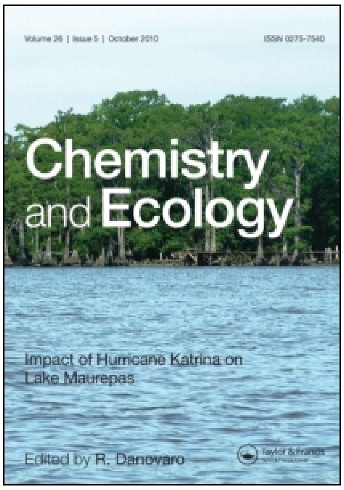

Chemistry and Ecology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455114

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To cite this Article Danovaro, R. and Pusceddu, A.(2007) 'Ecomanagement of biodiversity and ecosystem functioning in the Mediterranean Sea: concerns and strategies', Chemistry and Ecology, 23: 5, 347 — 360
To link to this Article: DOI: 10.1080/02757540701653384
URL: http://dx.doi.org/10.1080/02757540701653384

Chemistry and Ecology
Vol. 23, No. 5, October 2007, 347–360

Ecomanagement of biodiversity and ecosystem functioning in the Mediterranean Sea: concerns and strategies

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(Received 9 July 2007; in final form 20 August 2007)

Marine biodiversity is generally higher in benthic than in pelagic systems, and in coastal than in open sea systems. Sediments are the most human-impacted domain and therefore represent the target zone for both the study and actions needed for the preservation of biodiversity. Losses of marine diversity, higher (or simply more evident) in coastal areas, are generally the result of conflicting uses of coastal habitats. Large difficulties arise from the analysis and evaluation of the actual biodiversity, especially when different environments are compared, as often studies on biodiversity are dependent upon the distribution of the specialists. On the other hand, losses of marine biodiversity might be underestimated, due to the limited knowledge of the ecosystems' functioning, of the species inhabiting various habitats and of the still limited capacity to assess microbial biodiversity, which represents the largest fraction of the global marine biodiversity. Finally, claimed losses of biodiversity might be just apparent, as the sea floor is a bank of resting stages of various plankton species that are likely to spend even decades in the sediment before reactivating and inducing unattended blooms in the water column. The Mediterranean Sea displays high species diversity, but might reach the highest values in terms of adaptive strategies and functional diversity. Moreover, the Mediterranean Sea represents also a key area for the study of the relative influences of the natural and anthropogenic changes on biodiversity and its consequences on ecosystem functioning. Habitat destruction, over-fishing, contaminants, eutrophication, introduction of alien species, and climate changes are producing increasingly evident changes in community structure and biodiversity of this warm and miniature ocean. We summarized the main effects of different disruptive agents on the marine biodiversity of the Mediterranean Sea, with special attention on the biodiversity relevance in ecosystem functioning and possible implications in bio-geochemical cycles. The present overview aims at focusing and synthesizing the most important factors potentially affecting the interactions between biodiversity and ecosystem functioning in the Mediterranean in order to better define possible strategies of conservation and eco-management.

Keywords: Biodiversity; Ecosystem functioning; Disturbance; Resting stages; Life cycles

1. Introduction

1.1 *Census of biodiversity: a challenge for the present and future*

Biodiversity can be considered at different levels, from the taxonomic organization to the community and ecosystem. At the United Nations Conference on Environment and

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Chemistry and Ecology
ISSN 0275-7540 print/ISSN 1029-0370 online
http://www.tandf.co.uk/journals
DOI: 10.1080/02757540701653384

Development held in Rio in 1992, the Convention on Biological Diversity defined the biodiversity as: 'The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species and of ecosystems'. In the Biodiversity Convention, an ecosystem is defined as: 'A dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit'.

The most basic level of biological diversity is that found within a species and is known as genetic diversity, but the most commonly used proxy of diversity is the number of species found in a given area (i.e. species diversity). However, the absolute number of species is not the best descriptor of the actual biodiversity (figure 1). Therefore, in a given area, it has been proposed to also take into account the distribution of individuals among species [1]. Other ways to approach the biodiversity analysis are the phyletic diversity (e.g. Taxonomic Distinctness) [2], the functional diversity (based on the different functional types) and the ecosystem diversity.

In this study, we will refer basically to the concepts of species, functional, and ecosystem diversity. Although there are a number of reviews on global biodiversity [3], the knowledge and synthesis on marine biodiversity is still relatively poor [4–6]. Despite the enormous volume of the pelagic realm when compared with the benthos, only 3500–4500 phytoplankton species have been described. As a result, most marine species diversity is benthic rather than pelagic [7].

The number of species currently described on earth, excluding microbial species, ranges from 1.4 to 1.75 million [3]. In the last two decades, about 6000 new species have been recovered from the deep ocean, but there might be up to 0.5–10 million unrecognised species in the whole ocean [8].

Although there is still considerable controversy about the possible number of unrecognised species, these estimates are incredibly high when compared with the actual knowledge of the described species. Even if the lowest estimate is considered, this figure would modify substantially the picture of known marine species and biodiversity, providing evidence of how much work still has to be done. This must be kept in mind as most analyses on biodiversity changes carried out so far are flawed by a lack of information on the actual number of species present in the environment. Therefore, an evaluation of the biodiversity might be considered a real challenge for the future, but there is still inadequate financial support.

In recent years, disciplines other than taxonomy have received much more attention by the scientific community (largely due to the availability of financial support), and this has precluded the formation of an adequate number of experts in the different taxonomic fields. As

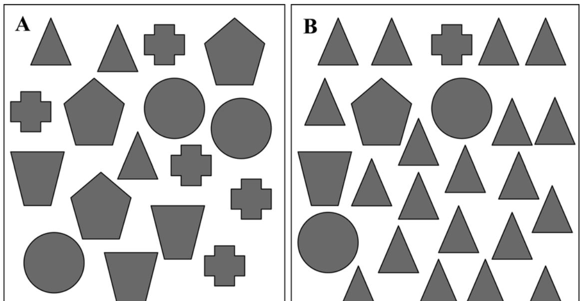

Figure 1. Visual appraisal of the unreliable use of the species number as an universal descriptor of diversity. Each type of polygon represents a species, and each polygon represents an individual. A community (A) composed of the similar numbers of individuals of the different species (polygon types) is visibly more diverse than a community (B) comprising the same number of species but dominated by individuals belonging to one species (triangles).

the number of specialists in the scientific community and the available funding for biodiversity studies are declining, it cannot be excluded that biodiversity will apparently decrease due to the diminished capacity of recognizing different species.

A highly important aspect of marine diversity is endemism. The Mediterranean Sea presents higher levels of endemism for species living in the coastal areas, compared with those living in the deep sea. The Mediterranean basin also displays large seasonal changes in most environmental parameters so that temperate and tropical species might often coexist, predominating during different seasons. Therefore, the peculiarity of the Mediterranean Sea is not only the high species diversity (indeed lower than in tropical areas), but the extremely diverse adaptive strategies determining high levels of functional diversity. Moreover, the well-documented habitat destruction, over-fishing, contaminants, eutrophication, species introduction, and climate changes make the Mediterranean Sea a keystone area for the study of the relative influence of the natural and anthropogenic changes on biodiversity.

In this regard, it should be mentioned that several initiatives have been initiated at the European level since the late 1990s to promote and foster new studies dealing with the census of marine biodiversity of the Mediterranean Sea. Among these, the Census of Marine Life (http://www.coml.org) and the European Network of Excellence MARBEF (Marine Biodiversity and Ecosystem Functioning; http://www.marbef.org) are actively working to provide new insights on and opportunities for the study of the biodiversity and ecosystem functioning relationships of the Mediterranean and other European Seas.

1.2 *Biodiversity, stability, and vulnerability: advantages and disadvantages*

Biodiversity can be considered from different points of view. It is generally accepted that high biodiversity corresponds to a large homeostasis of the system and therefore to an increased stability. High stability generally is interpreted as a feature able to increase the community resistance to any stress or disturbance. However, it has been hypothesized that high diversity might be a synonym for fragility as a community made of many species and including keystone species is more difficult to maintain and expose to disturbance than a community made of few species [9].

Several investigations carried out in aquatic systems (such as kelp beds, microbial microcosms, and marine invertebrate communities), evidenced a positive effect of species richness on community stability, and pointed out that species-rich communities showed a higher community stability under a range of environmental conditions, including stress and disturbance [10–14]. A large number of species are easy to 'disturb' and therefore have little resistance, but it is also likely that a highly diverse community, after disturbance, would display a higher resilience. However, the community resistance (or environmental robustness) is not simply a function of biodiversity. This appears evident in some natural (i.e. non-hypothetical) systems such as the coral reefs that are highly diverse but also fragile systems, and in the seagrass systems of the Mediterranean whose deterioration is constantly increasing because of fishing, tourism, waterfront developments, and shore construction [15].

1.3 *Biodiversity and ecosystem functioning paradigms in marine systems*

In the last decade, the idea that biodiversity can significantly influence ecosystem functioning (i.e. the cycling of energy, nutrients and organic matter that keeps ecosystems working) has attracted a huge number of studies. To date, the results from about 15 yrs of investigations have generated about 50 different hypotheses concerning the ecosystem consequences of biodiversity loss, but also a tremendous controversy on how diversity is related to, or affects,

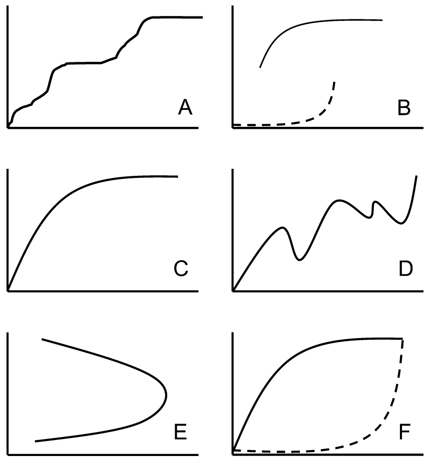

Figure 2. Some of the proposed relationships between biodiversity and ecosystem functioning: (A) rivet-popping [79]; (B) non-linear [80]; (C) redundancy [81, 82]; (D) idiosyncratic [83]; (E) hump-shaped [84]; (F) compensating/keystone [85].

ecosystem functioning [16]. These studies suggested that the loss of biodiversity might have different consequences in different ecosystem types, being able to impair the sustainable functioning of some ecosystems, while having null or idiosyncratic effects in others (figure 2).

There is still no universal consensus on how diversity would control ecosystems' functioning. The relationships between biodiversity and ecosystem functioning, indeed, might depend on several factors, including: (1) the spatial and temporal scales [17, 18], (2) the species role [19], (3) the trophic interactions [20], (4) the proxies and variables utilized for investigating these relationships [21], and (5) the experimental strategies [22].

Marine ecosystems are experiencing impacts of unprecedented intensity and frequency, which are directly and indirectly causing alterations of biodiversity, structure, and organization of marine assemblages. The hypothesis that a loss of biodiversity might threaten an ecosystems' functioning, thus reducing ecosystems' services and value, postulated at the end of the 1990s [23] has recently been demonstrated for marine ecosystems [24].

At a local scale, the loss of marine biodiversity is particularly relevant along the coastal oceans, where mangroves, coral reefs, seagrass beds, and lagoons are progressively impacted [25–27]. Large pelagic predators (i.e. sharks, carangids, and tunas) and their biodiversity are also at high risk due to over-fishing [28, 29].

Although investigations in marine ecosystems are much less developed than in terrestrial ecosystems [30], available studies, mostly based on the analysis of benthic marine diversity [31], have reported an idiosyncratic response of ecosystems' functioning to changes in the species number [32], leading to the hypothesis that the effect of biodiversity loss on marine ecosystem functioning can depend on the ecological role of the species [33–38].

While relative abundance alone is not consistently a good predictor of the ecosystem-level importance of a species, as even relatively rare species (e.g. keystone species) can strongly influence pathways of energy and material flows [39], there is growing evidence that the species' functional characteristics strongly influence ecosystem properties. Functional diversity is a component of biodiversity that generally concerns the range of things that organisms do in communities and ecosystems, and can explain and predict the impact of organisms on ecosystems [19]. For instance, the importance of functional characteristics of the species composing a community is related to the well-known effects of dominant and/or keystone species, ecological engineers, and interactions among species (e.g. competition, facilitation, mutualism, disease, and predation). However, the choice of the functional trait to investigate for a proper analysis of the relationship between functional biodiversity and ecosystem functioning is far from being completely achieved.

Despite the importance of coastal environments, very few investigations have addressed the relationship between biodiversity and ecosystem functioning in marine environments, most of which were coastal systems. Many of these indicated that the effect of any single species on the ecosystem functioning is strongly influenced by the identity and the ecological role of the eventually lost species, and others confirmed the idiosynchratic response of ecosystem functioning to changes in the species number [32]. Most of these studies have been conducted using large organisms (macrofauna) as a proxy of benthic biodiversity [32–40], almost completely neglecting other smaller benthic components such as meiofauna or prokaryotes [41].

2. Patterns of biodiversity in the Mediterranean Sea

2.1 *Coast to deep-sea patterns*

The presence of both soft and hard bottom communities, including fouling, results in an extremely high habitat heterogeneity that has important consequences in the species richness of the coastal Mediterranean areas. This holds true also for plankton assemblages whose biodiversity appears somehow related to the general bottom habitat diversity. In a long-term study (1960–1991) on phytoplankton carried out by Margalef [42], it has been reported that the diversity of coastal plankton assemblages of the Northwestern Mediterranean is very high, even when compared with highly diverse systems such as the Caribbean.

At the same time, the discovery of an astonishing high diversity of small-bodied animals (i.e. meiofauna) in the deep-sea modified completely the previous view of an impoverished deep-sea fauna. The Mediterranean bathyal is generally considered an impoverished area with a species richness and biomass lower than most other deep-sea areas [43]. The diversity of meiofauna is generally high, and the discovery of new species (and even higher taxa or phyla such as the Loricifera) goes on, even in intensively investigated areas such as the Mediterranean. The analysis of the nematode diversity (nematodes are the most abundant and metazoan taxon in all marine sediments) along transects of stations with increasing water depth in the Western Mediterranean indicated the lack of clear depth-related trends [44]. These results suggest that the paradigm stating that the biodiversity is higher in coastal rather than in deep-sea systems might not hold true for the Mediterranean sea, at least when only soft-bottom, assemblages are compared.

2.2 *Longitudinal gradients*

The present deep-sea macrofauna of the Mediterranean is characterized by a very low degree of endemism and low diversity when compared with the fauna of the Northeast Atlantic. The Gibraltar sill, 280 m deep, has historically been regarded as the physical barrier to the potential colonization of the Mediterranean from the richer Atlantic fauna. Most deep-water species have plankto-trophic larvae undergoing vertical ontogenetic migrations to surface layers and are able to cross the Gibraltar sill through surface currents. Some authors have suggested that the larval ecology of individual species is the single most important factor governing the composition of the deep Mediterranean benthos [45]. They also hypothesized that much of this Mediterranean deep-sea fauna consists of reproductively sterile pseudopopulations that are constantly derived through larval inflow. The same model could apply, *mutatis mutandis*, to the deep-sea benthos of other threshold basins such as the Red Sea.

Similar trends have been reported for meiofauna. The Shannon–Wiener diversity (H′) of nematode assemblages in the Atlantic is generally higher than in the western Mediterranean (based on genus level: 5.1–5.7 vs. 4.7–5.2) [44]. The lower diversity of the Mediterranean assemblages is usually explained by the young age (Messinian salinity crisis) and by the presence of a colonization barrier formed by the Gibraltar sill, but also the significantly different environmental conditions in the deep Mediterranean (temperatures $>13\,°C$) might significantly reduce the survival of the introduced species.

An interesting relationship between diversity and productivity has been reported in several environments. Diversity increases with increasing productivity until a threshold value over which increased productivity determines a decline of biodiversity. The general relationship between productivity and species richness is respected in the Mediterranean as longitudinal biodiversity analysis proved the presence of a strong Western-Eastern gradient. The gradient of biodiversity between Western and Eastern Mediterranean is much higher than between the Atlantic and Western Mediterranean. In the Central and Eastern Mediterranean, indeed, the Shannon diversity decreases to about half of that in the Western Mediterranean (Ionian Sea: 2.40–3.46; Cretan Sea: 2.42–3.25). However, more attention should be paid to the distribution of the individuals among species, as the easternmost part of the Mediterranean displays high values of equitability (J: Ionian 0.90, Cretan Sea 0.98 [46]).

3. Threatening biodiversity

The main concerns for environmental changes affecting local and regional biodiversity in the Mediterranean are: habitat destruction, fishing, increasing eutrophication, contaminants and other sources of pollution, the introduction of allochthonous species, and the possible effects of climate changes.

3.1 *Habitat destruction*

Habitat destruction is the most evident process along all Mediterranean coastal areas. The human impact on biodiversity is largely due to the increasing utilization of the shore. This results in a series of factors that modify the characteristics of the environments from different points of view. Besides the introduction of several kinds of contaminants and pollutants (discussed below) the progressive urbanization has determined the increased inputs of nutrients with evident consequences on eutrophication processes. The discharge of large amounts of inert material has modified the reduction in the light penetration with, among others, consequences in the distribution and extent of the Mediterranean seagrass meadows of *Posidonia oceanica*. This seagrass shows the highest polychaetes diversity among Mediterranean coastal soft bottoms [47]. Where these effects are acute, as in the Adriatic Sea, such seagrass meadows have completely disappeared with the consequent impoverishment of the local biodiversity (see below).

Besides urbanization processes, the rapid expansion of aquaculture activities mainly along the Italian and Greek coasts has induced a general concern on the effects on some key parameters potentially affecting benthic biodiversity. Recent studies have recently demonstrated that fish and mussel farming might induce a strong decline of the density and diversity of the meiofaunal assemblages inhabiting the farm-sediments [48, 49]. The creation of such strongly modified sediments implies strong habitat changes in areas (bays, inlets and ponds) generally characterized by large habitat heterogeneity and high diversity.

3.2 *Overfishing*

The increasing fishing activities both along the continental shelves and at bathyal depths are likely to induce considerable environmental changes with important implications also in terms of biodiversity. Among the different and extensively treated consequences on intense fishing activities on the environment, we want to focus here on aspects relatively neglected until recently. Bottom-trawling activities induce a large mortality of a conspicuous number of benthic invertebrates and might induce severe biodiversity and biogeochemical changes [50–54]. Recent studies have clearly demonstrated that such kind of activity determines an increasing dominance of the scavengers that benefit from the large amounts of fresh organic detritus produced during fishing. Therefore, the main consequences are not simply the selective removal of organisms belonging to few target species but also the impact on the trophic diversity (e.g. Heip index), which results in a modified functioning of the benthic assemblages (i.e. affecting the functional diversity) and altered biogeochemical cycles [52].

3.3 *Eutrophication, mucilage, and biodiversity changes in the Adriatic Sea*

The Adriatic Sea is probably the most impacted system of the entire Mediterranean. Increasing organic and nutrient loads have induced, in previous decades, considerable environmental changes with an increasing frequency of appearance of benthic dystrophic conditions. These phenomena, indeed, have been consistently reported since the end of the 1970s. When Italian national legislative policies reduced the input of phosphates introduced in the Adriatic mainly from the Po river outflow, these events, however, did not disappear. Eutrophication of the Adriatic Sea is, in fact, still important, and there is evidence for a progressive modification of the plankton diversity during the last 10 yrs. The analysis of long-term changes in phytoplankton species composition has indicated a strong reduction in dinoflagellates, which normally occur in large densities during summer, that were completely replaced by diatoms and small flagellates (Totti, personal communication). Present studies are trying to evaluate the actual diversity loss of species diversity due to such replacement (that might be just apparent if dinoflagellate cysts are present in the sediments; see below), but it is indubitable that this represents a clear case of modified functional diversity. These changes at the community level are only a part of the actual changes occurring in the northern Adriatic Sea.

Mucilage in the coastal areas of the Adriatic Sea was reported for the first time in 1729 as a ‘dirty sea’ phenomenon causing fishing-net clogging [55], and its frequency of appearance has increased almost exponentially in the last decades. Reports of this phenomenon indicate that its spatial extension and duration are also increasing in parallel with changes in the regional climate conditions and increased pollution levels, so that the economic impact related to the diminished affluence of tourists in areas affected by mucilage and the overall social concern are also of increasing importance [15, 56].

3.4 *Contaminants and various sources of pollution*

Oil spills are still one of the major sources of organic contamination of the marine environment. In the Mediterranean Sea, about $600-800 \times 10^6$ tonnes of hydrocarbons are transported per year (equivalent to about 30% of the world maritime transport of crude oil). Extraction activities contribute further to the release of hydrocarbons at sea, and about 300 000 tonnes of crude oil are dispersed in the Mediterranean every year. However, our knowledge of the actual impact of oil on the structure and functioning of natural ecosystems is far from complete. Benthos is the optimal domain for studying the effects of oil disturbance on the environment, as it has been demonstrated that soft bottoms represent 'retentive systems' able to record biological processes occurring in the entire ecosystem.

Despite the many studies carried out in the past 20 yrs, a general discussion of the effects of oil spills on benthic community structure and functioning is complex because oil impact can vary as a consequence of many factors, including the toxicity of the spilled oil, the time of the year, the degree of exposure of the affected area, the quantity of oil dispersed, the methods used to clean up the oil, and the environmental characteristics (i.e. temperature, salinity, and hydrology) [57]. The interpretation of the field results on the effects of oil pollution is complicated by the limited knowledge on the whole structure of the benthic communities and in most cases to the general lack of information on *pre-pollution* conditions [58]. Danovaro [59] summarized the result of the impact of the major oil spills in the Mediterranean. The case of the *Agip-Abruzzo* and *Haven* oil spills (Ligurian Sea, 1991) has indicated a clear decrease in the benthic diversity with evident effects also on taxa richness. K-dominance curves clearly detected the presence of disturbed faunal assemblage. Some genera, such as *Chromaspirina* (the dominant genus in non-polluted sediments), *Hypodontolaimus*, *Oncholaimellus*, *Paracanthonchus*, *Setosabatieria*, and *Xyala* disappeared immediately after the oil spill [60]. Moreover, pollution impact on the environment is often the result of synergic agents such as other sources of organic loads and heavy metals. Vivier [61] demonstrated that the discharge of aluminium in the canyon of Cassidaigne (NW Mediterranean) led to a clear decrease in the nematode diversity.

3.5 *Introduction of invasive species and susceptibility of the Mediterranean Sea*

The opening of the Suez Canal allowed the connection between the Mediterranean and the Red Sea, with important consequences on merchant activities. Over about 130 yr, Red Sea species migrating through the canal have been colonizing the Mediterranean, but in recent years there has been increasing evidence for profound changes in the indigenous Mediterranean biota. Nearly 300 Lessepsian species have established themselves and form reproducing populations in the Levant basin. Along the Israel coasts, Galil [62] reported cases of zooxanthellate jellyfish blooms of Red Sea provenance (*Rhodopilema nomadica*, reaching densities of 15 ind. m^{-3}). This determined a drastic decrease in the prevalent indigenous species (*Rhizostoma pulmo*), probably as a result of competitive displacement. Similarly, other species such as the penaeid prawn *Penaeus kerathurus*, previously very common, nearly disappeared, and its habitat was overrun by the Lessepsian peaneid prawns. In the Levantine Sea, a less dramatic competition might occur because of the bathymetric adjustment, such as the case of the red mullet *Mullus barbatus* and of the native *Merluccius merluccius*, both displaced into deeper, cooler waters.

The seagrass *Halophyla stipulacea*, another Red Sea endemic species, has permanently colonized large parts of the Sicilian coasts. The alga *Caulerpa taxifolia* represents probably one of the most important concerns for the Mediterranean Sea. This alga has been recently observed, for the first time in the Mediterranean, in the Ligurian Sea in the Cote d'Azur (facing Monte Carlo) as result of a possible non-intentional introduction due to the loss of propagules from the Monaco Aquarium. This fast-growing species is rapidly colonizing large sectors of the Ligurian, Tyrrhenian, and Corse coasts, and has been recently observed also along the Sicily coasts. The main concern due to the distribution of this species is that *Caulerpa* is gradually replacing the *Posidonia oceanica* meadows. This endemic species of seagrass represents one of the most important and fragile systems of the Mediterranean, covering extremely important ecological roles such as coastal protection from erosion, large export of primary organic matter, and nursery ground for a large number of species. The progressive substitution of *Posidonia oceanica* with *Caulerpa taxifolia* determines a modification of the communities associated with the two different systems and a consequent, albeit slight, decrease in benthic diversity [63].

Besides the many examples of Lessepsian migrations, a general worldwide concern deals with the species introduction due to the transport of ballast waters. The most striking example is that of the Chetognat *Mnemiopsis* probably introduced in the Black Sea from tankers coming from the United States. This macroplanktonic predator found in the Black Sea found an empty niche, relying for his nutrition on large available standing stocks of anchovies. The strong predation on this component determined a significant reduction in anchovy predation on mesozooplankton and consequently the lack of a top-down control on phytoplankton blooms with the self-evident consequence of an increased eutrophication and dystrophic phenomena inducing a high mortality [64].

As well as latitudinal range expansions of Lessepsian species correlated with changing temperature conditions, and effects on species richness and the correlated extinction of native species, some invasions may provoke multiple effects which involve overall ecosystem functioning (material flow between trophic groups, primary production, relative extent of organic material decomposition, and extent of benthic–pelagic coupling) [65]. Therefore, more and more effort is needed to assess the state of the marine Mediterranean environment on the light of present and past changes, to predict future changes, and to find and apply eco-sustainable tools for their mitigation or management.

3.6 *Climate changes: from coastal to deep-sea communities*

Recent studies have indicated large-scale climate changes in Mediterranean Sea [66–68] and changing biodiversity in response [69].

The increasing temperature in the western Mediterranean (Ligurian Sea) is modifying the establishment of pseudo-populations previously coming occasionally from the Tyrrhenian Sea as a result of strong winter cooling. Astraldi *et al.* [67] reported that the detection of warm-water (i.e. Tyrrhenian origin) species in the Ligurian Sea has become more frequent and nearly constant in recent years. They hypothesized that the water warming is allowing formerly sterile pseudo-populations to reproduce in the Ligurian Sea, thus ensuring independence from the larval supply by the Tyrrhenian current. This would certainly modify the diversity of the indigenous benthic communities.

Despite an overall tendency towards sea-surface warming, the Eastern Mediterranean has experienced a temperature decrease linked to local climate anomalies. This major event, defined as the Eastern Mediterranean transient, with a decline in temperature of about 0.4 °C down to >1500 m depth, caused a drastic decrease in faunal abundance and a significant change in faunal diversity [70, 71]. Between 1992 and 1994, a temperature shift of 0.3 °C resulted in a reduction of approximately 50% of nematode diversity (and possibly the diversity of other groups). Moreover, the extent of the impact on nematode diversity was directly related to the extent of the temperature shift. Temperature declines also caused a decrease in functional diversity and species evenness, resulting in increased similarity between the nematode fauna of the warm deep-Eastern Mediterranean and the colder deep Atlantic. After 1994, when the temperatures gradually recovered to pre-transient values, the biodiversity began to revert towards more evenness. However, the community composition in 1998 still differed from that observed in 1989 [71].

The different microclimates in the Mediterranean (ranging from climate conditions similar to those of the Northern Sea in the Adriatic to the sub-tropical features of the Eastern sector) would impair the prediction on large spatial scales of climate change effects. However, the results of investigations carried out so far indicate that, overall, the Mediterranean biodiversity assets—including structural and functional attributes—are highly vulnerable to climate change, are significantly affected by very small temperature shifts, and might be irreversible. This worrying scenario might be even worse for deep-sea ecosystems, in which vulnerability to climatic changes may in turn have important implications on the biodiversity and functioning of continental shelf ecosystems.

4. Pelagic–benthic coupling and the forgotten role of life cycles

Most studies on the benthic–pelagic coupling have focused on how energy flow and fluxes of organic matter might influence the production and structure of the benthic communities. The classical scenario depicts the input of organic material from the photic zone fertilizing the sea bed and the consequent benthic nutrient regeneration again supplying the water column to sustain primary production processes. However, previous studies have made clear that individuals of many taxa previously thought to spend their entire life cycle in the water column actually rest in the sea bed for periods ranging from a single adverse season to decades [72] or longer [73]. These benthic resting stages enable the persistence of species, having apparently disappeared, in the system and appear to be important agents of local re-colonization. Therefore, an example of pelagic–benthic coupling is valid not only for benthic assemblages but also for plankton communities which are supplied with what were formerly benthic propagules. Marine canyons at the edges of continental shelves are sites where fine sediments and cysts accumulate from shelf export. If material from canyons can be reintroduced onto continental shelves via upwelling, then canyons might provide a source of recruits for coastal plankton communities. This integrated vision of pelagic–benthic coupling as a 'supply vertical ecology' [74] has opened new perspectives also in terms of biodiversity. In fact, all marine sediments contain extremely high densities of resting stages (densities of copepod resting eggs are typically in the order of 10^6 m^{-2}), and most of these are unidentified. Species considered extinct because they have not been recorded for several years may persist as resting stages [74, 75]. Organisms derived from propagules of different ages allow for genetic flow among different cohorts [72]. Finally, noxious blooms are an increasingly important problem for the management of the coastal systems. They can lead to mass mortalities of both plankton, benthos, and nekton, and some species might produce toxins [76] that are harmful for humans eating fish or shellfish (e.g. ciguatera poisoning). The introduction of predator meiofaunal species to regulate the abundance of propagules of potentially dangerous species could prove effective as a means of biologically controlling the cyst banks of potentially dangerous bloomers [74].

5. Strategies for protecting the Mediterranean Sea: are we up to date?

The high number of coastal endemisms of the Mediterranean poses several problems for development of conservation strategies. There are several questions that need to be answered: Are all species equally important for conservation purposes? Do endemic species play a more important role than other allochthonous species in the structuring and functioning of the marine habitats? Are all biodiversity changes related to the increasing anthropogenic impact?

Strategies for protecting the marine environments should include:

(1) Monitoring of the environmental quality: concentrations of most pollutants are low in the water column, as they tend to accumulate in the sediments. The benthic environment should be regarded as the best domain for monitoring purposes.

(2) Making grey and black lists of chemicals: about 1000 new chemical compounds are produced per year. We do not know enough about their possible effects on the marine environment, but not all compounds have necessarily negative effects.
(3) Utilizing the best available technologies once they have been tested for their eco-sustainability. This would applying expensive tools but also preserving environmental integrity.
(4) Applying precautionary principles: reducing pollution emissions even though there is no scientific evidence of the harmfulness of the contaminant introduced. This might include the reversal of the burden of proofs: one must demonstrate that a substance entering the environment does not produce harm.
(5) Monitoring biodiversity and long-term temporal changes in community structure: estimating not only the apparent but also the potential biodiversity (cyst banks), and paying particular attention to species replacement in relation to functional biodiversity.

The environmental impact assessment (EIA [77]) might represent an important tool for protecting the marine environment as: (1) it provides quantitative estimates of the impact; (2) it identifies a priori the consensus on acceptable effects; (3) remedial actions are decided a priori; (4) it allows continuous feed-back monitoring.

There are a number of present limits dealing with all strategies in use for protecting the marine environment. One is the fact that the adoption of marine protected areas is not a solution whether or not it is included in a larger context of reduced marine pollution. The ability of an environment to recover its previous conditions after exploitation can be assumed to be one of the most important factors when considering the costs of any coastal ocean utilization. To this purpose, also in light of the supply-side ecology theory, the identification and utilization of Large Marine Ecosystems, as areas with a high carrying capacity and stability, is particularly important in most Mediterranean Seas [78].

Acknowledgements

This study was undertaken under the SESAME programme and is part of the EuroCOML and the NoE MARBEF.

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