entire shallow coastal ecosystems, causing the elimination of sensitive species as well as mass mortalities (Boero et al. 2008). Increasing frequency, severity and expansion of mass mortalities related to abnormal summer heat waves and to seasonal stratification were observed in different parts of the Mediterranean. Two major well-documented multispecies mass mortality events impacted the NW Mediterranean after the summer heat waves of 1999 and 2003 (Cerrano et al. 2000; Perez et al. 2000; Garrabou et al. 2001, 2009; Coma et al. 2009; Crisci et al. 2011). They affected many long-lived filter-feeders, structural invertebrates (Fig. 28.2) over several hundred kilometres of coastline in this area. Structural species provide biogenic structure, so other species not directly affected by the mass mortalities could also indirectly suffer the impact through modification of habitat conditions (Garrabou et al. 2009). The bottlenecks induced by mass mortality events reduce the genetic diversity of these key structural species and thus influence their next evolutionary trajectory. This strongly suggests that temperature anomalies, events of short duration, can, directly or indirectly, dramatically change the structural complexity of Mediterranean biodiversity, because of their essential role in maintaining the structure and species composition of the communities where they live. The lush coralligenous community (Fig. 28.3) has been one of the more affected in recent times by mass mortality events of some of its main structural species. Furthermore, it must be taken into account that although species known to have been affected by mass mortalities are structural or conspicuous species, small, cryptic, or poorly known species may be affected also by such events.

In addition to these two multispecies mass mortality major events, other mass mortality events that affected fewer species or were geographically restricted have been recorded in the Mediterranean Sea. For instance, the three common littoral Mediterranean sea urchins (*Paracentrotus lividus, Arbacia lixula* and *Sphaerechinus granulatus*) have been sometimes

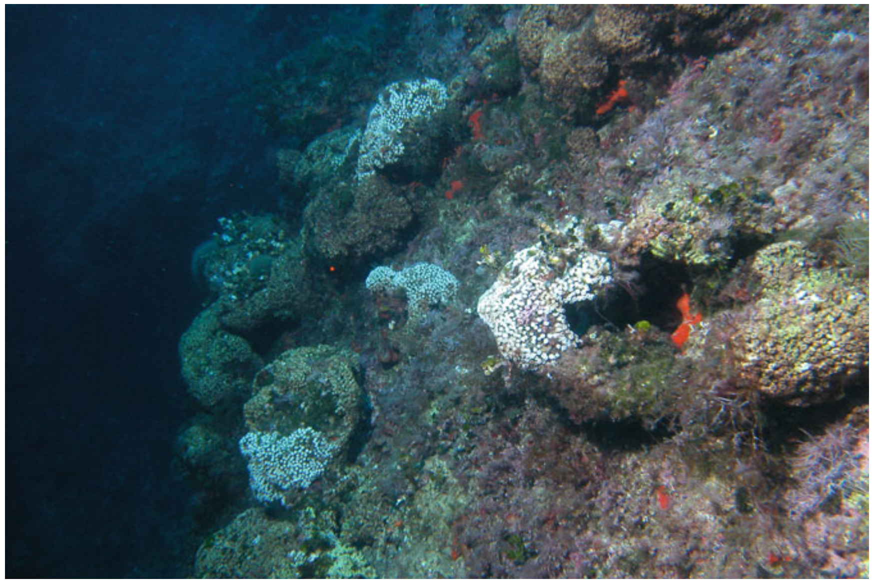

Fig. 28.2 The scleractinian coral *Cladocora caespitosa* is one of the long-lived filter-feeders structural invertebrates affected by mass mortalities after heat waves (Author: D.K. Kersting)

Fig. 28.3 The lush and colorful coralligenous community has been affected in recent times by mass mortality events of some of its main structural species (Author: J.C. Calvín)

involved in local mass mortalities (Miller 1985, obs, pers.). Sometimes such mortalities are caused by disease, possibly linked to overcrowding (Boero 1996). Episodic disease outbreaks of large Mediterranean sponges (mostly Dictyoceratida) have been documented also (Pronzato 1999; Maldonado et al. 2010; Cebrian et al. 2011). The bivalve *Spondylus gaederopus* (Fig. 28.4) suffered widespread mortality in the 1981–1983 summers (Meinesz and Mercier 1983). Because there were no temperature anomalies during these summers Meinesz and Mercier (1983) hypothesised a viral, bacterial or fungal infection. Local mortalities of this bivalve have been reported later (Kersting et al. 2006), along with that of other bivalves, such as the arcids *Arca noae* and *Barbatia barbata*.

Thermal stress may directly affect the physiology of organisms or reduce their resistance, resulting in numerous diseases affecting natural populations (Cerrano and Bavestrello 2009). Mass mortalities may be due to the exposure to lethal temperature and/or to pathogenic microorganisms, more probably to physiological stress that makes them more susceptible to opportunistic, residential, and/or pathogens, including bacterians, some fungi and protozoans (Cerrano et al. 2000; Coma et al. 2009). Many pathogens have the capacity to cause disease only in a host under stressful conditions (such as increased seawater temperature) that can trigger mortality by inducing a microbe to be more virulent or the host to become more vulnerable.

Fig. 28.4 The bivalve *Spondylus gaederopus* suffered widespread mortality in the 1981–1983 summers and local mortalities have been reported recently (Author: D.K. Kersting)

In recent years mortality of the coral *Oculina patagonica* has been caused by the pathogenic bacterium *Vibrio shiloi* (Rosenberg and Loya 1999). After the 2003 mass mortality, a dominant strain affecting the Mediterranean gorgonian *Paramuricea clavata* was identified as *Vibrio coralliilyticus*, previously identified as a thermodependent pathogen of a tropical coral species (Balli and Garrabou 2007).

Predicted global warming leading to long-lasting hot summer periods together with stratification resulting in energetic constraints, represent a major threat to the survival of benthic invertebrates in the temperate NW Mediterranean Sea due to potential disease outbreaks associated with *Vibrio* pathogens (Vezzulli et al. 2010). Bacteria belonging to the genus *Vibrio* are of particular concern as they constitute a considerable part of marine halophilic bacterial populations, are strongly thermodependent and are often associated with human and marine animals' diseases, including diseases of several benthic organisms, such as corals and bivalves. With predicted further warming of sea surface temperatures over the coming century, the severity of disease in invertebrate populations in the NW Mediterranean Sea is likely to increase, placing further pressure on the health of this marine ecosystem.

Jellyfish Blooms

Although cyclical or episodic dense jellyfish aggregations are a natural feature of pelagic ecosystems (Piraino et al. 2002), a picture is now emerging of more severe and frequent outbreaks in many areas. Furthermore, mounting evidence suggests that the structure of pelagic ecosystems can change rapidly from one that is dominated by fish to a less desirable gelatinous state, with lasting ecological, economic and social consequences (Richardson et al. 2009). Available evidence suggests a suite of human activities might act separately or synergistically to result in outbreaks of some jellyfish species. Of these human activities, overfishing, eutrophication and climate change seem to play a role in increasing jellyfish blooms, particularly in coastal areas. The results are that the energy that previously went into production of fish in the pelagic ecosystem may be switched over to the production of Cnidaria and Ctenophora.

Jellyfish and fish interact both as predators and competitors of each other. Many fish species compete for the same zooplankton prey as jellyfish, some fish are predators of jellyfish, and jellyfish also predate on fish larvae and eggs. Modern commercial fishing removes predators and competitors of jellyfish with increasing efficiency, enabling many gelatinous zooplancton species to proliferate (Sabatés et al. 2010). On the other hand, nutrients added to the coastal zone are rich in nitrogen and phosphorous, but poor in silica. Under such conditions non-siliceous phytoplankton, such as flagellates (that include some harmful red-tide species), proliferate and replace diatoms, resulting in a reduction in the size of primary and secondary producers. This modifies and simplifies the pelagic food webs. Diatoms are the main food of copepods, which are the main prey of planktivorous fish (anchovies, sardines, herrings), which are, in turn, eaten by larger pelagic fishes. Yet, jellyfish have a wide range of prey, including flagellates. Therefore, a future pelagic food web has been hypothesized supporting fewer fish, marine mammals, and seabirds, because of the replacement of diatoms and copepods by flagellates and gelatinous plankton, with a smaller average of food size (Pearson and Lalli 2002). Furthermore, warming of the sea surface can enhance water column stratification, leading to nutrient-poor surface water where flagellates can also outcompete diatoms. Such flagellate-dominated food webs are more favourable for jellyfish than for fish. Warmer waters also accelerate medusae growth and ephyrae production in many species.

Besides, jellyfish have a suite of successful attributes that enable them to survive in disturbed marine ecosystems, such as broad diet, fast growth rates, the ability to shrink when starved, the capacity to fragment and regenerate, and the ability to tolerate hypoxia (Richardson et al. 2009). These are characteristic of opportunistic species that give jellyfish advantages over fish in environments stressed by global change, eutrophication and overfishing.

In the last decades there has been a marked increase in the frequency and extent of jellyfish outbreaks in the whole Mediterranean Sea. The scyphomedusa *Pelagia noctiluca* have been especially noteworthy because the medusae sting and the summer blooms are highly harmful to summer bathers. *Pelagia noctiluca* is an opportunistic predator that consumes a wide variety of prey, but more than 10 % of which are fish larvae (Sabatés et al. 2010). Regular population fluctuations of this species are well known, with population peaks occurring in the past on average every 10–12 years (Goy et al. 1989; Mills 2001), mainly in spring and summer months. Nevertheless, nowadays plagues of this and other jellyfish species are becoming more frequent and happen at any time of year.

Noxious Algal Blooms

Harmful algae blooms are another emerging phenomenon causing health and economic concern, especially in tourist areas. The term 'harmful algal blooms' (HABs) covers a heterogeneous set of events that share two characteristics: they are caused by microalgae (mainly Dinoflagellates) and they have a negative impact on human activities. The concept of explosive high abundance is implicit in the term "bloom". Despite these common features, HABs are very diverse in terms of causative organisms, dynamics of blooms and type of impact (Zingone and Enevoldsen 2000), and have usually been associated with nutrients derived from anthropogenic activities. These blooms are often natural phenomena, but sometimes may be dangerous for human health and deleterious for the commercial exploitation of coastal areas. Problems related to HABs are not only associated with food safety and commercial shellfish activities. Environmental damage, health problems (not associated to shellfish consuming), such as allergic reactions, recreational shellfish harvesting or even aesthetic issues have important social implications and can prevent the use of coastal waters for recreational purposes, causing evident economic damage. Furthermore, a number of HABs affect organisms that may have no commercial value but nonetheless are functional components of the marine ecosystem. The degradation of high biomass blooms can exhaust oxygen supplies, thus killing not only commercially important species, but also other plants and animals that are unable to leave the anoxic area. In short, degradation of coastal water quality by HABs occurrence has direct economical impact on some Mediterranean tourism locations.

Records of toxic benthic dinoflagellates have dramatically increased along the Mediterranean coast over the last decades and the list of harmful species is growing (Garcés et al. 2000). In particular, *Ostreopsis ovata* has bloomed in the Mediterranean region in recent years, with increasing frequency, intensity, and distribution (both in western and eastern coasts of the Mediterranean), causing mortality of benthic organisms and human health problems. In turn, the genus *Alexandrium* is the group of dinoflagellates which causes most HABs, and *A. taylori* is one of the noxious species. It is known that blooms of this species have occurred in the northern Mediterranean beaches since the 1980s (Basterretxea et al. 2005). This dinoflagellate is a non toxin-producing organism but a high-biomass bloom-former that provokes greenish-brown discoloration of the water during the summer months in protected pocket beaches causing an evident water deterioration.

Furthermore, the geographical distribution of some specific harmful benthic dinoflagellates, such as the ciguatera-causing genus *Gambierdiscus*, mainly restricted to circumtropical areas until recently, have spread to temperate regions in recent times, including the Mediterranean sea (Aligizaki et al. 2009; Faimali et al. 2012). This poses a potential risk for a future occurrence of ciguatera in the area.

Proliferation of Mucilages

The production of mucilaginous aggregates is a well-known phenomenon in seawater occurring during intensive nuisance blooms of certain phytoplanktonic taxa, mainly diatoms, blue-green algae and Prymnesiophyceae (Metaxatos et al. 2003). Mucilage is made of expolymeric compounds with highly colloidal properties that are released by marine organisms through different processes and through death and decomposition of cell-wall debris. The dominant components of the algal mucilaginous material are exudates composed by polysaccharides, making the bulk of mucous biomass, but proteins, lipids and unidentified molecules are also components. Mucilages heavily affect marine ecosystems, mainly when the massive development of aggregates covers large areas of rocky substrate, suffocating benthic biocoenoses. Besides, marine mucilage can represent a new, though ephemeral, substrate for microbial colonization, including pathogenic forms (Danovaro et al. 2009), because it is a hot spot of viruses and bacterial diversity. Mucilage, in turn, can induce hypoxic phenomena and even promote extensive anoxia resulting in a decreased production of "ecosystem goods and services".

The proliferation of mucilages is a sporadic and recurrent phenomenon well documented in the Mediterranean, but it has increased almost exponentially in the last decades, spreading to most regions of the Mediterranean basin. Many environmental stresses seem to cause the hyperproduction of exudates (high irradiance, temperature anomalies, water column stability, nutrient availability). According to Innamoranti et al. (2001) nutrients are one of the main causes, particularly when the N/P ratio shifts toward a phosphorous deficiency. Nevertheless, Danovaro et al. (2009) note that mucilage is not necessarily associated with eutrophic conditions, as several mucilage outbreaks have been recently observed in oligotrophic areas. According to these authors, mucilage represents a symptomatic response of the Mediterranean ecosystem to direct and indirect anthropogenic impacts and additionally, a potentially expanding carrier of viruses and bacteria, including pathogenic forms that are harmful to the health of human and marine organisms.

Global Ongoing Changes and Predicted Trends

Humans are greatly altering Mediterranean marine biodiversity in many ways, including climatic change (Bianchi and Morri 2000), which is no longer to be considered as natural because of the increased anthropogenic emission of carbon dioxide (CO_2) and other 'greenhouse' gases into the atmosphere. Climatic models predict that the Mediterranean basin will be one of the regions most affected by the ongoing warming trend and by an increase in extreme events (Lejeusne et al. 2010). Therefore, climate and humans are combining their effects on Mediterranean Sea biodiversity. Since climate change interacts synergically with many other disturbances, there are reasons to believe that the Mediterranean is one of the most impacted seas in the world. An overview of ongoing changes in the Mediterranean Sea is summarized below:

Physico-chemical trends

- Temperature increase and higher frequency of short-term extreme events. Increase of heat waves, storm frequency and changes in wind speed and direction.
- Decline of water transparency (increase in water turbidity).
- Longer and deeper summer thermocline.
- Strengthening of the stratification and slowing down of thermohaline circulation.
- Changes in circulation patterns.
- Shift of the downward transfer of carbon (dioxide) by means of the "biological pump".
- Appearance of areas of hypoxia and stratification processes associated. Emergence and spread of anoxic zones.
- Increase of nutrient concentrations.
- Progressive acidification and decrease of the carbonate ion concentration.
- Decrease in the capacity to absorb atmospheric CO_2.
- A noisier environment for marine mammals.
- Reduction of sediment delivery due to widespread construction of dams.
- Towards a permanent stratification of the basin?

Biological trends

- Homogenization and impoverishment of the marine biota.
- Shift from endemic to "common" species.
- Extinction of some rare species.
- Decline of species abundance and increase of microbial communities.
- Loss of genetic variability.
- Decline of *Posidonia oceanica* meadows, fucoid algal beds and many other key species.
- The decline of *P. oceanica* meadows involves a reduction in natural carbon sink capacity.
- Replacement of canopy erect algae on shallow rocky shores by turf forming or filamentous algae cover and sea urchin barrens.
- Changes in the life cycles of the species, in their reproductive effort and in their demography. Progressive reduction of the size of species.
- Progressive decline of "cold" stenothermal species from the surface layer, which move to deeper layers, and increasing abundance and range extension of thermotolerant species.
- "Tropicalization" or "meridionalization" of the biota. Northward extension and increase in the abundance of native thermophilic species (meridionalization). Increase in arrival, establishment and range extension of tropical exotic species (tropicalization).
- Subtle adaptive responses (such as physiological adjustments and microevolutionary processes).
- Increase in primary production and shift in food web structure.
- Shift towards non-siliceous phytoplankton (from diatoms to coccolithophorides and flagellates).
- Shift from fish to jellyfish (decline of small pelagic fish and increase of gelatinous plankton).
- Modification of both bottom-up and bottom-down interactions.
- Spread of mucilages.
- Increasing episodes of mass mortalities.
- Increase in blooms of potentially toxic blue-green algae (cyanobacteria) and toxic dinobionts or harmful algae in coastal areas.
- Complex interactions and synergies between the various disturbance factors.

Human activities can lead to homogenization and impoverishment of ecosystems due to reductions in diversity within functional groups, food-web complexity, distribution range, biogenic habitat structure, and size of organisms (Claudet and Fraschetti 2010). Entire ecosystems may cease to function in their current form, potentially leading to a loss of the goods and services derived from them. Lost canopies of frondose algae (mainly fucales) tend to be replaced by species with lower structural complexity, such as turf-forming, filamentous or other ephemeral seaweeds, mussels, or sea urchin "barrens" (Perkol-Finkel and Airoldi 2010), and the extensive *Posidonia oceanica* meadows are being progressively decimated (Boudouresque et al. 2009). These meadows are considered to be among the most important Mediterranean marine ecosystems, with regard to both ecology and biodiversity, and for the services they provide.

In turn, the Mediterranean Sea is undergoing a rapid and dramatic transformation from a warm-temperate region to a warmer sea in which thousands of tropical species are becoming established owing largely to the human-constructed Suez Canal (Vermeij 2012). This so-called "tropicalization" (Bianchi 2007) will restore a biogeographical link between the Mediterranean and Indo-West Pacific (IWP) that last existed during the Middle Miocene (until 16 mya). This new tropical signature will, however, differ substantially from that prevailing during the warm Early Pliocene (5–3 mya), when most tropical elements in southern Europe had West African affinities. The future biota of a particular region depends on the species pools from which spreading taxa are drawn as well as on the nutritional and evolutionary regimes in both the donor and recipient regions (Vermeij 2012). So, if further warming should reduce the barrier of cold Canary Current and Saharan upwelling, as occurred during the productive and warm Early Pliocene, the tropical Atlantic elements will again be able to enter the Mediterranean as they did during its reflooding after the MSC. Moreover, taxa entering through the Suez Canal may spread toward West Africa. An increasingly oligotrophic Mediterranean will probably be more receptive to IWP immigrants from the Red Sea than to eastern Atlantic newcomers from the productive waters of West Africa, but a future Mediterranean biota with both African and IWP elements can be expected. Thus, the Mediterranean could become a fascinating meeting place (Vermeij 2012) for two tropical biota of contrasting source origins (tropical West Africa and Indo-Pacific), which have had separate histories for at least 16 million years.

The different driving forces of change act on very different time scales, but all have apparently accelerated in the last decades. According to Bianchi (2007), the time scale of the Atlantic influx is of the order of 10^4 years (since the beginning of the last interglacial), the introduction of exotic species by humans has acted on a time scale of 10^3 years, the time scale of lessepsian migration is of the order of 10^2 years (it started soon after the opening of the Canal in 1869), and finally sea warming has a time scale of 10^1 years, despite large cyclic fluctuation.

Concurrent expansion of the range of warm-water species and northward contraction of that of cold-water species are disrupting the present biogeographic patterns within the basin, and some authors have drawn attention to the homogenisation of the Mediterranean biota (Bianchi 2007; Boero et al. 2008; Lejeusne et al. 2010; Philippart et al. 2011). The idea of fading the commonly accepted biogeographic boundary between the western and eastern Mediterranean basins began to be raised in favour of a series of gradients in a south–north direction.

Uncertainties

Whereas the effects of each of the different impacts are now well documented, major unknowns remains as to how they will ultimately affect the functioning of ecosystems through cascade effects. The interaction of all these impacts acting synergistically may be greater than the sum of individual impacts. It is therefore necessary to know how all of them interact.

According to Por (2009), the Mediterranean is possibly and partly reverting to its original tropical warm-water biological condition, which was only relatively recently interrupted by the start of the glaciation cycles about 2.6 million years ago. Under a geological perspective, what is now happening is considered by this author to be a return to normal conditions, possibly a normalization event. The Present Climatic Optimum represents a return to the Pliocene Climatic Optimum and thus, can be seen as a repetition, a cyclic event and not as an artificial disruption (Por 2009). However, it should be noted that marine communities change in a progressive way, and do not fluctuate around a hypothetical "optimal" or "typical" configuration (Bianchi and Morri 2000). The fact is that the observed ongoing changes lead to a progressive degradation and impoverishment, which seem to veer away from the idyllic rich tropical sea of the past.

It is impossible to foresee to what extent the exuberance of warm-water species will affect the composition of marine communities, the trophic webs and the functioning of the whole Mediterranean ecosystem. While Mediterranean communities are being modified in their species composition pattern, they do not seem to be acquiring a more marked tropical physiognomy (Bianchi 2007). Mediterranean coastal marine ecosystems are still dominated by frondose algae (even if the species that are gaining ascendency are of tropical origin) and not by corals, as is the rule in tropical seas. Instead of coral reef, different Mediterranean organisms build significant monospecific or oligospecific bioconstructions, mainly coralline algae, plus a few vermetid gastropods, briozoans, serpulids or corals. But corals or other constructional organisms are not becoming more abundant; on the contrary they are perhaps going to face more frequent mass mortalities or weakening, such as the scleractinian coral *Cladocora caespitosa* (Bianchi 2007). So, the Mediterranean biota might loose in the near future what have been called their peculiarities and acquire a different and unprecedented configuration structure.

What Is the Role of Rare Species?

Rarity is a common state in the life of most species (commonness of rarity). A significant proportion of biodiversity at species level is composed of small and inconspicuous rare species. Most communities are composed of a few dominant species and a high number of rare species. Nevertheless, rare species are the neglected component of biodiversity and they are often considered as 'noise' in ecological studies and ignored (Boero 1994). Likewise, biodiversity conservation focuses mainly on a few charismatic species (generally either vertebrates or large and conspicuous invertebrates) and disregards what represents the bulk of biodiversity: a host of small rare species (Piraino et al. 2002). On the contrary, the importance of rare species could be crucial as a reservoir of potential diversity and provide the information for the possible future composition of a community after changes in environmental conditions. Boero (1994) argued that very small populations might represent the last representatives of a declining species or the first stages of an emerging one, or finally the normal abundance in a given time window. Rare species are the insurance for the continuation of biological diversity and, at least some of them, will take the place of species that are common now. Therefore, they are particularly important from the point of view of conservation, ecology and evolutionary biology (Lim et al. 2012). A flexible species composition may allow ecosystems to maintain their functioning unfalteringly (Bianchi and Morri 2000) and a high number of species serve as a buffer against the effects of environmental impacts and enhance the recovery potential of communities. Ecosystems with more species perform better and have higher resilience (the ability to recover after adverse impacts). Focusing conservation on a few charismatic species is a very biased and incomplete view of the problem. To understand the magnitude of changes that biodiversity is undergoing today, it is necessary to know what is happening to rare species. Unfortunately, we only know what is happening to a few species of vertebrates and conspicuous invertebrates.

Is It Possible for Marine Populations and Ecosystems to Recover?

Marine populations and ecosystems have a high recovery potential on timescales of a few years to a few decades after major disturbances. Despite long periods of intense human impact, most marine species persist and some populations show signs of recovery. This could provide a promising outlook on the future of Mediterranean ecosystems and biodiversity if those measures necessary for this to happen are urgently taken. Recovery often depends on intrinsic factors, such as life-history characteristics, meta-population structure and genetic diversity, but also on extrinsic factors, such as the type and magnitude of disturbance, and the conservation and management measures applied to reduce human impacts (Lotze et al. 2011). Small short lived organisms, such as most invertebrates and algae, have a much higher recovery potential than large vertebrates or long-lived, structural invertebrates.

The most obvious drivers of recovery are the reduction of those human impacts that caused the depletion or degradation, especially habitat loss, pollution and overexploitation, combined with recovery favorable environmental and life-history conditions. Awareness, legal protection and enforcement plans are also important. Once the ability of natural ecosystems to absorb and recover from multiple stressors of natural or human origin is eroded, the mere restoration of environmental conditions preceding the loss, if at all possible, may be a necessary but perhaps not sufficient condition for recovery (Perkol-Finkel and Airoldi 2010). In most cases a full recovery of the initial state after disturbance is not possible, and most often only a partial recovery to a reduced, altered or alternative stable state is achieved. The species with reduced fertility and/or low dispersal ability recover with more difficulty than those of high fertility and high dispersal capacity. New strategies for restoration and conservation are necessary, taking into account the resilience of the system in light of cumulative impacts, incorporating threshold models and feedback mechanisms (Perkol-Finkel and Airoldi 2010). Recovery is always the result of interactions between species and extrinsic factors, and there are circumstances where such interactions can feedback negatively, limiting recovery for decades.

Marine Protected Areas (MPAs) are created mainly for the recovery and conservation of marine populations and ecosystems. In fact, marine reserves lead to increases in total abundance, biomass and size of fish within their boundaries and adjacent areas, especially for species targeted by fisheries (Guidetti and Sala 2007). However, their role is less clear for the other components of the marine ecosystem, especially small invertebrates. Protection and recovery of fish assemblages may affect benthic ecosystems through cascading effects. Much has been written about MPAs as exporters of fish biomass and larvae to surrounding areas, but little has been said about them as recipients of larvae. On the one hand, if the exported larvae do not find appropriate places to settle outside the MPAs, most larvae exported are wasted. On the other hand, if MPAs do not import larvae from outside, then there will be a genetic impoverishment of their populations.

Therefore, although the establishment of MPAs is positive and necessary, it is not enough, and an integrated conservation of the entire marine ecosystem as a whole is required.

Suggestions

The Mediterranean is an ideal laboratory in which to investigate the kinds of biogeographical alterations that will become much more common as global warming intensifies (Vermeij 2012) and to understand how a variety of species respond to it.

To mitigate environmental degradation and biodiversity loss, first we need to mitigate the effect of those impacts we are more able to control (overfishing, habitat destruction, pollution). The effects of climate change would be attenuated if we were able to reduce the effect of the other disturbing factors (Calvo et al. 2011). Furthermore, a better knowledge of the basic components of biodiversity is necessary to detect the changes that are occurring. Hence research work in those scientific areas currently unfashionable by funding agencies (taxonomy, systematics or biogeography) is also necessary. Regrettably, while biodiversity problems are growing, we are losing expertise in biodiversity (Boero 2001; Giangrande 2003, among others), namely those experts able to identify, describe and classify species (taxonomists).

The Convention on Biological Diversity is calling for more systematic inventories. Promote systematic inventories and taxonomy may provide a permanent scientific record for documenting patterns of diversity, endemism and alien species across zones, ecosystems and habitats, baselines for monitoring programmes, it could identify indicator species of environmental changes and it is essential for identifying and establishing conservation priorities (Mikkelsen and Cracraft 2001). Small cryptic invertebrates, i.e. polychaetes, molluscs, crustaceans, etc. are numerically dominant in most marine ecosystems, but the inventory of these small invertebrates requires the participation of trained taxonomists.

Another issue related to the above is the need to make existing information available (especially historical records) on the distribution of both warm- and cold-water species at the basin scale, and to identify historical reference points to detect and understand recent changes that may occur in marine ecosystems and in species populations.

Inventories of selected taxa should be ideally coupled with long-term monitoring programmes. Large scale monitoring programs, and internationally co-ordinated networks of monitoring hydrological parameters and networks of MPAs are necessary. These programs would be pivotal to quantify trends of changes in habitats and species distribution and unequivocally attribute the causes.

Most studies have investigated the individual effects of a number of natural and human disturbances, but processes driving observed changes or those that may influence recovery of marine benthic communities remain untested (Sala et al. 2012). Currently, the methods used to evaluate the effects of climate warming on biodiversity are largely ecological, but it is necessary to look into physiological optima and thermal tolerance limits of species that, combined with genetic capacity of adaptation (genetic capacity variability), influence ecological and adaptive potentials. How potential for acclimatization and genetic adaptation will determine "winners" and "losers" (Somero 2010). Search on thermal tolerance limits and acclimatization capacities of the species will provide insight into potential rates of adaptive responses (adaptive capabilities vs rate of change; external forcing vs internal dynamics).

Genetic studies may allow inferences on past and contemporary temporal variations in effective sizes of the populations and genetic variability. These parameters, associated with ecological studies, are of primary importance to detect when a population is endangered, and to predict the influence of environmental changes on individual species (Lo Brutto et al. 2011). Over long times scales, phylogeography converges with biogeography, and these disciplines together shed light on past dispersal vicariance events and, possibly, may allow predictions of future population expansions or contractions prompted by climate change.

Both range expansion and local adaptation may be responses to climate warming and can often be detected with genetic analysis, which can also be used to test competing hypotheses. Furthermore, addressing the causes and consequences of adaptive genetic differentiation between populations promises to advance community ecology, climate change research, and the effective management of marine ecosystems (Sandford and Kelly 2011).

On the other hand, long-lived organisms can be useful witnesses of long-term changes in Mediterranean ecosystems. Long-lived species have records of short-scale climatic changes within their structures and could provide an insight into the ecosystem responses to changes (Duarte et al. 1999), and hence bridge the gap resulting from the paucity of direct records. Adequate techniques to reconstruct these responses are available, such as the use of growth marks in seagrass shoots, and sclerochronologic and stable isotope records in corals or molluscs. As an example, *Pinna nobilis* have the potential to provide records of changes in the isotopic composition of dissolved organic carbon in the Mediterranean surface waters (García-March et al. 2011). Likewise, vermetid reefs or the scleractinian coral *Cladocora caespitose* have been used as natural archives of past sea-level and surface temperature variations (Silenzi et al. 2004; Montagna et al. 2007; Chemello and Silenzi 2011).

To sum up, a number of research needs and suggestions that might be useful in order to deal as best as possible with the loss of biodiversity in the Mediterranean and its negative effects associated are provided bellow:

- Promote systematic inventories and taxonomy.
- Make existing information available (especially historic records) on the distribution of both warm- and cold-water species at the basin scale.
- Extend marine monitoring efforts: establish long-term, large scale monitoring programs, and an internationally co-ordinated network of monitoring the main hydrological, chemical and biological parameters and a network of MPAs.
- Standardize and simplify methodologies for monitoring.
- Find out the role of rare species in the maintenance of biodiversity and in the functionality and resilience of ecosystems.
- Study thermotolerance features of model species of different groups, and adaptive and acclimatization processes. Extend our knowledge on sensitivities and adaptation capabilities of marine key species to climate change and identify key species as suitable descriptors.
- Obtain more data on the population structure and genetic diversity of selected species (the "gene-climate approach").
- Study relationship between genetic diversity and resistance to warming.
- Examine the resilience (as a measure of resistance and recovery) of long-lived marine structural invertebrate species facing global change, inquiring into the interplays between processes underlying this resilience, such as recruitment, connectivity, genetic diversity and resistance to disturbances.
- Use long-lived organisms as witnesses of long-term changes in Mediterranean ecosystems.
- Not only document declines, but also examine the processes of resistance and recovery.
- Develop multidisciplinary approach, linking functional ecology with invasion biology, population genetics, macrophysiology and hydrology.
- Develop modelling tools and new methodological approaches to answer new and relevant questions in the fields of thermotolerances, supply side ecology (larval supply and source and sink populations), population genetics, and conservation biology.
- Extend our knowledge on the regional factors that determine the vulnerability and resilience of marine communities to climate change.
- Assess the synergies between multiple pressures on marine ecosystems and biodiversity.

Conclusion

We know something about the major impacts that nowadays affect the marine biodiversity of the Mediterranean. We also know something about the effects that individually produce each of these impacts, but we know very little about how the sum of all these impacts act together. However, when asked how will the Mediterranean be affected in the near future, the answer is clear: we address towards a poorer and most vulnerable Mediterranean Sea.

References

Airoldi L, Balata D, Beck MW (2008) The gray zone: relationships between habitats loss and marine diversity and their applications in conservation. J Exp Mar Biol Ecol 366:8–15

Aligizaki K, Katikou P, Nikolaidis G (2009) Toxic benthic dinoflagellates and potential risk in the mediterranean Sea. International Conference on Molluscan Shellfish Safety, Nantes

Attrill MJ, Wright J, Edwards M (2007) Climate-related increases in jellyfish frequency suggest a more gelatinous future for the North Sea. Limnol Oceanogr 52:480–485

Augier H (1982) Inventaire et classification des biocènoses marines benthiques de la Méditerranée. Conseil de l'Europe, Strasbourg

Aumann HH, Ruzmaikon A, Teixeira J (2008) Frequency of severe storms and global warming. Geophys Res Lett 35, L19805

Azzurro E (2008) The advance of thermophilic fishes in the Mediterranean Sea: overview and methodological questions. CIESM workshop monographs 35, Monaco

Balli M, Garrabou J (2007) Thermodependant bacterial pathogens and mass mortalities in temperate benthic communities: a new case of emerging disease linked to climate change. Glob Change Biol 13:2078–2088

Basterretxea G, Garcés E, Jordi A, Masó M, Tintoré J (2005) Breeze conditions as a favoring mechanism of *Alexandrium taylori* blooms at a Mediterranean beach. Estuar Coast Shelf Sci 62:1–12

Bellan-Santini D, Lacaze J-C, Poizat C (1994) Les biocénoses marines et littorales de Méditerranée, synthèse, menaces et perspectives. Muséum National d'Histoire Naturelle, Collection Patrimoines Naturels 19, Paris

Ben Rais Lasram F, Mouillot D (2009) Increasing southern invasion enhances congruence between endemic and exotic the Mediterranean fish fauna. Biol Invasions 11:697–711

Ben Rais Lasram F, Guilhaumon F, Albouy C et al (2010) The Mediterranean Sea as a "cul-de-sac" for endemic fishes facing climate change. Glob Change Biol 16:3233–3245

Bianchi CN (2007) Biodiversity issues for the forthcoming tropical Mediterranean Sea. Hydrobiologia 580:7–21

Bianchi CN, Morri C (1993) Range extension of warm-water species in the northern Mediterranean: evidence for climatic fluctuations? Porcup Newsl 5:156–159

Bianchi CN, Morri C (2000) Marine biodiversity of the Mediterranean Sea: situation, problems and prospects for future research. Mar Pollut Bull 40:367–376

Boero F (1994) Fluctuations and variations in coastal marine environments. Mar Ecol 15:3–25

Boero F (1996) Episodic events: their relevance to ecology and evolution. Mar Ecol 17:237–250

Boero F (2001) Light after the dark: the partnership for enhancing expertise in taxonomy. Trends Ecol Evol 16:266

Boero F, Bonsdorff E (2007) A conceptual framework for marine biodiversity and ecosystem functioning. Mar Ecol 28(supp. 1): 134–145

Boero F, Féral JP, Azzurro E et al (2008) Climate warming and related changes in the Mediterranean marine biota (Executive summary of CIESM workshop 35). CIESM workshop monographs 35, Monaco

Bombace G (2001) Influence of climate changes on stocks, fish species and marine ecosystems in the Mediterranean Sea. Arch Oceanogr Limnol 22:67–72
Bouchet P, Taviani M (1992) The Mediterranean deep-sea fauna: pseudopopulations of Atlantic species? Deep-Sea Res 39:169–184
Boudouresque CF (2004) Marine biodiversity in the Mediterranean: status of species, populations and communities. Sci Rep Port-Cros Natl Park 20:97–146
Boudouresque CF, Bernard G, Pergent G, Shili A, Verlaque M (2009) Regression of Mediterranean seagrasses caused by natural processes and anthropogenic disturbances and stress: a critical review. Bot Mar 52(39):395–418
Briggs JC (1974) Marine zoogeography. McGraw-Hill, New York
Calvo E, Simó R, Coma R et al (2011) Effects of climate change on Mediterranean marine ecosystems: the case of the Catalan Sea. Clim Res 50:1–29
Cebrian E, Uriz MJ, Garrabou J, Ballesteros E (2011) Sponge mass mortalities in a warming Mediterranean Sea: are cyanobacteria-harboring species worse off? PLoS One 6:e20211
Cerrano C, Bavestrello G (2009) Mass mortalities and extinctions. In: Wahl M (ed) Marine hard bottom communities, Ecological studies 206. Springer, Berlin
Cerrano C, Bavestrello G, Bianchi CN et al (2000) A catastrophic mass mortality episode of gorgonians and other organisms in the Ligurian Sea (north-western Mediterranean), summer 1999. Ecol Lett 3:284–293
Chemello R, Silenzi S (2011) Vermetid reefs in the Mediterranean Sea as archives of sea-level and surface temperature changes. Chem Ecol 27:121–127
Chevaldonné P, Lejeusne C (2003) Regional warming-induced species shift in NW Mediterranean marine caves. Ecol Lett 6:371–379
CIESM (2008) Impacts of acidification on biological, chemical and physical systems in the Mediterranean and Black Sea (F Briand edit). CIESM workshop monographs 36, Monaco
Claudet J, Fraschetti S (2010) Human-driven impacts on marine habitats: a regional meta-analysis in the Mediterranean Sea. Biol Conserv 143:2195–2206
Coll M, Lotze HK, Romanuk TN (2008) Structural degradation in Mediterranean Sea food webs: testing ecological hypotheses using stochastic and mass-balance modelling. Ecosystems 11:939–960
Coll M, Piroddi C, Steenbeek J et al (2010) The biodiversity of the Mediterranean Sea: estimates, patterns, and threats. PLoS One 5:e11842
Coma R, Ribes M, Serrano E et al (2009) Global warming-enhanced stratification and mass mortality events in the Mediterranean. Proc Natl Acad Sci USA 106:6176–6181
Coma R, Serrano E, Linares C et al (2011) Sea urchins predation facilitates coral invasion in a marine reserve. PLoS One 6:e22017
Courchamp F, Berec L, Gascoigne J (2008) Allee effects in ecology and conservation. Oxford University Press, Oxford
Crisci C, Bensoussan N, Romano JC, Garrabou J (2011) Temperature anomalies and mortality events in marine communities: insights on factors behind differential mortality impacts in the NW Mediterranean. PLoS One 6:e23814
Daniel B, Piro S, Charbonnel E, Francour P, Letourneur Y (2009) Lessepsian rabbitfish *Siganus luridus* reached the French Mediterranean coasts. Cybium 33:163–164
Danovaro R (2003) Pollution threats in the Mediterranean Sea: an overview. Chem Ecol 19:15–32
Danovaro R, Armeni M, Corinaldesi C, Mei ML (2003) Viruses and marine pollution. Mar Pollut Bull 46:301–304
Danovaro R, Fonda Unami S, Pusceddu A (2009) Climate change and the potential spreading of marine mucilage and microbial pathogens in the Mediterranean Sea. PLoS One 4:e7006
Despalatović M, Grubelić I, Nikolić V et al (2008) Allochthonous warm water species in the benthic communities and ichthyofauna of the eastern part of the Adriatic Sea. CIESM workshop monographs 35, Monaco
Duarte CM, Agustí S, Kennedy H, Vaqué D (1999) The Mediterranean climate as a template for Mediterranean marine ecosystems: the example of the northeast Spain littoral. Prog Oceanogr 44:245–270
Dulćić J, Scordella G, Guidetti P (2008) On the record of the Lessepsian migrant *Fistularia commersonii* (Rüppell, 1835) from the Adriatic Sea. J Appl Ichthyol 24:101–102
Emig C, Geistdoerfer P (2004) The Mediterranean deep-sea fauna: historical evolution, bathymetric variations and geographical changes. Carnets Géol 1:1–10
Faimali M, Giussani V, Piazza V et al (2012) Toxic effects of harmful benthic dinoflegellate *Ostreopsis ovata* on invertebrate and vertebrate marine organisms. Mar Environ Res 76:97–107
Fanelli G, Piraino S, Belmonte G et al (1994) Human predation along Apulian rocky coasts (SE Italy): desertification caused by *Lithophaga lithophaga* (Mollusca) fisheries. Mar Ecol Prog Ser 110:1–8
Ferretti F, Myers RA, Serena F, Lotze HK (2008) Loss of large predatory sharks from the Mediterranean Sea. Conserv Biol 22:952–964
Francour P, Mouine N (2008) First record of *Kyphosus sectator* (Kyphosidae) along the French Mediterranean coast. Cybium 32:275–276
Francour P, Boudouresque CF, Harmelin JG et al (1994) Are the Mediterranean waters becoming warmer? Information from biological indicators. Mar Pollut Bull 28:523–526
Fraschetti S, Terlizzi A, Boero F (2008) How many habitats are there in the sea (and where)? J Exp Mar Biol Ecol 366:309–332
Galil BS (2006) The marine caravan: the Suez Canal and the Erythrean invasion. In: Golash S, Galil BS, Cohen AN (eds) Bridging divides: maritime canals as invasion corridors. Springer, Heidelberg
Galil BS (2007) Loss or gain? Invasive aliens and biodiversity of the Mediterranean Sea. Mar Pollut Bull 55:314–322
Galil BS (2008) Alien species in the Mediterranean Sea: which, when, where, why? Hydrobiologia 606:105–116
Galil BS (2009) Taking stock: inventory of alien species in the Mediterranean Sea. Biol Invasions 11:359–372
Garcés E, Masó M, Vila M, Camp J (2000) HABs events in the Mediterranean Sea: are they increasing? A case study the last decade in the NW Mediterranean and the genus *Alexandrium*. Harmful Algal News 20:1–11
García-March JR, Surge D, Lees JM, Kersting DK (2011) Ecological and water mass properties in the Mediterranean recorded by stable isotope ratios in *Pinna nobilis*. J Geophys Res 116, G02009
García-Rubiés A, Mateo MA, Hereu B et al (2009) Preliminary assessment of the impact of an extreme storm on Catalan Mediterranean benthic communities. 11th Plinius Conference on Mediterranean storms, Barcelona
Garrabou J, Perez T, Sartoretto S, Harmelin JG (2001) Mass mortality event in red coral (*Corallium rubrum*, Cnidaria, Anthozoa, Octocorallia) population in the Provence region (France NW Mediterranean). Mar Ecol Prog Ser 217:263–272
Garrabou J, Coma R, Bensoussan N et al (2009) Mass mortality event in northwestern Mediterranean rocky benthic communities: effects of the 2003 heat wave. Glob Change Biol 15:1090–1103
Giangrande A (2003) Biodiversity, conservation and the 'taxonomic impediment'. Aquat Conserv 13:451–459
Goy J, Morand P, Etienne M (1989) Long-term fluctuations of *Pelagia noctiluca* (Cnidaria, Scyphomedusa) in the western Mediterranean Sea. Prediction by climatic variables. Deep-Sea Res 36:269–279
Guidetti P, Boero F (2001) Occurrence of the Mediterranean parrfish *Sparisoma cretense* (Perciformes: SCaridae) in south-eastern Apulia (south-east Italy). J Mar Biol Assoc UK 82:717–719
Guidetti P, Sala E (2007) Community-wide effects of marine reserves in the Mediterranean Sea. Mar Ecol Prog Ser 335:43–56

Hester KC, Peltzer ET, Kirkwood WJ, Brewer PG (2008) Unanticipated consequences of ocean acidification: a noisier ocean at lower pH. Geophys Res Lett 35, L19601

Innamoranti M, Nuccio C, Massi L et al (2001) Mucilages and climate changes in the Tyrrhenian Sea. Aquat Conserv 11:289–298

Jiménez JA, Sancho-García A, Bosom A et al (2012) Storm-induced damages along the Catalan coast (NW Mediterranean) during the period 1958–2008. Geomorphology 143–144:24–33

Katsanevakis S, Poursanidis D, Yokes MB et al (2011) Twelve years after the first report of the crab *Percnon gibbesi* (H. Milne Edwards, 1853) in the Mediterranean: current distribution and invasion rates. J Biol Res 16:224–236

Kersting DK, García-March JR, Templado J (2006) Evaluation of *Spondylus gaederopus* Linné, 1758, mass mortality event in the Columbretes Islands Marine Reserve (western Mediterranean, Spain). Org Divers Evol 6, Electr Suppl 16, part 1:45

Kružić P (2008) First records of *Cladopsammia rolandi* (Cnidaria: Antozoa) in the Adriatic Sea. Nat Croat 17:9–14

Lejeusne C, Chevaldonné P, Pergent-Martini C et al (2010) Climate change effects on a miniature ocean: the highly diverse, highly impacted Mediterranean Sea. Trends Ecol Evol 25:250–260

Lim GS, Balke M, Meier R (2012) Determining species boundaries in a world full of rarity: singletons, species delimitation methods. Syst Biol 61:165–169

Lo Brutto S, Arculeo M, Grant WS (2011) Climate change and population genetic structure of marine species. Chem Ecol 27:107–119

Lotze HK, Coll M, Magera AM, Ward-Paige C, Airoldi L (2011) Recovery of marine animal populations and ecosystems. Trends Ecol Biol 26:595–605

Maldonado M, Sánchez-Tocino L, Navarro C (2010) Recurrent disease outbreaks in corneous demosponges of the genus *Ircinia*: epidemic incidence and defense mechanisms. Mar Biol 157:1577–1590

Marbà N, Duarte CM (1997) Interannual changes in seagrass (*Posidonia oceanica*) growth and environmental change in the Spanish Mediterranean littoral. Limnol Oceanogr 42:800–810

Marbà N, Duarte CM (2010) Mediterranean warming triggers seagrass (*Posidonia oceanica*) shoot mortality. Glob Change Biol 16:2366–2375

Meinesz A, Mercier D (1983) Sur les fortes mortalités de Spondyles (Spondylus gaederopus Linné) observées sur les cotes de Méditerranée. Trav Sci Parc nation Port-Cros 9:89–95

Metaxatos A, Panagiotopoulos C, Ignatiades L (2003) Monosaccharide and aminoacid composition of mucilage material produced from a mixture of four phytoplanktonic taxa. J Exp Mar Biol Ecol 294:203–217

Mikkelsen PM, Cracraft J (2001) Marine biodiversity and the need for systematic inventories. Bull Mar Sci 69:525–534

Miller RJ (1985) Succession in sea urchin and seaweed abundance in Nova Scotia, Canada. Mar Biol 84:275–286

Mills CE (2001) Jellyfish blooms: are populations increasing globally in response to changing ocean conditions. Hydrobiologia 451:55–68

Montagna P, McCulloch M, Mazzoli C et al (2007) The non-tropical coral *Cladocora caespitosa* as the new climate archive for the Mediterranean: high-resolution (similar to weekly) trace elements systematics. Quat Sci Rev 26:441–462

Navarro L, Ballesteros E, Linares C, Hereu B (2011) Spatial and temporal variability of deep-water algal assemblages in the northwestern Mediterranean: the effects of an exceptional storm. Estuar Coast Shelf Sci 95:52–58

Occhipinti-Ambrogi A (2007) Global change and marine communities: alien species and climate change. Mar Pollut Bull 55:342–352

Pearson TR, Lalli CM (2002) Jellyfish population explosions: revisiting a hypothesis of possible causes. Mer (Paris) 40:111–121

Pérès JM, Picard J (1958) Manuel de bionomie benthique de la mer Méditerranée. Rec Trav Stat Mar Endoume 31:1–137

Perez T, Garrabou J, Sartoretto S et al (2000) Mortalité massive d'invertébrés marins: un événement sans precedent en Méditerranée nord-occidental. C R Acad Sc Paris sésrie III 323:853–865

Perkol-Finkel S, Airoldi L (2010) Loss and recovery potential of marine habitats: an experimental study of factors maintaining resilience in subtidal algal forests at the Adriatic Sea. PLoS One 5:e10791

Philippart CJM, Anadón R, Danovaro R et al (2011) Impact of climate change on European marine ecosystems: observations, expectations and indicators. J Exp Mar Biol Ecol 400:52–69

Piraino S, Fanelli G, Boero F (2002) Variability of species' roles in marine communities: change of paradigms for conservation priorities. Mar Biol 140:1067–1074

Por FD (2009) Tethys returns to the Mediterranean: success and limits of tropical recolonization. Bio Risk Assess 3:5–19

Privitera D, Noli M, Galugi C, Chiantore M (2011) Benthic assemblages and temperature effects on *Paracentrotus lividus* and *Arbacia lixula* larvae and settlement. J Exp Mar Biol Ecol 407:6–11

Pronzato R (1999) Sponge-fishing, disease and farming in the Mediterranean *Sea*. Aquat Conserv 9:485–493

Pronzato R, Marconi R (2008) Mediterranean commercial sponges: over 500 years of natural history and cultural heritage. Mar Ecol-Evol Persp 29:146–166

Puce S, Bavestrello G, Di Camillo CG, Boero F (2009) Long-term changes in hydroid (Cnidaria, Hydrozoa) assemblages: effect of Mediterranean warming? Mar Ecol 30:313–326

Pusceddu A, Fiordelmondo C, Polymenakou P et al (2005) Effects of bottom trawling on the quantity and biochemical composition of organic matter in coastal marine sediments (Thermaikos Gulf, northwestern Aegean Sea). Cont Shelf Res 425:2491–2505

RAC/SPA (2006) Classification of benthic marine habitat types for the Mediterranean region. RAC/SPA, Tunisia

Relini G (2009) *Ocypode cursor* in Sicilia. Not Soc Ital Biol Mar 56:49

Richardson AJ, Bakun A, Hays GC, Gibbons MJ (2009) The jellyfish joyride: causes, consequences and management responses to a more gelatinous future. Trends Ecol Evol 24:312–322

Rosenberg E, Loya Y (1999) *Vibrio shiloi* is the etiological (causative) agent of *Oculina patagonica* bleaching: general implications. Reef Encount 25:8–10

Sabatés A, Martín P, Lloret J, Raya V (2006) Sea warming and fish distribution: the case of the small pelagic fish, *Sardinella aurita*, in the western Mediterranean. Glob Change Biol 12:2209–2219

Sabatés A, Pagés F, Atienza D et al (2010) Planktonic cnidarian distribution and feeding of *Pelagia noctiluca* in the NW Mediterranean Sea. Hydrobiologia 645:153–165

Saenz-Agudelo P, Jones GP, Thorrold SR, Planes S (2011) Connectivity dominates larval replenishment in a coastal reef fish metapopulation. Proc R Soc B 278:2954–2961

Sala E (2004) The past and present topology and structure of Mediterranean subtidal rocky-shore food webs. Ecosystems 7:333–340

Sala E, Knowlton N (2006) Global marine biodiversity trends. Annu Rev Environ Resour 31:93–122

Sala E, Ballesteros E, Dendrinos P et al (2012) The structure of Mediterranean rocky reef ecosystems across environmental and human gradients, and conservation implications. PLoS One 7:e32742

Sandford E, Kelly MW (2011) Local adaptation in marine invertebrates. Annu Rev Mar Sci 3:509–535

Santangelo G, Abbiati M, Giannini F, Cicogna F (1993) Red coral fishing trends in the western Mediterranean Sea. Sci Mar 57:139–143

Silenzi S, Antonioli F, Chemello R (2004) A new marker for sea surface temperature trend during the last centuries in the temperate areas: Vermetid reef. Glob Planet Change 40:105–114

Somero GN (2010) The physiology of climate change: how potential for acclimatation and genetic adaptation will determine "winners" and "losers". J Exp Biol 213:912–920

Southward AJ (1995) The importance of long time-series in understanding the variability of natural systems. Helgol Wissenshafttliche Meeressunters 49:329–333
Taviani M (2002) The Mediterranean benthos from late Miocene up to present: ten million years of dramatic climatic and geologic vicissitudes. Biol Mar Mediterr 9:445–463
Thibaut T, Pinedo S, Torras X, Ballesteros E (2005) Long-term decline of the population of fucales (*Cystoseira* spp. and *Sargassum* spp.) in the Alberes coast (France, north-western Mediterranean). Mar Pollut Bull 50:1472–1489
Thunell RC (1979) Climatic evolution of the Mediterranean Sea during the last 5.0 million years. Sediment Geol 23:67–79
Tudela S (2004) Ecosystem effects of fishing in the Mediterranean: an analysis of the major threats of fishing gear and practices to biodiversity and marine habitats. General Fisheries Commission for the Mediterranean 74, FAO, Rome
Turley CM (1999) The changing Mediterranean Sea: a sensitive ecosystem? Prog Oceanogr 44:387–400
Vermeij GJ (2012) The tropical history and future of the Mediterranean biota and the west African enigma. J Biogeogr 39:31–41
Vezzulli L, Previati M, Pruzzo C et al (2010) *Vibrio* infections triggering mass mortality events in warming Mediterranean Sea. Environ Microbiol 12:2007–2019
Volulsiadou E, Koutsoubas D, Achparaki M (2009) Bivalve mollusc exploitation in Mediterranean coastal communities: an historical approach. J Biol Res – Thessloniki 12:35–45
Zenetos A, Siokou-frangou I, Gotsis-Skretas O (2002) The Mediterranean Sea – blue oxygen-rich, nutrient-poor waters. European Environment Agency, Copenhagen
Zenetos A, Gofas S, Verlaque M et al (2010) Alien species in the Mediterranean Sea by 2010. A contribution to the application of European Union's Marine Strategy Framework Directive (MSFD). Part I. Spatial distribution. Mediterr Mar Sci 11:381–493
Zingone A, Enevoldsen HO (2000) The diversity of harmful algal blooms: a challenge for science and management. Ocean Coast Manag 43:725–748