Research Article

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Marine biodiversity warming vs. biological invasions and overfishing in the Mediterranean Sea: Take care, 'One Train can hide another'

Abstract

Biodiversity means the variety of life, encompassing levels of complexity from within species to across ecosystems. Biodiversity therefore includes several dimensions: evolutionary scale (genetic, species, higher taxonomic levels and phylogenetic diversity), functional scale, organizational scale (patch, ecosystem, landscape/seascape diversity), spatial scale (from sample to local, regional and global richness) and heterogeneity diversity. Biodiversity can therefore be measured in different and complementary ways, thus involving the use of at least 200 different metrics, which can suggest different and contrasting conclusions. It is worth emphasizing that species richness may be the least appropriate metric, despite its popular acceptance. There is a growing tendency for stakeholders, managers, government officials, environmentalists, scientists, politicians and the media to focus, as concerns threats to biodiversity, on species richness and climate change. However, focusing on climate warming can mask other stressors that, today, and perhaps for decades to come, may have more impact on ecosystems than global warming. In the Mediterranean Sea, the overall impact of Non-Indigenous Species (NISs) and overfishing on species diversity, ecosystem diversity and ecosystem functioning exceeds to a greater or lesser degree the direct impact of warming. Drastically altered functioning patterns, and even new ecosystems are spreading throughout the Mediterranean Sea. This trend is likely to become more pronounced over the next decades. Ecosystem goods and services are also being profoundly altered, generally towards a decline, as illustrated by the overgrazed barren grounds of the eastern basin, which no longer support fisheries, by the impact of the *Caulerpa* meadows on the scuba diving business and the economic value of the fisheries of the western basin, by the brackish lagoon ecosystems and by the blooms of the introduced comb jelly *Mnemiopsis leidyi* in the Black Sea, before the arrival of its predator *Beroe ovata*. Here, we draw attention to the fact that, at this moment and probably also in the future, the huge flow of NISs and overfishing constitute worrying issues, although largely ignored by stakeholders and political authorities. Take care: Un train peut en cacher un autre (one train can hide another; i.e. one danger may hide other unsuspected dangers), that is to say the impact of warming may contribute to hiding other effects, of at least equal gravity, such as biological invasions and overfishing.

Keywords: biodiversity, biological invasions, global warming, mediterranean sea, overfishing, stakeholders

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Introduction

Global change is often considered erroneously as a nomenclatural equivalent to global warming. In fact, it refers to the interactions between natural changes in the Earth's physical and biological structure and the broader effects of human activities. Therefore, global change has natural and anthropogenic components. Global change encompasses biological invasions, modifications in biological diversity (species, ecosystems, etc.), ecosystem functioning, biogeochemical cycles, pollution, changes in land use and land cover, in addition to changes in climate and the distribution pattern of climatic zones, most of these parameters being in interaction (Figure 1 Board of Environmental Studies and Toxicology, 2000).[1,191] Biodiversity is too often considered as a nomenclature equivalent to species richness, which actually represents a rather limited part of the species diversity concept, itself a relatively small part of the biodiversity concept.[2] In fact, biodiversity is a multidimensional concept, involving the use of hundreds of metrics. Species richness is perhaps the least appropriate metric to choose for describing biodiversity, while it is too often favoured by managers, the political authorities and even by some scientists unfamiliar with the concepts of modern ecology (see below). Here, we attempt to show that global warming, both natural and human-driven through the increase in greenhouse gas emissions, although favoured as a research focus by some scientists (seeking funding?), could in fact represent a limited part of the expected global change, at least in the Mediterranean Sea.

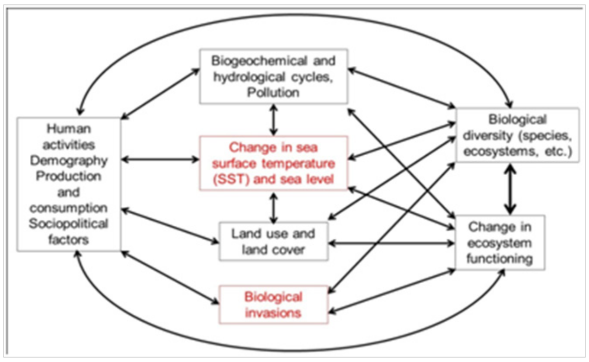

Figure 1 Conceptual model of global change due to human activities. From Board on Environmental Studies and Toxicology (2000) and Verlaque and Boudouresque (2004), modified, updated and redrawn.

The modern concept of biodiversity

'Biodiversity' is today a term that has gained popular currency, widely used not only by scientists, but also by political leaders, government officials, conservationists, environmentalists ('greens') and the public at large. Although scientists have long defended the need for the adoption of the biodiversity concept by end-users, as an essential good for human societies, it is not yet accepted that it actually encompasses a wide spectrum of concepts, sometimes worlds away from its popular definition.[2] The term 'biological diversity' was first used by Dasmann.[3] Thomas Lovejoy, in the foreword to the book 'Conservation Biology' (Soulé and Wilcox, 1980 [214]), introduced the term to the scientific community. The term's contracted form, 'biodiversity', was coined by Wilson[4] in the proceedings of the National Forum on Biological Diversity. It gained in popularity after the 'United Nations Conference on Environment and Development' (UNCED), also known as the Rio Summit, Rio Conference and Earth Summit, held in Rio de Janeiro (Brazil) from June 3 to 14, 1992.[5] Since then, both the term and the concept of biodiversity have achieved widespread use among biologists, conservationists, political leaders and the general public. The term is often used to reflect a concern for the natural environment, nature conservation and species extinctions. In the course of their more than 40-year lifespan, the meaning of the terms 'biological diversity' and 'biodiversity' has greatly evolved. The way their meaning has shifted in the environmentalist's jargon is quite different from changes of meaning within the scientific community. As a result, misunderstandings between environmentalists and scientists are all too frequent. Misunderstanding also occurs within the scientific community, between those who refer to biodiversity as it was originally defined and those who refer to it under its current definition, or one of its current definitions, or more exactly the suite of concepts they cover. Biodiversity means the variety of life, encompassing levels of complexity from within species to across ecosystems. For taxonomy concepts, see Boudouresque[193] and Boudouresque et al.[7] Biodiversity therefore includes several dimensions (Figure 2).[5]

Evolutionary scale, i.e. diversity within species (genetic diversity), diversity between species, diversity between taxa higher than species (genera, families, orders, classes, phyla, kingdoms, etc.) and phylogenetic diversity (mean phylogenetic distance between taxa; Faith[9]).

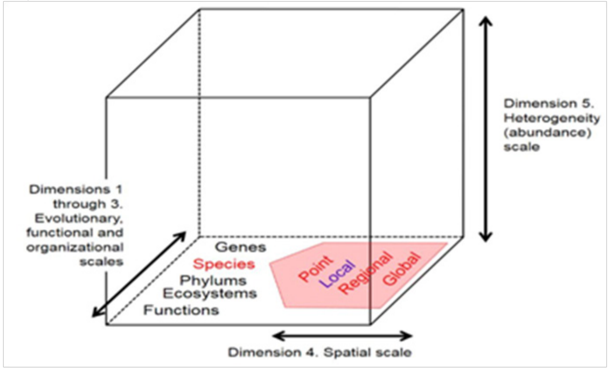

Figure 2 Biodiversity is a multidimensional concept. Dimensions 1 through 3: from genes to ecosystems, landscapes/seascapes and functions. Within each evolutionary, functional and organizational level (e.g. species), dimension 4 (spatial scale), from point to global. Within each spatial level (e.g. local), dimension 5 (proportional distribution), from e.g. very rare to dominant. From Boudouresque, 2014 (modified).

Functional scale, i.e. diversity in the functional role of species, functional groups and guilds within ecosystems, e.g. photosynthetic or chemosynthetic primary producers, diazotrophic species, filter-feeders, suspension-feeders.

Organizational scale, i.e. diversity between patches, communities, ecosystems, landscapes/seascapes, including beta-diversity.[10,2]

Spatial scale, from local and regional to global.[10–12] As far as the species diversity is concerned (evolutionary scale), it can be considered at the scale of a sample (point diversity), of an ecosystem within a region (alpha-diversity), of all the ecosystems of a region (gamma-diversity) and of all the ecosystems of a large biogeographic province (epsilon-diversity). The spatial (geographic) scale matters a great deal for biodiversity estimates Boudouresque.[2,13–15]

In addition, biodiversity includes the proportional distribution of the individuals among the species, the so-called heterogeneity diversity, abundance diversity or evenness.[12]

The concept of biodiversity integrates not a single but a multitude of meanings: it is par excellence a multidimensional concept. The choice with regard to the meaning (qualitative or quantitative, compositional or functional, scale, etc.) depends primarily on one's goals and interests. Biodiversity can therefore be measured in different and complementary ways and thus involves the use of at least 200 different metrics (Sala and Knowlton, 2006; Boudouresque, 2014). This complexity of meanings, scale and units makes it impossible to assess the state of biodiversity using a single measure.

Species diversity (= species richness) means the taxonomic diversity at the level of the species (generally sensu the Linnaean system of classification), i.e. the number of species at a given scale of space (sample, habitat, ecosystem, landscape/seascape, region, Earth). Species diversity squares with the most popular perception of the concept of biodiversity.[21] Most studies dealing with biodiversity report this simple measure of biodiversity. Although species diversity may be relevant (as long as the spatial scale is provided) for comparisons between ecosystems, or within ecosystems over time, and therefore represent a prerequisite, it may not constitute a good measure of the structure, function and degree of disturbance of the ecosystems. Moreover, different measures can suggest different and/or contrasting conclusions[15,10,2] A naïve approach to the biodiversity concept could lead to regarding such conclusions as diametrically opposed. It is worth emphasizing that species richness maybe the least appropriate metric, despite its popular acceptance, often inducing bias in ecological reasoning, within global change science. Obviously, the taxonomic knowledge (including the species level) is of paramount importance in biodiversity studies and cannot be omitted; however, this cannot justify the kind of 'species richness dictatorship' found in most biodiversity studies.

The Mediterranean: a biodiversity hotspot

The Mediterranean Sea is a hotspot of marine epsilon species diversity; it harbours at least 17 000 taxa.[16,17,2,18,198] While it represents only 0.3 and 0.8 % of the volume and the surface area of the world ocean, respectively, it harbours 6.4 % of the world marine taxa, with species diversity of sponges (Porifera; kingdom Opisthokonta) and brown algae (Phaeophyceae; kingdom Stramenopiles) of up to 10 % and 17 % of the known species worldwide, respectively[19,26,194,198] The Mediterranean is one of the few regions harbouring a species diversity hotspot in both the marine and continental realms.[18,23–25] Why are there so many species in the Mediterranean Sea? According to Lejeusne et al.,[26] a first reason is its tormented geological history, which has led to high rates of environmental changes with successive extinctions, re-colonisations and speciation. A second reason is the

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wide range of climatic and hydrological situations which can be found in this sea, resulting in the co-occurrence of cold, temperate and subtropical biota. Finally, the rate of endemism is relatively high in the Mediterranean Sea, reaching at least 25 % of the whole biota. The sea has been considered as a factory designed to produce endemics. During the Pleistocene climatic glacial cycles, North-Atlantic species periodically shifted their latitudinal ranges, allowing populations to enter the Mediterranean via the Strait of Gibraltar. Once within this new environment, populations were subject to higher evolutionary pressures, in relation with wide variations in sea level, temperature and salinity. In addition, the Alboran basin, to the east of Gibraltar, might act as a buffer reducing gene flow, and highly compartmentalised coasts (total length 46 000 km) further increase isolation between already isolated sectors.[26,192] As pointed out by Bianchi,[189] the Mediterranean functions as a 'diversity pump' from the Atlantic Ocean. Moreover, the presence of paleo-endemic species (e.g. the sea grass *Posidonia oceanica*) attests that the region also acted as a refuge for Tethyan relicts.[27,28,205] The Mediterranean Sea also harbours a wide range of ecosystems, some of them being unique, in terms of their structure and functioning,[20,26,5] such as the mediolittoral *Lithophyllum byssoides* rims,[29–32] the shallow vermetid platforms,[30,31] the *Posidonia oceanica* sea grass meadow,[8,33] the *Cystoseira* seaweed forest,[29,34–40] the coralligenous assemblages[30,31,41,42,101,188] and the dark submarine caves.[43–45]

The Mediterranean: a hotspot of biological invasions

The Mediterranean is the area that is worldwide the most severely hit by biological invasions, with ~1000 Non-Indigenous Species (NIS) recorded so far.[46–49,200,211] This is in contradiction (at least within the marine realm) with the old paradigm of Elton (1958),[80] who claimed that species diversity was a factor of resistance to invasions.[80] In fact, in the marine realm, it frequently occurs that the higher the species richness is, the more vulnerable the habitat; this may concern point diversity, alpha diversity, gamma diversity and/or epsilon diversity; the reason partly lies in the fact that species-rich habitats are favourable for the life of organisms, regardless of their native or exotic status[52–54] (see Fridley et al.,[55] for the 'invasion paradox'). What matters is also the presence of a vector[80] such as the Suez Canal[22,56,61] and aquaculture facilities.[58,59]

The main vector of introduction of new species into the Mediterranean Sea is the Suez Canal, which was opened in 1869 and connects the Red Sea and the Eastern Mediterranean Basin. Since then, it has been enlarged and deepened several times, the last such operation having been conducted in 2015.[133,201] The flow of tropical Red Sea species entering the Mediterranean, the so-called Lessepsian species, was first concentrated within the Levantine Basin, but these species have been steadily spreading westwards and northwards[22,26,56,61,62] The second most important vector is shellfish farming (reared species escaping from the farms and species accompanying shellfish transfers), with warm and cold areas of the North Pacific Ocean as donor regions.[59,63,65,196,212] Other vectors include fouling and clinging on ship hulls, ballast waters, aquarium trade, fishing baits and waterways crossing watersheds.[67–70,72–74,199,213]

Invisibility relies first upon the occurrence of a vector, and then on the propagule pressure.[76–80] The invasion success also depends on a number of factors,[80] such as the release from enemies (ERH, Enemy Release Hypothesis; Ivanov et al.,[204] MacLeold et al.,[206], the availability of unused resources, a community becoming more susceptible to invasion whenever there is an increase in the amount of unused resources, because there is either more resource supply or less resource uptake (FRAT, Fluctuation in Resource Availability Theory[81,82]), reallocation of resources from chemical defence towards growth and reproduction, made possible through the release from enemies (EICA, Evolution of Increased Competitive Ability;[83,84]), the possession of toxic biochemical compounds ('allelochemical weapons') unknown to native species in the recipient area (NWH, Novel Weapon Hypothesis;[71,85,86]) and the naïveté of native species, which do not recognize as an enemy the introduced predator and hence do not escape.[87] In contrast, warming is not a direct factor favouring habitat/ecosystem invisibility or species invasiveness;[212] but see[88]. Warming can advantage thermophilic introduced species; however, at the same time, it can disadvantage cold water introduced species. The overall amount of new introduced species and the dominance of introduced species might therefore be unchanged. The alleged 'aggressiveness' of tropical introduced species, such as *Caulerpa taxifolia* and *C. cylindracea* (Chlorobionta; kingdom Archaeplastida) in the Mediterranean Sea, is due to the fact that they have been considered as of tropical origin,[89] while they are actually from temperate seas.[90,26,210] Their success in the Mediterranean, a mostly temperate sea, is therefore in no way unexpected. Some of the most invasive species, such as *Caulerpa* spp., *Sargassum muticum* (Phaeophyceae, kingdom Stramenopiles) and the comb jelly *Mnemiopsis leidyi* (ctenophores, Metazoa, kingdom Opisthokonta), are not of tropical origin, but of temperate or even of cold water origin. This highlights the leading role of vectors that by far outweighs that of warming.[80]

The overwhelming impact of biological invasions on Mediterranean species and ecosystems

NISs can be non-established (no sexual or asexual reproduction in the wild), casual (non-lasting reproduction), introduced (i.e. established, naturalized; reproduction in the wild without human assistance), invasive (high impact on native species and on the ecosystem functioning, and/or an economic impact, and/or an impact on human health) or transformers (ecosystem engineer of a new ecosystem)[47,60,80,91,92] Macrophyte NISs are widespread in the Mediterranean ecosystems of the infralittoral and circalittoral zones[93] from sea level down to 30-40m depth and from 30-40 m depth down to the lower limit of photosynthetic organisms, respectively. Disturbance regimes do not matter: NIS prevalence, NIS species richness and NIS cover and biomass generally do not differ between disturbed and pristine areas, such as Marine Protected Areas (MPAs)[53,80,94,195] but see.[95] This contradicts the old paradigm of Elton,[50] who claimed that disturbances enhance ecosystem invasibility. Undisturbed Mediterranean benthic ecosystems are characterized by a low level of herbivory; the sea urchin *Paracentrotus lividus* and the teleost *Sarpa salpa* are the most conspicuous macro-herbivores.[96,39,97–99] As a result, the food web is driven by the detritus-feeders rather than by the herbivores. In addition, most Mediterranean Multicellular Photosynthetic Organisms (MPOs) have not developed chemical defences against herbivores (Figure 3).[8,33,100,103]

In the north-western Mediterranean, the dramatic arrival of strongly defended and poorly palatable invasive species, such as *Caulerpa taxifolia* (Chlorobionta), *Asparagopsis armata, Lophocladia lallemandii* and *Womersleyella setacea* (Rhodobionta; kingdom Archaeplastida), has profoundly changed the functioning of the ecosystems, with a further decrease of the flow running through the herbivores being expected (Figure 4).[71,86,100,104–107] In contrast, in the eastern Mediterranean, the arrival of voracious herbivorous teleosts (*Siganus luridus* and *S. rivulatus*) from the Red Sea, via the Suez Canal, has strongly intensified the herbivore pressure (Figure 5).[100,

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[107–111,202] The recent arrival in the Levantine Basin of the voracious sea urchin, *Diadema setosum*, will further enhance the herbivore compartment.[57,112] This has resulted in an impressive regime shift, from ecosystems dominated by canopy-forming primary producers and under bottom-up control, such as *Cystoseira* spp. and *Sargassum* spp. (Phaeophyceae; kingdom Stramenopiles), to an Alternative Stable State (ASS) dominated by encrusting calcified corallines (Rhodobionta) and sometimes characterized also by sea urchin overgrazing, called 'barren ground', with top-down control.[113,96,40,114] Finally, in coastal lagoons harbouring shellfish farm facilities, on natural and artificial hard substrates, the dominance (species richness, cover, biomass) of MPOs introduced from the cold-temperate northern Pacific Ocean is overwhelming. In Thau Lagoon (Southern France), they represent 32% of the gamma species diversity, 97-99% and 48-95% of the spring and autumn biomass, respectively, and 100% of the cover (Figures 6) (Figure 7). Similar observations have been reported in other Mediterranean lagoons, e.g. the Venice Lagoon (northern Adriatic Sea, Italy).[115–117]

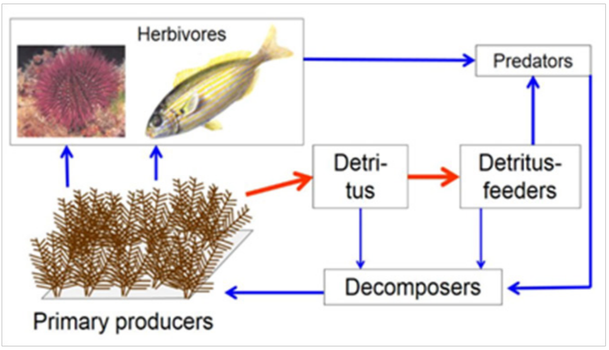

Figure 3 A simplified sketch of food-webs in undisturbed Mediterranean marine benthic ecosystems. Here, a *Cystoseira* forest. Herbivores are the sea urchin *Paracentrotus lividus* and the teleost *Sarpa salpa*. The intensity of the flow is proportional to the width of the arrow between functional compartments (in red, the main path). From Boudouresque et al. (2005) and Boudouresque (2015b), modified.

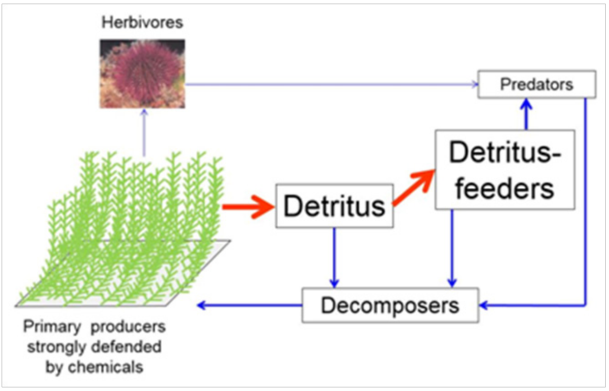

Figure 4 A simplified sketch of a food-web in a Mediterranean benthic ecosystem, in the presence of non-palatable primary producers, here Caulerpa taxifolia. The possible increase in the DOC (Dissolved Organic Carbon) release towards the pelagic ecosystem is not considered here. The herbivore is Paracentrotus lividus. The intensity of the flow is proportional to the width of the arrow between functional compartments (in red, the main path). From Boudouresque et al. (2005) and Boudouresque (2015b), modified.

At Kos Island (Greece, eastern Mediterranean), Bianchi et al.[118] compared benthic data collected in 1981 and in 2013, by the same persons with the same method. During this 30+ year period, increases in Sea Surface Temperature (SST, +1-2°C), human pressure (resorts and hotels, 15 to 163 beds/km²), and NISs (e.g. rabbitfish *Siganus rivulatus* and *S. luridus*) were observed. Huge changes occurred in rocky reef habitats; the once flourishing *Cystoseira* and *Sargassum* forests have disappeared in favour of sponges and wide bare substratum areas (Figure 8).

These changes can be seen as a synergistic action between biological invasions, SST warming and human impacts. More realistically, they evidence the supremacy of NISs (especially overgrazing rabbitfish), over the other stressors, including warming. Open ocean and coastal lagoon pelagic ecosystems are also widely impacted by NISs. The textbook case is the introduction in 1982 of one of the top 100 worst invasive species, according to IUCN, the ctenophore *Mnemiopsis leidyi* in the Black Sea through ballast waters. The introduction of this strong predator, native to the Gulf of Mexico,[119,120] coincided with the collapse of local fisheries. Whether the introduction of this ctenophore is the reason for the collapse or just a collateral event that made things worse is still not clear. Nevertheless, the intentional introduction in 1997 of *Beroe ovata* (ctenophore), which feeds almost exclusively on *M. leidyi* in its native habitat, resulted in impressive changes in the pelagic ecosystem.[121–126] *M. leidyi* has been spreading through the Mediterranean Sea, possibly following currents, but other vectors must also be involved, especially in the case of coastal lagoons with very little connection with the patterns of circulation of main currents (Jasper et al., unpublished data). High abundance in some coastal lagoons, such as the Berre, Bages-Sigean, Salses-Leucate and Biguglia lagoons along the French coasts, have been observed for ~10years.[127,128]

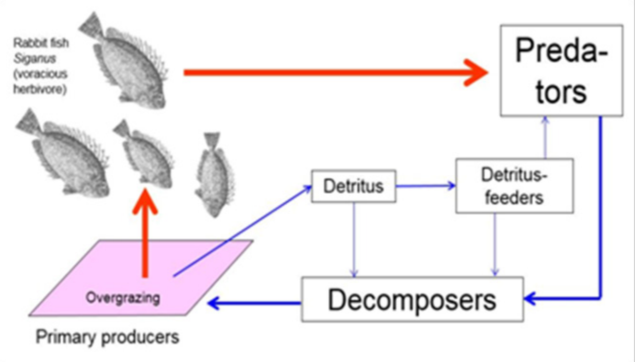

Figure 5 A simplified sketch of a food-web in a Mediterranean benthic ecosystem, in the presence of herbivorous fish of the genus *Siganus* (eastern Mediterranean), here, a barren-ground. The intensity of the flow is proportional to the width of the arrow between functional compartments. In red, the main path. From Boudouresque et al. (2005) and Boudouresque (2015b), modified.

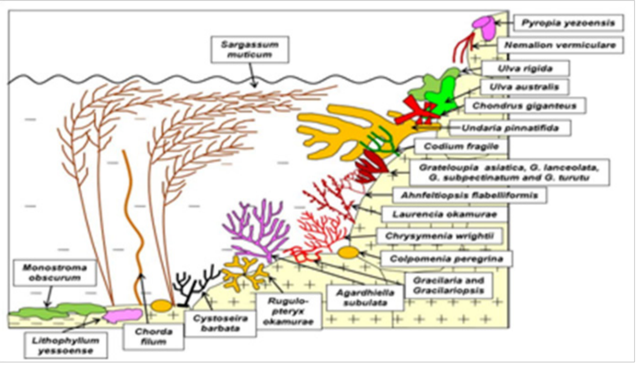

Figure 6 A sketch of the dominant MPOs on shallow (down to 1 m depth) rocky substrates of the Thau Lagoon (southern France) in spring. Most of these taxa are native to Japan, Korea and the northwestern Pacific Ocean (see Figure 7). From Boudouresque et al., 2011, modified.

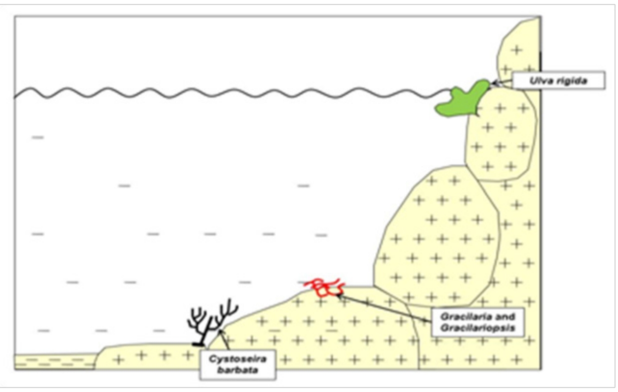

Figure 7 The same sketch as that of figure 6, after the removal of the species native to the northwestern Pacific Ocean. The only native taxa are *Cystoseira barbata*, *Gracilaria* sp. and *Gracilariopsis* sp. *Ulva rigida* is probably a cryptogenic species (sensu Carlton, 1996). Drawn from data in Boudouresque et al. (2011).

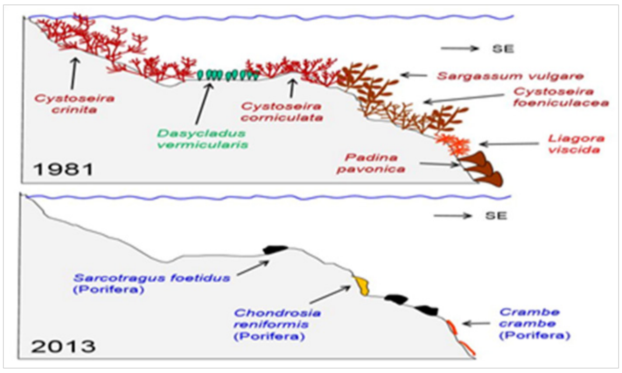

Figure 8 Schematic profile of a reef slope down to about 7 m depth at Kos Island (Greece), illustrating the impressive change between 1981 (top) and 2003 (bottom). Brown algae (Phaeophyceae) are in brown and red-brown, green algae (Chlorobionta) are in green, red algae (Rhodobionta) in red and sponges (Porifera, Metazoa) in blue. From Bianchi et al. (2014), redrawn.

The Levantine Basin has hosted first the Lessepsian species, among which several conspicuous jellyfish *Rhopilema nomadica, Phyllorhiza punctata* and *Cassiopea andromeda* have been reported. Most large jellyfish are well known for feeding upon eggs and larvae of fish and crustaceans, but also for interacting strongly with human activities such as clogging fishing nets, damaging boat and power plant intakes and fishing gear and causing the closure of productive areas to fishing activities. *Rhopilema nomadica*, native to the Red Sea, has a bell diameter of up to 90 cm and can constitute dense rafts of up to dozen kilometres in length, drifting with the alongshore currents.[129–133] The jellyfish is spreading autochthonically as current-borne adults, reaching Maltese waters in 2004,[134] and then the Tunisian coasts in 2008,[132] where the species has established a reproducing population. *Phyllorhiza punctata*, another pelagic species known previously only from Australia, the Philippines and Japan entered the Mediterranean Sea either through the Gibraltar strait or the Suez Canal via vessels, and most likely as sessile polyp stages attached to ship hulls or drilling rigs.[135] *Cassiopea andromeda* is an atypical jellyfish, living upside down on the seafloor in shallow waters, and dispersion is mainly done through juvenile stages (ephyrae), so of limited extension within the oriental basin, even more so in the western basin. But it was observed in Turkey in 2000,[136] and then in 2010 further west in the central Mediterranean, around the Maltese Islands.[137] It is suggested therefore that the most likely vector responsible for transporting this species is shipping (ballast waters, hull-fouling).[135,138]

The impact of overfishing

Overfishing is ubiquitous in the Mediterranean Sea, as in most of the world ocean.[139–141] Both benthic and pelagic ecosystems are concerned. Some fishing techniques, such as artisanal fishing gear, target specific prey (see e.g. Leleu et al.[142]), while others, such as trawling, capture non-targeted species and have a stong mechanical impact upon benthic ecosystems.[143–146] Due to overfishing, most benthic ecosystems are strongly depleted in teleosts (fish), especially in invertivores (consumers of invertebrates) and top predator fish, with a dramatic decrease in mean size and in number of individuals.[64,147–149] Only a very few Marine Protected Areas (MPAs), such as the Port-Cros National Park (Provence, France), the Stait of Bunifaziu Natural Reserve, the Scandula Natural Reserve (Corsica) and the Cabrera National Park (Balearic Islands), are free of this impact.[40,149,150] As a result, there is often an increase in the pressure of herbivorous species, such as the sea urchin *Paracentrotus lividus* and the teleost *Sarpa salpa*, which are released from predation by top predators[96,151] (but see[152]). This results in overgrazing, the decline or the collapse of marine forests (*Cystoseira* spp. and *Sargassum* spp.) and the phase shift to 'barren grounds' dominated by encrusting corallines (red algae, Rhodobionta), turf MPOs and sea urchins (*Paracentrotus lividus*, *Arbacia lixula*) (Figure 9). These barren grounds constitute an Alternative Stable State (ASS) of the previous forest state; even a small number of sea urchins, where the overfishing of their predators is reduced, can prevent the shift back towards the forest state[153–155] The effects of other fishing techniques, such as uprooting by fishing nets, can also contribute to the extirpation of *Cystoseira* spp. and *Sargassum* spp.[66] Barren grounds nowadays occupy extensive, ever-increasing surface areas of infralittoral Mediterranean benthic habitats.[156]

Figure 9 A barren ground dominated by sea urchins, encrusting corallines and turf MPOs. 5-6 m depth, Bay of Kotor, Montenegro. Photo © Thierry Thibaut.

The formerly canopy-forming species, *Cystoseira* spp. and *Sargassum* spp., are locally or functionally extinct in many Mediterranean regions.[34,102,157] This is particularly worrying if one considers that these long-lived (perhaps more than one century) species grow slowly and often disseminate at only very short distances, so that recolonization of lost habitats may be unlikely at the human timescale.

In pelagic ecosystems, the proliferation of gelatinous planktonic organisms drives a regime shift from ecosystems dominated by top predators to ecosystems dominated by jellyfish[158–160] (but see[161]). The collapse of shark species, in the Mediterranean Sea, is particularly conspicuous; some species, such as hammerhead (*Sphyrna* spp.), blue (*Prionace glauca*), thresher (*Alopia vulpinus*) and shortfin mako sharks (*Isurus oxyrhinchus*) have declined by between 96 and 99.99 % since the late 19th century or the mid-20th century (Ferretti et al., 2008).[148]

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The direct impact of the sea surface temperature warming

The warming of the Mediterranean Sea (SST) began at the end of the Last Glacial Maximum (LGM), ~20 ka ago. The mean annual SST was then between 8˚C and 2˚C lower than today, in the north western and the eastern basins, respectively.[162] Fucoids (Phaeophyceae; kingdom Stramenopiles) currently restricted to the North Atlantic Ocean, e.g. *Fucus vesiculosus*, were probably present in the NW Mediterranean Sea and in the Adriatic Sea, not only during the LGM, but must have remained until 6000years ago.[163] The distribution of species and ecosystems 20ka ago was probably radically different from today, although this is partly speculative. The post-LGM natural reorganization of the Mediterranean biota could be still incomplete, as calcified remains of the thermophilic scleractinian *Astroides calycularis*, dating back to previous interglacial periods, have been discovered far north of their current distribution range.[89] The current warming of the Mediterranean Sea water triggers the northwards and eastwards range extension of warm water native species, such as the teleosts *Coryphaena hippurus, Sardinella aurita, Sparisoma cretense, Sphyrena sphyrena and Thalassoma pavo*, the sea urchin *Arbacia lixula,* the molluscs *Erosaria spurca, Luria lurida* and *Stramonita haemastoma*, the seagrass *Cymodocea nodosa* and the Chlorobionta *Caulerpa prolifera.*[26,89,164–167] and unpublished data]. This trend should become more pronounced by the end of the 21st century [168,169]. Cold water native species, such as the teleost *Sprattus sprattus sprattus,* the echinoderm *Marthasterias glacialis,* the seagrass *Zostera marina*, the Rhodobionta *Calliblepharis jubata* and *Gymnogongrus crenulatus* and the Phaeophyceae *Fucus virsoides*, which are trapped in the northern Mediterranean, and cannot escape via the northwards shift of their range area, could therefore be threatened with local extinction. Recurrent mass mortality events among sponges, gorgonians (cnidarians) and other sessile metazoa, during high temperature anomalies, have dramatically illustrated this issue.[26,170–177,209] Possible effects of the increase in temperature and/or pCO_2 on a Rhodobionta which plays a role in the coralliferous bioconstructions, *Lithophyllum cabiochae*, have been suggested by Martin and Gattuso.[207]

In contrast to the above mentioned examples, the direct impact of the warming on habitat-forming MPOs could be weaker. Parravicini et al.[178] show that the increase in temperature may be more complex than the simple prediction of species modifying their distribution range according to their thermal limit, near their boundary, with even a decrease in their cover on shallow rocky reefs. The worrying regression of *Cystoseira* and *Sargassum* forests, with several species locally and/or functionally extinct, seems to be related to overfishing (resulting in overgrazing by herbivores; see above), uprooting by fishing nets and coastal development, in addition to invasive NISs, rather than to sea water warming,[34,66,102,157,179,180] but see.[166] As far as the *Posidonia oceanica* seagrass meadows are concerned, a negative effect of warming is unclear; it can shrink its range near its warm limit (e.g. in south-eastern Turkey) and favour its expansion near its cold limit (e.g. northern Adriatic and Gulf of Lions),[51,145,181] but see.[182,183] Conversely, the increasingly rapid rise of the sea level will result in a significant withdrawal of the lower *P. oceanica* limit, whenever it is beyond the compensation depth.[145]

Finally, one of the most important effects of sea water warming could be to enhance the range area progression of Red Sea (Lessepsian) invasive species, such as the rabbit-fish *Siganus* spp., and the lion-fish *Pterois miles*,[184] with a potentially overwhelming impact.

Conclusion

There is a growing tendency for stakeholders, managers, government officials, environmentalists, scientists, political leaders and media reports to focus, as concerns threats to biodiversity, on species richness and climate change. They can hardly be blamed, as climate change obviously constitutes a major threat to species diversity, ecosystem diversity, ecosystem functioning, and to human lifestyles. However, the 'species richness lobby' and focusing on climate warming can mask other stressors that, today, and perhaps for decades to come, may have more impact on ecosystems than global warming[185–195] It would be beyond the scope of the present paper to discuss the reasons why most scientists, stakeholders and political leaders prefer to focus on global warming and its direct impact, such as the acidification of seawater.

In the Mediterranean Sea, the overall impact of NISs and overfishing on species diversity, ecosystem diversity and ecosystem functioning exceeds to a greater or lesser degree the direct impact of warming. Drastically altered functioning patterns and even new ecosystems are spreading throughout the Mediterranean Sea. This trend is likely to become more pronounced over the next decades. Ecosystem goods and services are also being profoundly altered, generally towards a decline, as illustrated by the overgrazed barren grounds of the eastern basin, which no longer support fisheries,[40] by the impact of the *Caulerpa* meadows on the scuba diving business and the economic value of the fisheries of the western basin[186,187] and by the blooms of the introduced comb jelly *Mnemiopsis leidyi* in the Black Sea, before the arrival of its predator *Beroe ovata*.

In addition to direct impacts, which are far from negligible, warming not only boosts the expansion of the range of NISs but also triggers the rise of the sea-level; it therefore increases the huge impact of NISs and contributes to the submersion and death of the *Lithophyllum byssoides* algal rim, in the lower part of the mediolittoral zone[190] and to the withdrawal of *Posidonia oceanica* meadows at their lower depth limit.

Mediterranean coastal lagoons, such as Thau Lagoon and Venice Lagoon, and rocky reefs at Kos Island, Greece, may unfortunately be the harbingers of future Mediterranean seascapes. Here, we draw attention to the fact that, at this moment and probably also in the future, the huge flow of Non-Indigenous Species and overfishing constitute worrying issues, although largely ignored by stakeholders, managers, government officials and political leaders. Take care: Un train peut en cacher un autre (one train can hide another; i.e. there may be other, unsuspected dangers), that is to say the effects of the warming may contribute to hiding other effects, of at least equal importance, such as biological invasions and overfishing. The synergistic effects of the cocktail constituted by biological invasions, overfishing and global warming in the coming decades require, as a matter of urgency, a major effort at global scale in order to better assess the putative impact on Mediterranean marine ecosystems, and the goods and services they provide for the benefit of human society.

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Conflicts of interest

The authors declare there is no conflict of interests.

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References

1. Verlaque M, Boudouresque CF. Invasions biologiques marines et changement global. Actes des 2° journées de l'Institut français de la biodiversité 'Biodiversité et changement global, dynamique des interactions'. Marseille 25–28 Mai; 2004:74–75.
2. Boudouresque CF. Insights into the diversity of the biodiversity concept. *Sci Rep Port–Cros natl Park*. 2014;28:65–86.
3. Dasmann RF. A different kind of country. New York, MacMillan Company publ i–viii; 1968:1–276.
4. Wilson EO. Biodiversity. Washington, National Academies Press publ; 1988:1–538.
5. Boudouresque CF, Ruitton S, Bianchi CN, et al. Terrestrial versus marine diversity of ecosystems. And the winner is:the marine realm. Proceedings of the 5th Mediterranean Symposium on Marine Vegetation (Portorož, Slovenia, 27–28 October 2014). Langar H & Bouafif C (Eds.), RAC/SPA publ, Tunis; 2014:11–25.
6. Verlaque M, Ruitton S, Mineur F, et al. CIESM Atlas of exotic species. 4. Macrophytes. Briand F(Edt.), CIESM Publisher, Monaco; 2015:1–362.
7. Boudouresque CF, Caumette P, Bertrand JC, et al. Systematic and evolution of microorganisms:general concepts. In:Environmental microbiology:Fundamentals and applications. In: Bertrand JC, Caumette P, Lebaron P, editors. Microbial ecology. Springer publ; 2015:107–144.
8. Boudouresque CF, Personnic S, Astruch P, et al. Ecosystem–based versus species–based approach for assessment of the human impact on the Mediterranean seagrass *Posidonia oceanica*. In: Ceccaldi H, Hénocque Y, Koike Y, editors. Marine productivity:perturbations and resilience of socio–ecosystems. Springer International Publishing Switzerland; 2015:235–241.
9. Faith DP. Conservation evaluation and phylogenetic diversity. *Biol Conserv*. 1992;61(1):1–10.
10. Sala E, Knowlton N. Global marine biodiversity trends. *Annu Rev Environ Resour*. 2006;31:93–122.
11. Ramade F. Qu'entend–t–on par Biodiversité et quels sont les problématiques et les problèmes inhérents à sa conservation? *Bull Soc Entomol Fr*. 1994;99 (num. spécial):7–18.
12. Gray JS. The measurement of marine species diversity, with an application to the benthic fauna of the Norwegian continental shelf. *J Exp Mar Biol Ecol*. 2000;250(1–2):23–49.
13. Warwick RM. Scaling of marine biodiversity. *Océanis*. 1998;24(4):51–59.
14. Ellingsen KE. Biodiversity of a continental shelf soft–sediment macrobenthos community. *Mar Ecol Prog Ser*. 2001;218:1–15.
15. Willis KJ, Whittaker RJ. Species diversity – Scale matters. *Science*. 2002;295:1245–1248.
16. Fredj G, Bellan–Santini D, Meinardi M. Etat des connaissances sur la faune marine méditerranéenne. Bull Inst océanogr Monaco, Num. special. 1992;9:133–145.
17. Bianchi CN, Morri C. Marine biodiversity of the Mediterranean Sea:situation, problems and prospects for future research. *Mar Poll Bull*. 2000;40(5):367–376.
18. Cuttelod A, Garcia N, Abdul Malak DA, et al. The Mediterranean:a biodiversity hotspot under threat. In:Vié JC, Hilton–Taylor C, Stuart SN (Eds.). The 2008 review of the IUCN Red List of threatened species. IUCN publ, Gland; 2008:1–13.
19. Giaccone G, Di Martino V. Past, present and future of vegetational diversity and assemblages on Mediterranean Sea. Proceedings of the first Mediterranean symposium on marine vegetation, RAC/SPA publ. Tunis. 2000:34–59.
20. Boudouresque CF. The erosion of Mediterranean biodiversity in:The Mediterranean Sea: an overview of its present state and plans for future protection. In: Rodríguez–Prieto C, Pardini G, editors. Servei de Publicacions de la Universitat de Girona; 2003:53–112.
21. Boero F. The study of species in the era of biodiversity:a tale of stupidity. *Diversity*. 2010;2(1):115–126.
22. Katsanevakis S, Coll M, Piroddi C, et al. Invading the Mediterranean Sea:biodiversity patterns shaped by human activities. *Front Mar Sci*. 2014;1(32):1–11.
23. Myers N, Mittermeier RA, Mittermeier CG, et al. Biodiversity hotspots for conservation priorities. *Nature*. 2000;403:853–858.
24. Médail F. Mediterranean. In: Jørgensen SE, Fath BD, editors. Ecosystems. *Encyclopedia of Ecology*. 2008;3:2296–2308.
25. Blondel J, Médail J. Biodiversity and conservation. In:Woodward JC (Ed.), The physical geography of the Mediterranean. Oxford University Press, Oxford; 2009:615–650.
26. Lejeusne C, Chevaldonné P, Pergent–Martini C, et al. Climate change effects on a miniature ocean:the highly diverse, highly impacted Mediterranean Sea. *Trends in Ecology & Evolution*. 2000;25(4):250–260.
27. Boury–Esnault N, Pansini M, Uriz MJ. A new Discorhabdella (Porifera, Demospongiae), a new Tethyan relict of pre–Messinian biota? *Journal of Natural History*. 1992;26:1–7
28. Athanasiadis A. Mesophyllum macedonis, nov. sp. (Rhodophyta, Corallinales), a putative Tethyan relic in the North Aegean Sea. *European Journal of Phycology*. 1999;34(3):239–252.
29. Molinier R. Étude des biocénoses marines du Cap Corse. *Vegetatio*. 1960;9(4–5):121–192.
30. Laborel J. Marine biogenic constructions in the Mediterranean. a review. *Sci Rep Port–Cros Natl Park*. 1987;13:97–126.
31. Laborel J, Boudouresque CF, Laborel–Deguen F. Les bioconcrétionnements littoraux de Méditerranée. Les biocénoses marines et littorales de Méditerranée, synthèse, menaces et perspectives. In: Bellan–Santini D, Lacaze JC, Poizat C,editors. Muséum National d'Histoire Naturelle publ Paris; 1994:88–97.
32. Faivre S, Bakran–Petricioli T, Horvatinčić N, et al. Distinct phases of relative sea level changes in the central Adriatic during the last 1500 years – influence of climatic variations? *Palaeogeogr Palaeoclim Palaeoecol*. 2013;369:163–174.
33. Personnic S, Boudouresque CF, Astruch P, et al. An ecosystem–based approach to assess the status of a Mediterranean ecosystem, the Posidonia oceanica seagrass meadow. *Plos One*. 2014;9(6):(e98994).
34. Thibaut T, Blanfuné A, Boudouresque CF, et al. Decline and local extinction of Fucales in the French Riviera:the harbinger of future extinctions? *Mediterranean Marine Science*. 2015;16(1):206–224.
35. Verlaque M. Contribution à l'étude du phytobenthos d'un écosystème photophile thermophile marin en Méditerranée occidentale. Étude structurale et dynamique du phytobenthos et analyses des relations Faune–Flore. PhD Thesis, Université d'Aix–Marseille II, France; 1987. 389 p.
36. Ballesteros E. Structure and dynamics of the community of *Cystoseira zosteroides* (Turner) C. Agardh (Fucales, Phaeophyceae) in the Northwestern Mediterranean. *Sci Mar*. 1990;54:217–299.
37. Ballesteros E. Structure and dynamics of the *Cystoseira caespitosa* Sauvageau (Fucales, Phaeophyceae) community in the North–Western Mediterranean. *Sci Mar*. 1990;54(2):155–168.
38. Giaccone G, Alongi G, Pizzuto F, et al. La vegetazione marina bentonica fotofila del Mediterraneo:2:Infralitorale e circalitorale:proposte di aggiornamento. *Boll Accad Gioenia Sci Nat Catania*.1994;27(346):111–157.

Citation: Boudouresque CF, Blanfune A, Fernandez C, et al. Marine biodiversity warming vs. biological invasions and overfishing in the Mediterranean Sea:Take care, 'One Train can hide another'. *MOJ Eco Environ Sci.* 2017;2(4):172–183. DOI: 10.15406/mojes.2017.02.00031

39. Hereu Fina B. The role of trophic interactions between fishes, sea urchins and algae in the northwestern Mediterranean rocky infralittoral. Tesi Doctoral, Univ. Barcelona:i–xii; 2004:1–237.

40. Sala E, Ballesteros E, Dendrinos P, et al. The structure of Mediterranean reef ecosystems across environmental and human gradients, and conservation implications. *Plos One*. 2012;7(2):e32742.

41. Laubier L. Le coralligène des Albères:monographie biocénotique. Thèse Doct. Etat, Univ. Paris;1996:1–315.

42. Boudouresque CF, Blanfuné A, Harmelin–Vivien M, et al. Where seaweed forests meet animal forests:the examples of macroalgae in coral reefs and the Mediterranean coralligenous ecosystem. Marine animal forests. In: Rossi S, editor. Springer International Publishing, Switzerland; 2016:1–28.

43. Harmelin JG, Vacelet J, Vasseur P. Les grottes sous–marines obscures:un milieu extrême et un remarquable biotope refuge. *Téthys*. 1985;11:214–229.

44. Chevaldonné P, Lejeusne C. Regional warming–induced species shift in north–west Mediterranean marine caves. *Ecology Letters.* 2003;6(4):371–379.

45. Lejeusne C, Chevaldonné P. Brooding crustaceans in a highly fragmented habitat:the genetic structure of Mediterranean marine cave–dwelling mysid populations. *Molecular Ecology*. 2006;15(13):4123–4140.

46. Ribera MA, Boudouresque CF. Introduced marine plants, with special reference to macroalgae: mechanisms and impact. Progress in phycological Research. In: Round FE, Chapman DJ, editors. Biopress Ltd publ. 1995;11:187–268.

47. Boudouresque CF, Verlaque M. Biological pollution in the Mediterranean Sea:invasive versus introduced macrophytes. *Mar Poll Bull.* 2002;44(1):32–38.

48. Galil B, Froglia C, Noel P. CIESM Atlas of exotic species in the Mediterranean 2. Crustaceans. In: Briand F, editor. CIESM publ, Monaco; 2002:1–192.

49. Zenetos A, Gofas S, Verlaque M, et al. 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*. 2010;11(2):381–493.

50. Elton CS. The ecology of invasions by animals and plants. Methuen publ. Reprinted 2000 by University of Chicago Press:i–xiv; 1958:1–181.

51. Pergent G, Bazairi H, Bianchi CN, et al. Mediterranean seagrass meadows:resilience and contribution to climate change mitigation. A short summary. IUCN publ Gland Málaga; 2012:1–40.

52. Dunstan PK, Johnson CR. Invasion rates increase with species richness in a marine epibenthic community by two mechanisms. *Oecologia*. 2004;138(2):285–292.

53. Klein J, Ruitton S, Verlaque M, et al. Species introductions, diversity and disturbances in marine macrophyte assemblages of the northwestern Mediterranean Sea. *Mar Ecol Prog Ser*. 2005;290:79–88.

54. Mineur F, Johnson MP, Maggs CA. Non–indigenous marine macroalgae in native communities:a case study in the British Isles. *J mar biol Ass UK*. 2008;88 (4):693–698.

55. Fridley JD, Stachowicz JJ, Naeem S, et al. The invasion paradox:reconciling pattern and process in species invasions. *Ecology*. 2007;88(1):3–17.

56. Por FD. Lessepsian migrations. The influx of Red Sea biota into the Mediterranean by way of the Suez Canal. Springer publ, Berlin:i–viii; 1978:1–228.

57. Katsanevakis S, Acar Ü, Ammar I, et al. New Mediterranean biodiversity records Mediterr. *Mar Sci*. 2014;15(3):675–695.

58. Verlaque M. Checklist of the macroalgae of Thau Lagoon (Hérault, France), a hot spot of marine species introduction in Europe. *Oceanologica Acta*. 2001;24(1):29–49.

59. Boudouresque CF, Klein J, Ruitton S, et al. Biological Invasion:The Thau Lagoon, a Japanese biological island in the Mediterranean Sea. Global change:mankind–marine environment interactions. In: Ceccaldi HJ, Dekeyser I, Girault M, editors. Springer publ, Netherlands; 2011:151–156.

60. Ojaveer H, Galil BS, Campbell ML, et al. Classification of non–indigenous species based on their impacts:considerations for application in marine management. *Plos Biology*. 2015;13(4):1–13 (e1002130).

61. Por FD. Lessepsian migrations. An appraisal and new data. *Bull Inst Océanogr*. 1990;7 (numéro spécial):1–10.

62. Boudouresque CF. The Red Sea – Mediterranean link:unwanted effects of canals. Invasive species and biodiversity management. In: Sandlund OT, Schei PJ, editors. Kluwer Academic publ; 1999:213–228.

63. Verlaque M. Checklist of the macroalgae of Thau Lagoon (Hérault, France), a hot spot of marine species introduction in Europe. *Oceanologica Acta*. 2001;24(1):29–49.

64. Bănaru D, Harmelin–Vivien M, Boudouresque CF. Man induced change in community control in the nort–western Black Sea:the top–down bottom–up balance. *Marine Environmental Research*. 2010;69(4):262–274.

65. Mineur F, Le Roux A, Maggs CA, et al. Positive feedback loop between introductions of non–native marine species and cultivation of oysters in Europe. *Conservation Biology*. 2014;28(6):1667–1676.

66. Thibaut T, Blanfuné A, Boudouresque CF, et al. Unexpected temporal stability of Cystoseira and Sargassum forests in Port–Cros, one of the oldest Mediterranean marine National Parks. *Cryptogamie Algologie*. 2016;37(1):61–90.

67. Sancholle M. Présence de Fucus spiralis (Phaeophyceae) en Méditerranée occidentale. *Cryptogamie Algologie.* 1988;9(2):157–161.

68. Vinogradov ME, Shushkina EA, Musayeva EI, et al. A newly acclimated species in the Black Sea:the ctenophore Mnemiopsis leidyi (Ctenophora:Lobata). *Oceanology*. 1989;29(2):220–224.

69. Meinesz A, Hesse B. Introduction et invasion de l'algue tropicale Caulerpa taxifolia en Méditerranée nord–occidentale. *Oceanologica Acta*. 1991;14(4):415–426.

70. Ribera MA, Boudouresque CF. Introduced marine plants, with special reference to macroalgae:mechanisms and impact. Progress in phycological Research. In: Round FE, Chapman DJ, editors. Biopress Ltd publ; 1995;11:187–268.

71. Boudouresque CF, Lemée R, Mari X, et al. The invasive alga Caulerpa taxifolia is not a suitable diet for the sea–urchin Paracentrotus lividus. *Aquatic Botany*. 1996;53:245–250.

72. Meinesz A, Boudouresque CF. Sur l'origine de Caulerpa taxifolia en Méditerranée. *CR Acad Sci Paris Life Sci*. 1996;319:603–613.

73. Vacchi M, Chiantore MC. Abudefduf vaigiensis (Quoy & Gaimard 1825): a tropical damselfish in Mediterranean Sea. Biol *Mar Medit*. 2000;7(1):841–843.

74. Galil BS, Nehring S, Panov V. Waterways as invasion highways –impact of climate change and globalization. In: Nentwig W, editor. Biological invasions, Springer–Verlag publ, Berlin Heidelberg; 2007:59–74.

75. Ojaveer H, Galil BS, Campbell ML, et al. Classification of non–indigenous species based on their impacts:considerations for application in marine management. *Plos Biology*. 2015;13(4):1–13(e1002130).

76. Kolar CS, Lodge DM. Progress in invasion biology:predicting invaders. *Trends Ecol Evol*. 2001;16(4):199–204.

Citation: Boudouresque CF, Blanfune A, Fernandez C, et al. Marine biodiversity warming vs. biological invasions and overfishing in the Mediterranean Sea:Take care, 'One Train can hide another'. *MOJ Eco Environ Sci.* 2017;2(4):172–183. DOI: 10.15406/mojes.2017.02.00031

77. Ruiz GM. Propagule supply as a driver of biological invasions. Alien marine organisms introduced by ships in the Mediterranean and Black seas, CIESM Workshop monographs; 2002;20:83–86.
78. Taylor CM, Hastings A. Allee effects in biological invasions. *Ecology Letters*. 2005;8(8):895–908.
79. Roman J, Darling JA. Paradox lost:genetic diversity and the success of aquatic invasions. *Trends in Ecology and Evolution*. 2007;22(9):454–464.
80. Boudouresque CF, Verlaque M. An overview of species introduction and invasion processes in marine and coastal lagoon habitats. *Cah Biol mar*. 2012;53(3):309–317.
81. Davis MA, Grime JP, Thompson K. Fluctuating resources in plant communities:a general theory of invasibility. *J Ecol*. 2000;88(3):528–534.
82. Blumenthal DM. Interactions between resource availability and enemy release hypothesis. *Ecology Letters*. 2006;9:887–895.
83. Blossey B, Notzold R. Evolution of increased competitive ability in invasive non–indigenous plants:a hypothesis. *J Ecol*. 1995;83(5):887–889.
84. Beaton LL, Van Zandt PA, Esselman EJ, et al. Comparison of the herbivore defense and competitive ability of ancestral and modern genotypes of an invasive plant, Lespedeza cuneata. Oikos. 2012;120(9):1413–1419.
85. Callaway RM, Ridenour WM. Novel weapons:invasive success and the evolution of increased competitive ability. *Front Ecol Environ*. 2004;2(8):436–443.
86. Tomas F, Box A, Terrados J. Effects of invasive seaweeds on feeding preference and performance of a keystone Mediterranean herbivore. *Biol Invasions*. 2011;13(7):1559–1570.
87. Hutson KS, Ross DJ, Day RW, et al. Australian scallops do not recognise the introduced predatory seastar Asterias amurensis. *Mar Ecol Prog Ser*. 2005;298:305–309.
88. Leishman MR, Gallagher RV. Will alien plant invaders be advantaged under future climates? In:Biological invasions in changing ecosystems. Vectors, ecological impacts, management and predictions. Canning–Clode J, editor. De Gruyter publ, Warsaw, Berlin; 2015:368–388.
89. Bianchi CN. Biodiversity issues for the forthcoming tropical Mediterranean Sea. *Hydrobiologia*. 2007;580:7–21.
90. Jousson O, Pawlowski J, Zaninetti L, et al. Invasive alga reaches California. *Nature*. 2000;408:157–158.
91. Blackburn TM, Pyšek P, Bacher S, et al. A proposed unified framework for biological invasions. *Trends in Ecology and Evolution*. 2011;26(7):333–339.
92. Canning–Clode J. General introduction–aquatic and terrestrial biological invasions in the 21st century. In:Biological invasions in changing ecosystems. Vectors, ecological impacts, management and predictions. In: Canning–Clode J, editor. De Gruyter publ, Warsaw, Berlin; 2015:13–20.
93. Pérès JM. Les biocoenoses benthiques dans le système phytal. *Rec Trav Stat mar Endoume*. 1967;42(58):3–113.
94. Cohen AN, Carlton JT. Accelerating invasion rate in a highly invaded estuary. *Science*. 1998;279:555–558.
95. Glaby TM, Connell SD, Holloway MG, et al. Nonindigenous biota on artificial structures:could habitat creation facilitate biological invasions? *Marine Biology*. 2007;151(3):887–895.
96. Sala E, Boudouresque CF, Harmelin–Vivien M. Fishing, trophic cascades and the structure of algal assemblages:evaluation of an old but untested paradigm. *Oikos*. 1998;82(3):425–439.
97. Coma R, Serrano E, Linares C, et al. Sea urchin predation facilitates coral invasion in a marine reserve. *Plos One*. 2011;6(7):1–12.
98. Boudouresque CF, Verlaque M. Paracentrotus lividus. In: JM Lawrence, editor. Sea Urchins: Biology and Ecology, 3rd edn. Elsevier Publ; 2013:297–327.
99. Agnetta D, Badalamenti F, Ceccherelli G, et al. Role of two co–occurring Mediterranean sea urchins in the formation of barren grounds. *Estuarine, Coastal and Shelf Science*. 2015;152(2015):73–77.
100. Boudouresque CF, Ruitton S, Verlaque M. Large–scale disturbances, regime shift and recovery in littoral systems subject to biological invasions. Large–scale disturbances (regime shifts) and recovery in aquatic ecosystems: challenges for management towards sustainability. In: Velikova V, Chipev N, editors. Unesco publ, Paris; 2015:85–101.
101. Ruitton S, Personnic S, Ballesteros E, et al. An ecosystem–based approach to assess the status of the Mediterranean coralligenous habitat. Proceedings of the 2nd Mediterranean symposium on the conservation of coralligenous and other calcareous bio–concretions. In: Bouafif C, Langar H, Ouerghi A, editors. RAC/SPA publ, Tunis; 2014:153–158.
102. Thibaut T, Blanfuné A, Verlaque M, et al. The Sargassum conundrum:highly rare, threatened or locally extinct in the NW Mediterranean and still lacking protection. *Hydrobiologia*. 2015.
103. Thibaut T, Blanfuné A, Boudouresque CF, et al. An ecosystem–based approach to assess the status of Mediterranean algae–dominated shallow rocky reefs. *Mar Pollut Bull*. 2017;117(1–2):311–329.
104. Ruitton S, Verlaque M, Aubin G, et al. Grazing on Caulerpa racemosa var. cylindracea (Caulerpales, Chlorophyta) in the Mediterranean Sea by herbivorous fishes and sea urchins. *Vie Milieu*. 2006;56(1):33–41.
105. Deudero S, Box A, Alós J, et al. Functional changes due to invasive species:food web shifts at shallow Posidonia oceanica seagrass beds colonized by the alien macroalga Caulerpa racemosa. *Estuar coast Shelf Sci*. 2011;93(2):106–116.
106. Tomas F, Cebrian E, Ballesteros E. Differential herbivory of invasive algae by native fish in the Mediterranean Sea. *Estuar Coast Shelf Sci*. 2011;92:27–34.
107. Boudouresque CF. Les invasions biologiques. In:Les écosystèmes marins dans la régulation du climat. Fonds Français pour l'Environnement Marin publ, Paris; 2015:54–55.
108. Lundberg B. Food habit of Siganus rivulatus, a Lessepsian migrant, as adapted to algal resources at the coast of Israel. In:Environmental quality and ecosystem stability. In: Spanier E, Steinberger Y, Luria M, editors. ISEEQS Publ Jerusalem; 1989:113–124.
109. Golani D. Lessepsian fish migration–Characterization and impact on the eastern Mediterranean. Workshop on Lessepsian migration, Gökçeada, Turkey. In: Öztürk B, Başusta N, editors. Turkish mar Res Foundation publ; 2002:1–9.
110. Azzuro E, Fanelli E, Mostarda E, et al. Resource partitioning among early colonizing Siganus luridus and native herbivorous fish in the Mediterranean:an integrated study based on gut content analyses and stable isotope signatures. *J Mar Biol Ass UK*. 2007;87:991–998.
111. Shakman E, Boedecker C, Bariche M, et al. Food and feeding habits of the Lessepsian migrants Siganus luridus Rüppel, 1828 and Siganus rivulatus Forsskål, 1775 (Teleostei:Siganidae) in the southern Mediterranean (Libyan coast). *J Biol Res Thessaloniki*. 2009;12:115–124.
112. Yokes B, Galil BS. The first record of the needle–spined urchin Diadema setosum (Leske, 1778) (Echinodermata:Diadematidae) from the Mediterranean Sea. *Aquatic Invasions*. 2006;1(3):188–190.
113. Sala E, Kizilkaya Z, Yildirim D, et al. Alien marine fishes deplete algal biomass in the Eastern Mediterranean. *Plos One*. 2011;6(2):e17356.
114. Ballesteros E. Tras las últimas focas del Mediterráneo. Crónicas de mis

viajes científicos por el Mediterráneo Oriental. Gallocanta publ Spain. 2012:1–220.

115. Occhipinti Ambrogi A. Biotic invasions in a Mediterranean lagoon. *Biological Invasions*. 2000;2(2):165–176.
116. Pranovi F, Franceschini G, Casale M, et al. An ecological imbalance induced by a non–native species:the Manila clam in the Venice Lagoon. *Biological Invasions*. 2006;8(4):595–609.
117. Sfriso A, Curiel D. Check–list of seaweeds recorded in the last 20 years in Venice Lagoon, and a comparison with the previous records. *Botanica Marina*. 2007;50(1):22–58.
118. Bianchi CN, Corsini–Foka M, Morri C, et al. Thirty years after:dramatic change in the coastal marine ecosystems of Kos Island (Greece), 1981–2013. *Medit Mar Sci*. 2014;15(3):482–497.
119. Bolte S, Fuentes V, Haslob H, et al. Population genetics of the invasive ctenophore Mnemiopsis leidyi in Europe reveal source–sink dynamics and secondary dispersal to Mediterranean Sea. *Marine Ecology Progress Series*. 2013;485:25–36.
120. Ghabooli S, Shiganova TA, Briski E, et al. Invasion pathway of the ctenophore Mnemiopsis leidyi in the Mediterranean Sea. *Plos One*. 2013;8(11):e81067.
121. Konovalov SM. Impact of man on Black Sea ecosystem. *Rapp PV Réun Commiss Int Explor Sci Médit*. 1992;33:17.
122. Travis J. Invader threatens Black, Azov Seas. *Science*. 1993;262(5138):1366–1367.
123. Petran A, Moldoveanu M. Post–invasion ecological impact of the Atlantic Ctenophore Mnemiopsis leidyi Agassiz, 1865 on the zooplankton from the Romanian Black Sea waters. *Cercetari marine*. 1995;27–28:135–157.
124. Zaitsev Y, Mamaev V. Biological diversity in the Black Sea. A study of change and decline. United Nations Publications, New York:i–xv; 1997:1–208.
125. Shiganova TA, Bulgakova YV. Effects of gelatinous plankton on Black Sea and Sea of Azov fish and their food resources. *ICES J Mar Sci*. 2000;57(3):641–648.
126. Stone R. Attack of the killer jellies. *Science*. 2005;309:1805–1806.
127. Delpy F, Pagano M, Blanchot J, et al. Man–induced hydrological changes, metazooplankton communities and invasive species in the Berre Lagoon (Mediterranean Sea, France). *Mar Poll Bull.* 2012;64(9):1921–1932.
128. Delpy F, Albouy–Boyer S, Pagano M, et al. Identifying the drivers of abundance and size of the invasive ctenophore Mnemiopsis leidyi in Northwestern Mediterranean lagoons. *Marine Environmental Research*. 2016;119:114–125.
129. Spanier E, Galil BS. Lessepsian migrations:a continuous biogeographical process. *Endeavour*. 1991;16(3):102–106.
130. Galil BS. Lessepsian migration. Biological invasion of the Mediterranean. In: Boudouresque CF, Briand F, Nolan C, editors. Introduced species in Euro–pean coastal waters, European Commission publ, Luxembourg 1994;:63–66.
131. Kideys AE, Gucu AC. Rhopilema nomadica:a lessepsian Scyphomedusan new to the Mediterranean coast of Turkey. *Israel J Zool*. 1995;41:615–617.
132. Daly Yahia MN, Kéfi–Daly Yahia O, Gueroun SKM, et al. The invasive tropical scyphozoan Rhopilema nomadica Galil, 1990 reaches the Tunisian coast of the Mediterranean Sea. *Bioinvasion Records*. 2013;2(4):319–323.
133. Galil BS, Boero F, Campbell ML, et al. 'Double trouble':the expansion of the Suez Canal and marine bioinvasions in the Mediterranean Sea. *Biological Invasions*. 2015;17(4):973–976.
134. Deidun A, Arrigo S, Piraino S. The westernmost record of Rhopilema nomadica (Galil, 1990) in the Mediterranean – off the Maltese Islands. *Aquatic Invasions*. 2011;6 (Supp 1):S99–S103.
135. Bolton TF, Graham WM. Morphological variation among populations of an invasive jellyfish. Marine Ecology Progress Series 2004;278:125–139.
136. Bilecenoğlu M. Türkiye kıyılarında ilk kez rastlanan bir denizanası türü:Cassiopea andromeda (Forsskal, 1775) *(Cassiopeidae, Scyphozoa)*. *Sualtı Dünyas Dergisi*. 2002;72:42–43.
137. Schembri PJ, Deidun A, Vella PJ. First record of Cassiopea andromeda *(Scyphozoa:Rhizostomeae:Cassiopeidae)* from the central Mediterranean Sea. Marine Biodiversity Records. 2010;3:e6.
138. Galil B, Shoval L, Goren M. Phyllorhiza punctata von Lendenfeld, 1884 *(Scyphozoa:Rhizostomeae:Mastigiidae)* reappeared off the Mediterranean coast of Israel. *Aquatic Invasions*. 2009;4(3):481–483.
139. Pauly D, Alder J, Bennett E, et al. The future for fisheries. *Science*. 2003;302:1359–1361.
140. Lloret J, Muñoz M, Casadevall M. Threats posed by artisanal fisheries to the reproduction of coastal fish species in a Mediterranean marine protected area. *Estuarine, Coastal and Shelf Science*. 2012;113:133–140.
141. Christensen V, Coll M, Piroddi C, et al. A century of fish biomass decline in the ocean. *Marine Ecology Progress Series*. 2014;512:155–166.
142. Leleu K. Pelletier D, Charbonnel E, et al. Métiers, effort and catches of a Mediterranean small–scale coastal fishery:the case of the Côte Bleue Marine Park. *Fisheries Research*. 2014;154:93–101.
143. Kaiser MJ. Scraping the bottom:are towed fishing gears a threat to benthic biodiversity? *Océanis*. 1998;24(4):258–270.
144. Roberts CM, Hawkins JP. Extinction risk in the sea. *Trends Ecol Evol.* 1999;14(6):241–246.
145. Boudouresque CF, Bernard G, Pergent G, et al. Regression of Mediterranean seagrasses caused by natural processes and anthropogenic disturbances and stress:a critical review. *Botanica Marina*. 2009;52:395–418.
146. Boudouresque CF, Bernard G, Bonhomme P, et al. Protection and conservation of Posidonia oceanica meadows. RAMOGE and RAC/SPA publ, Tunis; 2012:1–202.
147. Myers RA, Worm B. Rapid worldwide depletion of predatory fish communities. *Nature*. 2003;423:280–283.
148. Ferretti F, Myers RA, Serena F, et al. Loss of large predatory sharks from the Mediterranean Sea. *Conservation Biology*. 2008;22(4):952–964.
149. Harmelin–Vivien M, Cottalorda JM, Dominici JM, et al. Effects of reserve protection level on the vulnerable fish species Sciaena umbra and implications for fishing management and policy. *Global Ecology and Conservation*. 2015;3:279–287.
150. Meinesz A, Blanfuné A. 1983–2013:Development of marine protected areas along the French Mediterranean coasts and perspectives for achievement of the Aichi target. *Marine Policy*. 2015;54:10–16.
151. Sala E, Zabala M. Fish predation and the structure of the sea urchin Paracentrotus lividus populations in the NW Mediterranean. *Mar Ecol Progr Ser*. 1996;140:71–81.
152. Sala E, Ribes M, Hereu B, et al. Temporal variability in abundance of the sea urchins Paracentrotus lividus and Arbacia lixula in the northwestern Mediterranean:comparison between a marine reserve and an unprotected area. *Mar Ecol Progr Ser*. 1998;168:135–145.
153. Guidetti P. Marine reserves reestablish lost predatory interactions and cause community changes in rocky reefs. *Ecol Appl*. 2006;16(3):963–976.

154. Hereu B, Zabala M, Sala E. Multiple controls of community structure and dynamics in a sublittoral marine environment. *Ecology*. 2008;89(12):3423–3435.

155. Ling SD, Scheibling RE, Rassweiler A, et al. Global regime shift of catastrophic sea urchin overgrazing. *Phil Trans R Soc B.* 2015;370:1–10.

156. Falace A, Alongi G, Cormaci M, et al. Changes in the benthic algae along the Adriatic Sea in the last three decades. *Chemistry and Ecology*. 2010;26(S1):77–90.

157. Thibaut T, Pinedo S, Torras X, et al. Long–term decline of the populations of Fucales *(Cystoseira spp. and Sargassum spp.)* in the Albères coast (France, North–western Mediterranean). *Mar Pollut Bull*. 2005;50:1472–1489.

158. Pauly D, Christensen V, Dalsgaard J, et al. Fishing down marine food webs. *Science.* 1998;279:860–863.

159. Mills CE. Jellyfish blooms:are populations increasing globally in response to changing ocean conditions? *Hydrobiologia*. 2001;451:55–68.

160. Boero F, Bouillon J, Gravili C, et al. Gelatinous plankton:irregularities rule the world (sometimes). *Marine Ecology Progress Series.* 2008;356:299–310.

161. Condon RH, Graham WM, Duarte CM, et al. Questioning the rise of gelatinous zooplankton in the world's oceans. *Bio Science*. 2012;62(2):160–169.

162. Kuhlemann J, Rohling EJ, Krumrei I, et al. Regional synthesis of Mediterranean atmospheric circulation during the Last Glacial Maximum. *Science*. 2008;321(5894):1338–1340.

163. Assis J, Serrão EA, Claro B, et al. Climate–driven range shifts explain the distribution of gene pools and predict future loss of unique lineages in a marine brown alga. *Mollecular Ecology*. 2014;23(11):2797–2810.

164. Francour P, Boudouresque CF, Harmelin JG, et al. Are the Mediterranean waters becoming warmer? Information from biological indicators. *Mar Poll Bull*. 1994;28(9):523–526.

165. Sabatés A, Martin P, Lloret J, et al. Sea warming and fish distribution:the case of the small pelagic fish, Sardinella aurita, in the western Mediterranean. *Global Change Biology*. 2006;12(11):2209–2219.

166. Privitera D, Noli M, Falugi C, et al. Benthic assemblages and temperature effects on Paracentrotus lividus and Arbacia lixula larvae and settlement. *J Exp Mar Biol Ecol*. 2011;407(1):6–11.

167. Lloret J, Sabatés A, Muñoz M, et al. How a multidisciplinary approach involving ethnoecology, biology and fisheries can help explain the spatio–temporal changes in marine fish abundance resulting from climate change. *Global Ecology and Biogeography*. 2015;24(4):448–461.

168. Ben Rais Lasram F, Guilhaumon F, et al. The Mediterranean Sea as a 'cul–de–sac' for endemic fishes facing climate change. *Global Change Biol*. 2010;16(12):3233–3245.

169. Adloff F, Somot S, Sevault F, et al. Mediterranean Sea response to climate change in an ensemble of twenty first century scenarios. *Climate Dynamics*. 2015;45(9–10):2775–2802.

170. Cerrano C, Bavestrello G, Bianchi CN, et al. A catastrophic mass–mortality episode of gorgonians and other organisms in the Ligurian Sea (North–western Mediterranean), summer 1999. *Ecology Letters*. 2000;3(4):284–293.

171. Romano JC, Bensoussan N, Younes WAN, et al. Anomalie thermique dans les eaux du golfe de Marseille durant l'été 1999. Une explication partielle de la mortalité d'invertébrés fixés? *CR Acad Sci Life Sci*. 2000;323(4):415–427.

172. Garrabou J, Perez T, Sartoretto S, et al. Mass mortality event in red coral Corallium rubrum populations in the Provence region (France, NW Mediterranean). *Mar Ecol Progr Ser*. 2001;217:263–272.

173. Garrabou J, Laubier L, Perez T. Sessile benthic invertebrates as indicators of climate change. Mass mortalities in the north–western Mediterranean in summer 1999. *Ocean Challenge*. 2002;12(1):17–23.

174. Coma R, Linares C, Ribes M, et al. Consequences of a mass mortality in populations of Eunicella singularis (Cnidaria:Octocorallia) in Menorca (NW Mediterranean). *Mar Ecol Progr Ser*. 2006;327:51–60.

175. Coma R, Ribes M, Serrano E, et al. Global warming–enhanced stratification and mass mortality events in the Mediterranean. *Proc Nation Acad Sci US*. 2009;106(15):6176–6181.

176. Bensoussan N, Romano JC, Harmelin JG, et al. High resolution characterization of northwest Mediterranean coastal waters thermal regime:to better understand responses of benthic communities to climate change. *Estuarine, Coastal and Shelf Science*. 2010;87(3):431–441.

177. Rivetti I, Fraschetti S, Lionello P, et al. Global warming and mass mortalities of benthic invertebrates in the Mediterranean Sea. *Plos One*. 2014;9(12):e115655.

178. Parravicini V, Mangialajo L, Mousseau L, et al. Climate change and warm–water species at the north–western boundary of the Mediterranean Sea. *Marine Ecology*. 2015;36(4):897–909.

179. Perkol–Finkel S, Airoldi L. Loss and recovery potential of marine habitats:an experimental study of factors maintaining resilience in subtidal algal forests at the Adriatic Sea. *Plos One*. 2010;5(5):11.

180. Fraschetti S, Terlizzi A, Guarnieri G, et al. Effects of unplanned development on marine biodiversity:a lesson from Albania (central Mediterranean Sea). *J Coast Res*. 2011;58:106–115

181. Giakoumi S, Halpern BS, Michel LN, et al. Towards a framework for assessment and management of cumulative human impacts on marine food webs. *Conservation Biology.* 2015;29(4):1228–1234.

182. Mayot N, Boudouresque CF, Charbonnel E. Changes over time of shoot density of the Mediterranean *seagrass Posidonia oceanica* at its depth limit. *Biol Mar Medit*. 2006;13(4):250–254.

183. Marbà N, Duarte CM. Mediterranean warming triggers seagrass *(Posidonia oceanica)* shoot mortality. *Global Change Biol*. 2010;16(8):2366–2375.

184. Kletou D, Hall–Spencer JM, Kleitou P. A lionfish (Pterois miles) invasion has begun in the Mediterranean Sea. *Marine Biodiversity Records*. 2016;9(1):1.

185. Maxwell SL, Fuller RA, Brooks TM, et al. The ravages of guns, nets and bulldozers. *Nature*. 2016;536(7615):143–145.

186. Harmelin–Vivien M, Francour P, Harmelin JG, et al. Dynamics of fish assemblage alterations caused by the introduced alga Caulerpa taxifolia near Menton (France). In: Gravez V, Ruitton S, editors. Fourth international workshop on Caulerpa Taxifolia, GIS Posidonie publ, Marseille; 2001:236–245.

187. Boudouresque CF. The spread of a non–native species, Caulerpa taxifolia. Impact on the Mediterranean biodiversity and possible economic consequences. In: Di Castri F, Balaji V, editors. Tourism, Biodiversity and Information, Backhuys publ, Leiden; 2002:75–87.

188. Ballesteros E. Mediterranean coralligenous assemblages:a synthesis of present knowledge. Oceanogr. *Mar Biol Ann Rev*. 2006;44:123–195.

189. Bianchi CN. The state of marine biodiversity. International Symposium on Mediterranean Biodiversity, Agenda for New Technologies, Energy and Sustainable Economic Development; 1996:51–61.

190. Blanfuné A, Boudouresque CF, Thibaut T, et al. The sea level rise and the collapse of a Mediterranean ecosystem, the Lithophyllum byssoides algal rim. In: Thiébault S, Moatti JP, editors. The Mediterranean region under climate change. A scientific update. AllEnvi, IRD editions publisher Marseille; 2016:285–289.

191. Board on environmental studies and toxicology. Global change ecosystem research. National Academy Press, Washington, USA, DC:xii; 2000:1–48.

192. Boudouresque CF. Marine biodiversity in the Mediterranean:status of species, populations and communities. *Sci Rep Port–Cros Natl Park*. 2004;20:97–146.

193. Boudouresque CF. Taxonomy and evolution of unicellular eukaryotes. In: Bertrand JC, Caumette P, Lebaron P, editors. Environmental microbiology: Fundamentals and applications. Microbial ecology. Springer publ; 2015:191–257.

194. Boudouresque CF, Boury–Esnault N, Harmelin–Vivien M. Marine biodiversity: trends, patterns and threats. Seminar on biodiversity and biological conservation. In: Villà M, Rodà F, Ros J, editors. Institut d'Estudis Catalans publ, Barcelona; 2003:391–410.

195. Boudouresque CF, Meinesz A, Ribera MA, et al. Spread of the green alga *Caulerpa taxifolia* (Caulerpales, Chlorophyta) in the Mediterranean:possible consequences of a major ecological event. *Scientia Marina*. 1995;59(1):21–29.

196. Boudouresque CF, Perret–Boudouresque M, Verlaque M. Donor and recipient regions for exotic species of marine macrophytes:a case of unidirectional flow, the Mediterranean Sea. Rapports de la Commission Internationale pour la Mer Méditerranée. 2016;41:426.

197. Carlton JT. Biological invasions and cryptogenic species. *Ecology*. 1996;77(6):1653–1655.

198. Coll M, Piroddi C, Steenback J, Kaschner K, et al. The biodiversity of the Mediterranean Sea:Estimates, patterns and threats. *Plos One*. 2010;5(8):1–334 (e11842).

199. David M, Gollasch S, Cabrini M, et al. Results from the first ballast water sampling study in the Mediterranean Sea–the port of Koper study. *Mar Poll Bull*. 2007;54(1):53–65.

200. Galil BS. Alien species in the Mediterranean Sea – which, when, where, why? *Hydrobiologia*. 2008;606(1):105–116.

201. Galil B, Boero F, Fraschetti S, et al. The enlargement of the Suez Canal and introduction of non–indigenous species to the Mediterranean Sea. *Limnol Oceanogr Bull*. 2015;24(2):43–45.

202. Golani N, Orsi–Relini L, M Quignard JP. CIESM atlas of exotic species in the Mediterranean. In: Briand F, editor. Monaco: CIESM Publishers; 2002:1–254.

203. Harmelin JG, Vacelet J, Vasseur P. Les grottes sous–marines obscures:un milieu extrême et un remarquable biotope refuge. *Téthys*. 1985;11:214–229.

204. Ivanov VP, Kamakin AM, Ushivtzev VB, et al. Invasion of the Caspian Sea by the comb jellyfish *Mnemiopsis leidyi* (Ctenophora). *Biological Invasions*. 2000;2(3):255–258.

205. Logan A, Bianchi CN, Morri C, et al. The present–day Mediterranean brachiopod fauna:diversity, life habits, biogeography and paleobiogeography. *Scientia marina*. 2004;68(1):163–170.

206. MacLeold CJ, Paterson AM, Tompkins DM, et al. Parasites lost–do invaders miss the boat or drown on arrival? *Ecology Letters*. 2010;13(4):516–527.

207. Martin S, Gattuso JP. Response of Mediterranean coralline algae to ocean acidification and elevated temperature. *Global Change Biol*. 2009;15(8):2089–2100.

208. Perez T. Impact des changements climatiques sur la biodiversité en mer Méditerranée. CAR/ASP publ Tunis. 2008:1–62.

209. Perez T, Garrabou J, Sartoretto S, et al. Mortalité massive d'invertébrés marins :un événement sans précédent en Méditerranée nord–occidentale. *CR Acad Sci Life Sci*. 2000;323:853–865.

210. Verlaque M, Durand C, Huisman JM, et al. On the identity and origin of the Mediterranean invasive Caulerpa racemosa *(Caulerpales, Chlorophyta)*. *Eur J Phycol*. 2003;38:325–339.

211. Verlaque M, Ruitton S, Mineur F, et al. CIESM Atlas of exotic species. In: Briand F, editor. Monaco: CIESM Publisher; 2015:1–362.

212. Boudouresque CF, Verlaque M. Is global warming involved in the success of seaweed introductions in the Mediterranean Sea? In: Israel A, Einav R, Seckbach J, editors. Seaweeds and their role in globally changing environments. Springer publ, Dordrecht; 2010:31–50.

213. Carlton JT, Ruiz GM. Anthropogenic vectors of marine and estuarine invasions:an overview framework. In:Biological invasions in changing ecosystems. Vectors, ecological impacts, management and predictions. In: Canning–Clode J, editor. De Gruyter publ., Warsaw, Berlin; 2015:30–36.

214. Soulé ME, Wilcox BA. Conservation biology:an evolutionary–ecological perspective. Sunderland, Massachusetts, USA, Sinauer Assiociates publ; 1980:1–395.

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