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Review article

How human health and well-being depends on healthy marine habitats in the Mediterranean: A review

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ABSTRACT

Human health and well-being, and how they are affected by terrestrial and freshwater ecosystems have been the subject of numerous studies. In contrast, there are very few such studies relating to marine ecosystems. Here, in the context of the Mediterranean Sea, we assess evidence of the broad interplay of relationships between marine habitats and human health and well-being. Our review shows that the major Mediterranean marine habitats provide various provisioning, cultural and regulating services that improve physical and mental health in a number of different ways. These include: (i) the provision of seafood rich in omega-3 fatty acids, which help to reduce the risk of developing certain types of illnesses; and also, species that produce bioactive compounds that are potential sources of new drugs; (ii) the provision of *blue spaces* – areas of water suitable for leisure and recreational activities able to inspire, educate, and appeal to the aesthetic senses – that not only increase physical and psychological health, but also foster an individual and collective sense of place and identity and contribute to improving social relations; and (iii) the regulation of climate change, and of water quality and pollution, for example via sequestration of carbon and heavy metals, thus reducing the associated health risks. Our results show that Mediterranean marine habitats are valuable for health and well-being, thus highlighting the need to conserve as much of these habitats as possible (particularly through marine protected areas) and to carry out new studies to determine the specific causal pathways by which certain characteristics of marine habitats – including biotic (e.g. marine biodiversity) and abiotic (e.g. water quality) factors – affect human health and well-being.

1. Introduction

Ecosystems are essential for human health and well-being due to the various goods and services that they provide [1]. The natural world provides goods and services – analogous to those of modern economics – which are vital for our health and survival. However, this inherent dependence is often difficult to recognize because it is most often indirect, and disconnected from our everyday experience. Evidence in recent decades of escalating human impacts on terrestrial and aquatic ecosystems has raised concerns around the world about the impact that biodiversity loss and habitat changes have had on human health and well-being [1].

Never in human history has there been such rapid change in the structure and functioning of the world's marine ecosystems than in the latter half of the last century [2]. Of all the environmental problems affecting oceans, the decline in marine biodiversity is believed

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to be one of the most serious. This decline is a consequence of habitat change (degradation, destruction, fragmentation and loss) stemming not only from climate change, but from specific human activities, such as destructive fishing, aquaculture, organic enrichment, oil and gas exploitation on a large scale, offshore construction of renewable energy infrastructure, coastal development and engineering, and the expansion of invasive species, as well as the cumulative effects of climate change ([3–6]).

While there is rapidly growing evidence of how natural environments contribute to human health ([7–9]), research into the relationships between ecological characteristics and human health is scarce, and most of it concentrates on terrestrial and freshwater ecosystems ([10–12]). In marine ecosystems, however, there is still less information on how habitat characteristics, such as biodiversity and abiotic factors, are interlinked with human health and well-being. Although a number of studies document a relationship between blue spaces and human health outcomes (e.g. Refs. [13–15]), they do little to explain the causal pathways via which marine habitat features may work to establish those relationships. Of the large body of research on blue spaces and human health, the vast majority focus on the size of the blue spaces near populated areas, the time people spend in such areas ([16,17]), or the sporting activities they take part in ([15,18]), with little or no attention to the ecological characteristics of these areas. Therefore, existing studies tell us little about the impact that the myriad forms of marine habitats can have on people's health – whether in direct contact, or in close proximity – or about how changes in marine biodiversity and habitats can affect this relationship.

Taking the Mediterranean as the study area, in this review, we (i) analyze the evidence for the links between a number of highly representative Mediterranean marine habitats and human health and well-being (i.e., health benefits), (ii) assess the implications of loss or degradation of these habitats for human health and well-being (i.e., health risks) and (iii) identify future research directions. We hope the outcomes of our paper can contribute to bringing academic research, public policies and management practices involving marine habitats into line with efforts to promote public health, marine biodiversity and habitat conservation.

2. Materials and methods

We identified numerous studies in this field of research listed in scientific databases (e.g. Science Direct, PubMed and Web of Science) using combinations of the basic keywords "health", "well-being" and "Mediterranean" with each of the following specific terms: marine biodiversity; marine habitat; marine biodiversity; fisheries; seafood; marine drugs; marine pharmaceuticals; marine recreational activities; marine sports; and marine ecosystem services. There were no restrictions regarding the year of publication. The

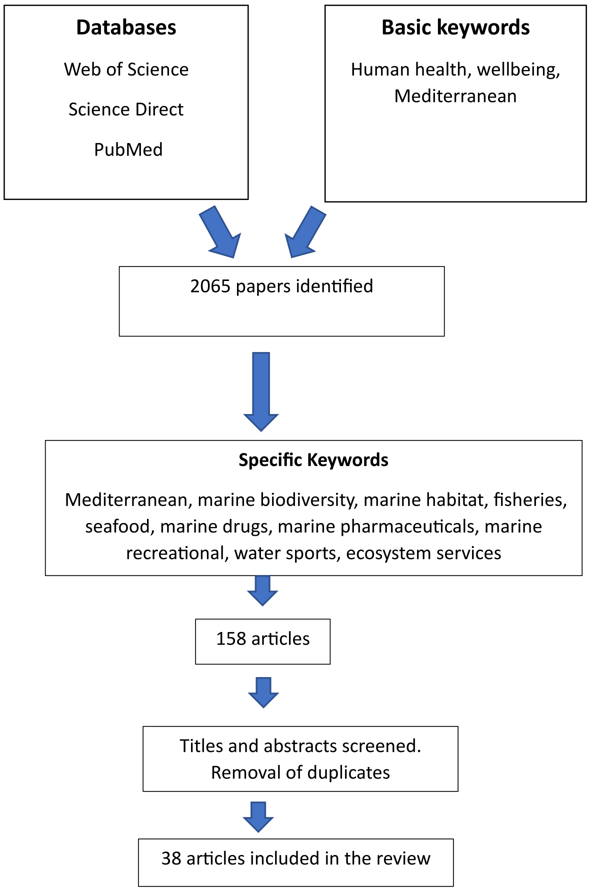

Fig. 1. Visualisation of the selection process.

initial electronic search identified 2065 studies with the basic keyworkds and 158 studies with the specific terms, as potentially relevant. After screening titles and abstracts, we first excluded those that were not relevant to our study (i.e., those in which keyword combinations existed, but in unrelated contexts). Only papers that reported data on habitat and health outcomes were assessed in detail. In the end, 38 key documents were selected for review in order to find evidence of health benefits provided by the major Mediterranean marine habitats (Fig. 1). The information gathered in the Mediterranean was then compared to other studies carried out on this subject in other seas and oceans. Therefore, this study offers a narrative – rather than systematic – review, since the only papers chosen were those considered to be highly relevant with specific examples of the issues identified.

The evidence of health benefits provided by the major Mediterranean marine habitats were classified according to the provisioning, regulating and cultural services presented in the Millennium Ecosystem Assessment (2005) [1]. These three services are also embedded in the key topics of the Oceans and Human Health field identified by Strategic Research Agenda ([19,20]): Fish and Health; Leisure, Health, and well-being; and Medicines from the Sea. The adverse health risks from habitat change comprise not only the loss of these services, but also the health risk categories proposed by Ref. [11], adapted to the marine environment. A fourth category, "supporting services", refers to the features of the habitat needed to maintain all the other services, and for this reason the term "supporting services" does not appear explicitly in this section. Regarding cultural services, we concentrated exclusively on recreational benefits, while disregarding any aesthetic or spiritual benefits (e.g., aesthetic enjoyment and spiritual fulfillment) because any links these may have to human health are much less clear.

The term habitat is used in this study to denote an area which is identifiable by its physical features (abiotic environment) and from the plant and animal species that inhabit it (biodiversity) [21].

3. Health benefits provided by the main Mediterranean habitats

In this section, we summarize the evidence of health benefits provided by the major Mediterranean marine habitats in relation to the provisioning, regulating and cultural services they provide, which are detailed in Supplementary Table 1 and schematized in Fig. 2.

3.1. Provisioning services and health

Mediterranean marine habitats contribute to physical health in humans through different provisioning services, among which medicines and seafood are the most important ones. Natural products that are used for other uses (e.g. food additives and cosmetics) are not considered because their contribution to human health is very weak, or non-existent.

3.1.1. Seafood provisioning

Productive marine pelagic and benthic habitats are a source of seafood through marine capture fisheries and aquaculture, and it is well-documented that seafood makes a positive contribution to the so-called "Mediterranean diet". The long-chain omega-3 (or n-3) fatty acids found in seafood provide various health benefits [22]. Research has consistently associated the seafood-rich Mediterranean diet with favorable health outcomes and improved quality of life (reviewed by Refs. [23–26]). Mediterranean habitats provide a high diversity of species, which are exploited by various kinds of fishing gears, and are an essential part of this traditional Mediterranean diet (Supplementary Table 1). This genetic and species diversity is essential for a well-balanced, nutritious diet [27]. The omega-3 fatty acids from these species help to improve cardiovascular health and protect against the development of, for example, breast and prostate cancer, among others (reviewed by Refs. [22,25,26]).

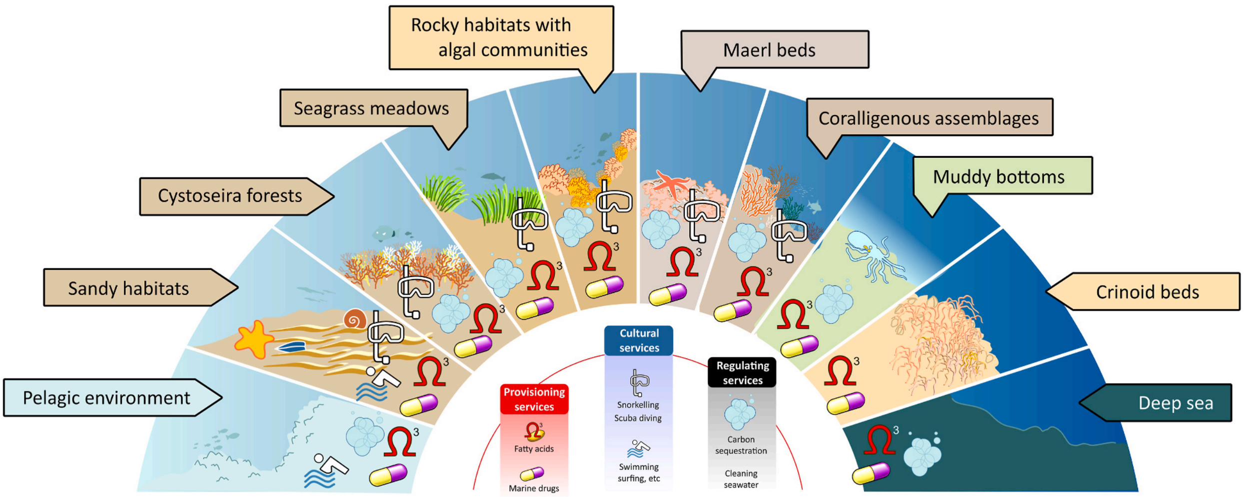

Fig. 2. Scheme of the health benefits provided by the major Mediterranean marine habitats in relation to the provisioning, regulating and cultural services they provide.

As well as protection from cancer and cardiovascular disease, further positive health outcomes have also been linked with seafood intake, including a reduction in symptoms of depression in adults and lower levels of asthmatic and respiratory allergies among children (see reviews by Refs. [22,25,26]). Biological and biochemical research has shown that both pelagic and benthic Mediterranean species are good dietary sources of omega-3 fatty acids (Supplementary Table 1). Pelagic fish species, in particular, are especially important for consumer health because their lipid content (which includes the omega-3 fatty acids) is concentrated in the edible parts of the fish (muscle). These include anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*), bluefin tuna (*Thunnus thynnus*), and Atlantic mackerel (*Scomber scomber*). In contrast, the lipid content of benthic species – for example, red mullets (*Mullus* spp), and European hake (*Merluccius mercluccius*) – which are found in Mediterranean habitats such as maërl beds, muddy bottoms and deep-sea waters, tends to concentrate more in their livers, which are usually not consumed ([25,28,29]).

Importantly, the amount of omega-3 fatty acids found in Mediterranean pelagic fish, such as sardine and anchovy [30] and benthic species, such as red mullet [29], depends on the characteristics of the habitats and, more specifically, on the quantity and quality of prey inhabiting these habitats, which consists of plankton for small pelagic species, and infauna for many benthic species. This is because omega-3 fatty acids are produced by phytoplankton and marine plants (algae and seagrass meadows), consumed by primary consumers in benthic habitats and then passed up through the food chain [31].

3.1.2. Marine drugs

Biodiverse ecosystems have been the source of numerous pharmaceutical compounds over millennia [32]. Drug discovery currently includes sourcing natural bioactive molecules from land and marine based plants, animals, and microorganisms. These original molecules often serve as inspiration for synthetic ones that are later produced as components for new drugs [32].

Marine habitats contain species with bioactive compounds which can become important components of traditional medicine as well as modern pharmaceutical products [33]. Marine habitats rich in species are likely to hold many more compounds that could be used to treat debilitating diseases and alleviate pressures on health systems [32]. The capacity to develop drugs from compounds found in marine species is a prime example of how important a rich biodiversity in different marine habitats can be for human health [34]. Examples of marine-derived drugs currently in use include: antibiotics from marine fungus; compounds isolated from marine sponges used in cancer treatment and to treat viral infections such as herpes; and a neurotoxin isolated from a marine snail with painkiller properties that make it 10 000 times more potent than morphine and without the side effects [32]. Currently, there are several marine compounds isolated from marine sponges, algae, and other marine species that are being investigated for their neuroprotective effects against Alzheimer's Disease [35].

Compounds with bioactive potential have been found in many Mediterranean organisms, most of which are found in benthic habitats, such as tunicates, sponges, bryozoans, and cnidarians ([36–40]), though there are also fish species with bioactive compounds inhabiting the pelagic environment (Supplementary Table 1). In order to fend off predators, competitors, parasites and harmful microorganisms, these species produce a wide variety of bioactive compounds made up of diverse molecules. These include anticancer peptides (with well-known cytotoxic properties and antitumor action against various cancer cell lines), as well as secondary metabolites or toxins, and antitoxins with antibacterial, antifungal and antiviral properties ([36–40]). For example, in a study of 833 species (including both fish and macro-invertebrates) in the Cap de Creus (northwestern Mediterranean), 166 (20 %) were found to have some kind of bioactive potential [39]. Another study investigated the bioactive potential of animals caught and discarded by trawling on crinoid beds (characterized by a high density of the crinoid *Leptometra phalangium*) in the northwestern Mediterranean. While potentially bioactive molecules were found in 14 % of the 64 species investigated, it was strongly suspected that a further 16 % might also produce such compounds as they were congeneric with species that are known to do so [40]. The species reviewed in these two studies showed various types of bioactive potential, including the capacity to produce biotoxins, but also molecules with wide-ranging properties – antibacterial, antifungal, antioxidant, antitumor, cytotoxic, anti-inflammatory, hypertensive and anticoagulant – all of which are of great interest in the search for new marine drugs.

3.2. Regulating services and health

Mediterranean marine habitats contribute to physical health in humans through a number of different regulating services, among the most important of which are their roles in climate regulation, in acting as a buffer against natural disasters, and in the regulation of water quality and pollution.

3.2.1. Climate regulation

All Mediterranean marine habitats contain species that play a major role in the regulation of the regional climate: greenhouse gases such as CO_2 and methane are stored in their tissues (as is the case, for example, with seagrass meadows); carbon is retained in deep bottoms (as is the case with plankton inhabiting the pelagic environment). Such systems are collectively known as 'blue carbon' ecosystems ([41]) (Supplementary Table 1). It is not only vegetated coastal habitats, such as seagrass meadows and *Cystoseira* forests, that act as significant natural carbon sinks [42]; habitats where calcareous species predominate, such as muddy bottoms (where many bivalves are found) and coralligenous assemblages (where gorgonians, corals, bryozoans and other calcifying organisms live) can also do so (e.g. Refs. [43–45]). Through carbon sequestration, all these habitats can therefore help alleviate climate change, which will impact human health and well-being in many ways. One of the most severe impacts is an increasing number of heat waves ([46]). The Mediterranean is most at risk from European heatwaves [47], which are linked to heat-related mortality (mainly from respiratory diseases in the elderly), particularly in people living in Mediterranean cities [48].

3.2.2. Buffers against natural disasters

The Mediterranean tourism sector is exposed to growing pressures linked to the effects of climate change [49]. Coastal erosion, for example, is already evident throughout the Mediterranean, especially in more southern areas. This is just one of the challenges that climate change poses to tourism operators and other stakeholders on the shores of the Mediterranean [49]. Mediterranean coastal habitats such as seagrass meadows lessen the impact of natural disasters because, by buffering strong waves and reducing the loss of sand and shale, they defend shorelines from beach erosion and storm damage [50]. Seagrasses entrap sediment, stabilize the seafloor and thus, prevent erosion of the coasts. When seagrasses trap the sediment, the bottom gets shallower, and the waves break further away from the shoreline, resulting in less coastal erosion during storms [51]. Seagrasses also slow down the movement of ocean currents between the seabed and the tips of their leaves [51]. Storm surges have contributed to coastal disasters causing human casualties, as well as huge damage to assets and coastal infrastructures, in the Mediterranean [52].

3.2.3. Regulation of water quality and pollution

Mediterranean coastal habitats contribute to our well-being by regulating water quality and pollution (Supplementary Table 1), which are key factors in human health. For example, the ability of seagrass meadows to remove heavy metals and microplastics from water is well known (Supplementary Table 1). On the other hand, filtering organisms can contribute to cleaner seawater by filtering water and regulating phytoplankton densities (Supplementary Table 1). Bivalves, such as mussels and oysters, and sponges inhabiting habitats such as rocky habitats and coralligenous assemblages, can absorb and transform pollutants [53]. Therefore, in different ways, these Mediterranean habitats lower the risks of gastroenteritis and other diseases that can occur when humans come into contact with polluted water, usually while swimming or surfing, or through seafood consumption ([54,55]). Furthermore, deposit-feeding species, such as sea cucumbers inhabiting muddy bottoms, contribute to water purification by nutrient cycling in organically-enriched sediments [56].

3.3. Cultural services and health

Mediterranean marine habitats are appreciated as places of outstanding natural beauty, providing inspiration, as well as spaces for leisure (in the form of tourism and recreation), all of which fosters human health and well-being. There are studies (summarized in Supplementary Table 1) showing the health benefits of physical activity in Mediterranean pelagic and benthic habitats ([15,18]). Non-motorized water sports that require physical effort, such as swimming, scuba diving, kayaking, sailing or surfing, have a positive impact on the physical and mental health of those who take part in these activities, in the Mediterranean [14] and in other seas and oceans ([15,57–59]). When carried out in well-preserved habitats, such sports can be highly effective components of wellness and health recovery programs, and can be used as a community tool for preventative health and rehabilitation strategies ([15,15,57–59]). The COVID-19 pandemic lockdowns showed that enjoying nature was important for many people's health and well-being [60]. In Spain, for example, people under strict lockdown perceived that nature helped them to cope with lockdown measures; and emotions were more positive among individuals with accessible outdoor spaces and blue-green elements within view of their homes [61]. The presence, accessibility and proximity of green and blue spaces determine how positive the effects on human health can be, although the role of habitat features (including the abiotic environment and biodiversity) in human health and well-being remains underexplored [11].

3.3.1. Mental health

Interviews with water sports instructors working in the Cap de Creus Natural Park (northwestern Mediterranean) provide evidence that sea swimming, kayaking, sailing, surfing, windsurfing and stand-up paddle boarding (SUP), carried out in the pelagic habitat, and scuba diving and freediving, carried out in rocky and coralligenous habitats, are highly beneficial for people with mental health problems ([15,18]). Doing water sports regularly, as well as visiting the coast, can improve the quality of life not only of healthy people, but also patients with various medical conditions that affect their physical and/or mental/emotional/psychological well-being ([13,15,15,57–59]). Such sports offer benefits that go much further than simply enhancing people's fitness. These activities are associated with more self-control, concentration and self-reflection and reduced perceived stress, among other outcomes, evidence for which is found in studies carried out in different seas and oceans ([13,57]; [58 [15,15,59]). Therefore, sea-based water sports in well-preserved marine environments could be considered as tools for promoting health and well-being, providing they are accompanied by measures to limit their environmental impact on fragile sites [15].

3.3.2. Physical health

The results of the interviews described in the previous section also support the idea that these non-motorized water sports generally improve the physical condition of the human body, including better aerobic strength and coordination, increased muscle strength and endurance, and improvements in lung capacity, control of body weight, mobility and muscle development, body posture and cardiovascular function, among others (reviewed by Ref. [15]). Specific benefits for individuals with physical disabilities, such as paralysis, were also reported [15]. These positive health effects are supported by works carried out in other seas and oceans (reviewed by Refs. [15,57,58]) and highlight the potential benefits of non-motorized sports carried out in Mediterranean marine habitats for people suffering from post-traumatic stress disorder, tetraplegia or spinal cord injuries (among other conditions) and for others overcoming the side effects of treatments such as chemotherapy [15].

4. Implications of loss or degradation of Mediterranean marine habitats for human health and well-being

In this section, the adverse effects that the degradation or loss of Mediterranean marine habitats can have on human health are analyzed in a context where people and business organizations are increasingly turning to marine ecosystems for the development of the Blue Economy.

4.1. Loss of provisioning, regulating and cultural services

Human activities in the Mediterranean are major drivers of marine habitat change and biodiversity loss. These activities include fisheries, particularly bottom trawling ([3,5,62]); aquaculture [63]; tourism activities, such as leisure boating [64] and cruising ([15, 65]); and offshore energy projects, including those producing renewable energy [66]. As a result of such activities, the provisioning, regulating and cultural services listed in Supplementary Table 1 are lost or degraded in various degrees, depending on the activity and the habitat. One particular example is the destruction of essential habitats (i.e. habitats that are essential for the life cycle of fishes), such as coralligenous assemblages, maërl beds, seagrass meadows and crinoid beds, which has a major impact on the seafood provisioning services [29].

Furthermore, the destruction of habitats inhabited by species with bioactive compounds results in the loss of these species and the consequent loss of their biomedical potential which, in turn, harms human health. This relates not only to coastal habitats, such as coralligenous and rocky habitats, where most studies have been carried out (see e.g. Ref. [36]), but also to other deeper, offshore habitats that are still being explored, including crinoid beds [40], and the deep seas [67]. Many Mediterranean species with bioactive compounds are already considered vulnerable. For example, 40 % of the species that have been shown to have bioactive potential in the marine protected area of Cap de Creus are classified as vulnerable to human activities [39].

Also, the destruction or degradation of Mediterranean habitats through trawling, anchoring and other activities, including new floating offshore wind farms, threatens habitats that provide important regulating services linked to human health and well-being, such as climate change mitigation through carbon sequestration, while limiting the possibilities marine habitats have to reduce health risks associated with water pollution. This ongoing destruction or degradation also deprives people of the cultural services important for human health and well-being (e.g., diminishing blue spaces where humans can, for example, practice sustainable activities that promote good health) (Supplementary Table 1). For example, surfers may be at risk of exposure to and colonization by clinically important antibiotic-resistant *E. coli* in polluted coastal waters (pelagic environment), as has been observed in the United Kingdom [68]. Another example is the degradation of coralligenous assemblages, which are the most popular places for scuba diving, an activity which, in a study carried out in the Mediterranean Sea, has been shown to be beneficial for the mental health of practitioners [18].

4.2. Contact with species that cause harm

Some Mediterranean species can cause harm to people who come into contact with them. This has mainly involved sharks, venomous fish – such as weevers from the genus *Trachinus* [69], certain species of jellyfish [70] and harmful algal blooms, or HABs [71]. However, whereas sharks are in decline due to overfishing [72], some venomous and toxic species are on the rise due to global climate change. This is the case with stinging jellyfish species such as *Pelagia noctiluca* [73], and HABs such as those produced by the benthic dinoflagellate *Ostreopsis* spp [71]. The latter produces a range of toxins (including palytoxin) that pose a risk for public health: HABs involving this dinoflagellate have been linked to sporadic acute respiratory symptoms and general malaise among people on a number of Mediterranean beaches who were exposed to marine aerosols [74]. Climate change and the intensification of human activities are leading to rapidly increasing numbers of non-indigenous species (NIS), known also as non-native or alien species, some of which constitute a threat not only to human health, but also to the health of ecosystems ([1,75]). For example, the venomous lionfish (*Pterois miles*) was originally restricted to the Indian Ocean, and but has expanded into the Mediterranean Sea [75]. The spines of this fish contain venom that causes pain, nausea, and even paralysis to people who touch them [76]. It should be noted, however, that when this fish is handled appropriately, it is still a source of seafood (provisioning service).

The increasing presence in the Mediterranean Sea of tetrodotoxin (TTX) is also linked to sea warming. Bacterially-produced TTX, which is a powerful neurotoxin, is present in many puffer fish (*Lagocephalus* spp.) and a number of other marine organisms [77]. Marine puffer fish species are mainly distributed in tropical and subtropical areas but they are spreading to temperate areas of the Mediterranean Sea as sea temperatures rise [78]. For example, in the eastern Mediterranean Sea, there have been reports of TTX poisoning linked to ingestion of *Lagocephalus sceleratus*, an invasive species which is putting consumers in serious danger (reviewed by Refs. [26,79]). Human intoxications manifest in diffuse muscle weakness, vomiting, tachycardia and hypertension, and can be fatal [80]. A recent study listed 93 reported cases of intoxication and 12 deaths due to the consumption of this species in the Mediterranean Sea [80]. The likelihood of catching *L. sceleratus* in the Mediterranean Sea is increasing and consequently, so is the possibility of it accidently ending up in the food chain [81]. However, as with the lionfish, when handled appropriately, this species can still be a source of seafood (provisioning service) as is the case in Japan, where puffer fish (locally known as "fugu") are highly-prized gastronomically.

Furthermore, the spread of people and infrastructure into biodiverse habitats, which is expected to increase significantly due to the development of aquaculture plants and offshore wind farms in the Mediterranean Sea, may provide new pathways for some NIS and opportunistic species, including, for example, harmful jellyfish. When natural habitat conditions are replaced by manmade infrastructure, new artificial substrates appear which provide ideal conditions for the sessile polyp phase of jellyfish, thus playing a crucial role in their proliferations ([82,83]).

It must be stressed, however, that while there is a significant amount of research (revised by Ref. [11]) on terrestrial and freshwater ecosystems, showing that contact with wildlife may lead to injuries through encounters with poisonous plants, fungi, snakes and amphibians, as well as large predators, such as bears or alligators, research on this topic in the context of marine ecosystems is relatively scarce.

4.3. Exposure to agents causing human infectious diseases and other diseases

Many infectious diseases (i.e. diseases caused by pathogens) can be, or have the potential to be, transmitted from wild animals to humans, sometimes directly or else via vectors, such as insects or parasites, etc. [1]. Natural ecosystems tend to constrain such diseases to particular geographical areas or particular seasons. However, changes to habitats can be beneficial to certain disease vectors or to the pathogens themselves, resulting in higher rates of infection [1].

In the Mediterranean Sea, we found some evidence showing that habitat change – due to fishing, tourism activities, sea warming, acidification and pollution, etc. – influences the risk of transmission of infectious diseases from marine species to humans, often involving foodborne disease. For example, gastroenteritis caused by *Vibrio* (an opportunistic bacterial pathogen) infections in contaminated seafood is now a major public health concern [84]. Vibrio species are becoming increasingly common in marine environments as sea-surface temperatures rise [85], and, therefore, *Vibrio* infections in Mediterranean coastal areas (which not only affect humans, but also benthic animals, such as benthic corals) appear to be climate-linked ([86,87]). The risk of disease from contaminated seafood may also be augmented by climate change, as is the case with salmonellosis, which is more prevalent in areas with higher temperatures and is also associated with extreme precipitation and flooding [84]. Combined with a growing and increasingly elderly population, annual cases of *Vibrio* infections may double in the coming decades, stressing the need for increased individual and public health awareness in many countries [88].

Having said that, most of the evidence showing how habitat changes influence the risk of transmission of infectious diseases to humans comes from terrestrial and freshwater ecosystems, where habitat loss and degradation has been linked to human health, including outbreaks of infectious diseases such as Ebola, malaria, dengue, zika, SARS-COV-2, etc. ([10,89]). As natural habitats around the world are increasingly disturbed, destroyed, or transformed into agricultural, industrial or urban areas, the interaction between local communities and the flora and fauna around them also changes. One potential consequence of this is increased contact between humans and animals carrying viruses, bacteria and other pathogens [90].

5. Future research needs

There is still much to learn about the links between marine habitat features (e.g. biodiversity and abiotic factors), habitat services and human health and well-being. Further research is required and this needs to be tackled in an integrated way (benefits, risks and threats).

With regard to the provisioning services provided by marine habitats, new studies are needed to ascertain how certain types of fisheries affect the omega-3 fatty acids that benthic habitats provide. Trawling, for example, can reduce the abundance and biomass of infauna, which serves as food source for many benthic fish species ([62,91]). Fisheries can also reduce the omega-3 fatty acid stocks provided by pelagic species such as krill [92] and mesopelagic fish [93]. Global climate change can reduce the omega 3 fatty acids provided by pelagic habitats by reducing the quantity and quality of plankton, which serves as food source for small pelagic fish such as sardines and anchovies [94] and this also requires further investigation. Some studies have predicted substantial declines in the essential fatty acid, eicosapentaenoic acid (one of several omega-3 fatty acids), over the next century [95], but none have yet investigated the serious deleterious effects this may have on fisheries and human health. Besides human nutrition, there is a need to evaluate the effect of trawling and other maritime activities on benthic habitats that are particularly rich in species with bioactive compounds from which new marine drugs may be obtained, with a view to protecting these habitats. Also, robust investigation is required into the overexploitation of vulnerable species by the biotechnology industry (e. g. the case of the American horseshoe crab (*Limulus polyphemus*) [96] or by the so-called "traditional medicine" business in certain Asian countries [97].

With regard to the regulation services provided by marine habitats related to health, further studies are needed to assess the extent to which greenhouse gases can be stored in different Mediterranean habitats, and the capacity of certain habitats, such as seagrass meadows, to become buffers against natural disasters and to regulate water quality and pollution.

With regard to the cultural services provided by marine habitats, to date, no study has investigated which marine habitat features facilitate better physical and mental health outcomes. Worldwide, such specific studies have been only conducted in terrestrial and freshwater ecosystems, where enhanced biodiversity has been shown to promote physical activity. For example, biodiverse neighborhoods tend to have more trees which provide a setting for social interaction and improved social cohesion. In addition, healthier positive emotions have been linked with habitats that provide specific ecological elements, such as greater species richness of various taxa of, for example, trees and birds, high vegetation density and landscape heterogeneity, and higher abundance of some taxa (reviewed by Refs. [10,11]).

Furthermore, new studies are needed to understand how marine habitats can help to maintain mental health and well-being by providing environments for physical activity and social interaction, or by providing restorative environments that stimulate interest, and provide pleasant, calm spaces that help restore psychological well-being ([10,11]). To our knowledge, no study has yet investigated the links between transcendent experiences such as humility, awe and reflection and place attachment or identity and health in marine ecosystems. Again, such studies have only been conducted in the context of terrestrial and freshwater ecosystems, where, for example, qualitative research has shown that people's sense of humility and awe is boosted while observing wildlife, and quantitative research has shown that the number of habitat types, and species richness of different taxa (from plants and birds to butterflies) were positively associated with reflection and people's place attachment and identity (reviewed by Refs. [10,11]).

Finally, new studies are needed to investigate how changes to marine habitats give rise to the geographical expansion of marine species that are harmful to human health – via consumption or contact – in the form of venom or other biotoxins (e.g. tetrodotoxins and ciguatoxins), infectious agents such as parasites, virus and bacteria, or allergenic compounds.

6. Discussion

Protecting and restoring marine habitats, particularly by means of marine protected areas (MPAs), is an essential part of protecting and maintaining human health. MPAs are playing an increasingly important role due to globally-agreed goals that seek to protect 30 % of the world's oceans by 2030 [98]. In line with this, the official target of the EU's recently approved Biodiversity Strategy for 2030 [99] is to provide protection for 30 % of marine and terrestrial areas, with 10 % of this being under strict protection. However, at present, less than 10 % of the Mediterranean Sea has been officially granted protected status [100]. At the same time, only a few types of marine habitats – namely seagrass meadows, rocky reefs (including coralligenous assemblages), and maërl beds – are taken into consideration by the EU Habitats Directive [101]. The Directive includes habitats per se, as is the case of the seagrass meadows of *Posidonia oceanica* (classed as a priority habitat, code 1120 in Annex I of the Habitats Directive) and/or areas defined by the main species conforming them, as is the case with maërl beds (the two main maërl species, *Lithothamnion corallioides* and *Phymatolithon calcareum*, appear in Annex I as part of the Sandbanks, code 1110, and in Annex V). Other habitats such as crinoid beds, despite their ecological importance (due to their ability to fix large quantities of nutrients from the water column to the substrate), do not have any special protection in the Mediterranean [40]. The Habitats Directive is the EU's main instrument for protecting marine species and habitats and Member States are required to take appropriate management measures to ensure the 'Favorable Conservation Status' of these habitats. The European Union is working on a nature restoration law, which aims to return nature and ecosystems to good conservation condition [102]. The new rules would aim to restore habitats in EU countries that are in poor condition. This concerns ecosystems on land, and in coastal, marine and freshwater habitats. The goal would be to put restoration measures in place for at least 30 % of these habitats EU-wide by 2030.

Habitat change and loss reduces the potential of marine ecosystems to provide healthy seafood, innovative pharmaceutical treatments, and the opportunity to take part in healthy recreational and sporting activities. At the same time, among other dangers, it increases the risk of disease and the detrimental health consequences of climate change.

Mitigation strategies of prevention, limitation, or management of habitat damage are crucial in addressing the impact of habitat change on human health. Adaptation strategies to protect individuals and populations from the consequences of habitat change are also necessary. The aims of the United Nations' *Millennium Development Goals* (MDGs) are "to improve human well-being by reducing poverty, hunger, and child and maternal mortality; ensuring education for all; controlling and managing diseases; reducing gender disparities; ensuring sustainable development; and pursuing global partnerships". The ongoing degradation or loss of habitats and the harmful consequences this has for human health is a significant impediment to achieving these MDGs. Furthermore, the negative impacts more often affect the more vulnerable human populations globally: the well-being of poorer populations is more directly impacted by changes in ecosystems than that of wealthier populations ([1,103]). Historically, with increased demand from people from wealthier areas, poorer people face a disproportionate loss of access to ecosystem services ([1,104]). In particular, seafood provisioning is an important issue in low-income coastal regions, because the health of the communities living there, as in other parts of the world, often depends directly on locally productive ecosystems to meet their basic nutritional needs ([1,105]). In the Mediterranean, four low-income countries (Türkiye, Tunisia, Algeria and Egypt), make up about 50 % of the total fishing capacity, which illustrates the importance of local fisheries for these countries. Coastal habitats in developing countries, which had previously provided local populations with food and livelihoods, can be rapidly transformed into huge areas of intensive aquaculture, whose produce – shrimp is a common example – is mostly exported. Overfishing is another problem and many areas negatively impacted by it are officially classed by the UN's Food and Agriculture Organization (FAO) as LIFDCs, or low-income, food-deficit countries. Large foreign fishing fleets catch significant quantities of fish off the coasts of various West African countries. But this contributes little to the nutritional needs of local populations, since most of the catch is destined for Europe and Asia ([1,106]). Such developments widen the gap between rich and poor countries, in terms of health and social conditions, leading to a negative spiral of more poverty, worsening health and further degradation of ecosystems.

Various regional, national and international policy makers are increasingly recognizing the links between human health and biodiversity, including those of marine habitats [19]. However, our understanding of the mechanisms and causal pathways that link biodiversity and other features of marine areas to human health is still limited and this, in turn, places constraints on efforts to promote nature-based public health solutions, and informed debate aimed at influencing public policy. In order to facilitate the integration of marine policy with research in this field, the relationships between marine habitats, biodiversity, and human health need to be better identified and defined. Determining the specific causal pathways by which certain marine habitat features affect human health is a crucial aspect of such research. One way forward is to formulate conceptual frameworks that can be exploited in diverse ways, such as identifying health indicators and interventions, policy making, and communication and dissemination among the broad range of stakeholders ([10,11]). A good example of this is the conceptual framework linking biodiversity and human health developed by Ref. [11], which was mainly derived from terrestrial and freshwater contexts; a similar framework adapted to the peculiarities of marine ecosystems needs to be developed in the future.

7. Conclusions

Overall, this study shows that Mediterranean marine habitats are valuable for human health and well-being, thus highlighting the need to conserve as many of them as possible. Major Mediterranean marine habitats provide various provisioning, cultural and regulating services that improve physical and mental health in a number of different ways. These include: (i) the provision of seafood rich in omega-3 fatty acids, which help to reduce the risk of developing certain types of illnesses; and also, species that produce bioactive compounds that are potential sources of new drugs; (ii) the provision of blue spaces – areas of water suitable for leisure and recreational activities able to inspire, educate, and appeal to the aesthetic senses – that not only increase physical and psychological health, but also foster an individual and collective sense of place and identity and contribute to improving social relations; and (iii) the regulation of climate change, and of water quality and pollution, for example via sequestration of carbon and heavy metals, thus reducing the associated health risks.

Protecting and restoring marine habitats and biodiversity (particularly through marine protected areas) is crucial for promoting human health and well-being. In order to facilitate the integration of marine policy and research on conservation and public health preservation, we need to better identify and characterize the specific causal pathways via which certain features of marine habitats – including biotic factors (e.g. marine biodiversity) and abiotic factors (e.g. water quality) – affect human health and well-being. This could be achieved through specific conceptual frameworks, as long as these are adapted to the peculiarities of the marine environment.

There is still much to learn about the links between marine habitat features, habitat services and human health and well-being. Further research is required and this needs to be tackled in an integrated way (benefits, risks and threats). With regard to the provisioning services provided by marine habitats, new studies are needed to ascertain how fisheries and climate change affect the omega-3 fatty acids that marine habitats provide. With regard to the regulation services provided by marine habitats related to health, further studies are required to assess the extent to which greenhouse gases can be stored in different Mediterranean habitats, and the capacity of certain habitats to become buffers against natural disasters and to regulate water quality and pollution. With regard to the cultural services provided by marine habitats, studies on which marine habitat features facilitate better physical and mental health outcomes are needed. Furthermore, new studies are necessary to understand how marine habitats can help to maintain mental health and well-being by providing environments for physical activity and social interaction, or by providing restorative environments. Finally, new studies are needed to investigate how changes to marine habitats give rise to the geographical expansion of marine species that are harmful to human health – via consumption or contact.

Policy makers should recognize the links between human health and marine biodiversity and should promote nature-based public health solutions. Furthermore, mitigation strategies of prevention, limitation, or management of habitat damage are crucial in addressing the impact of habitat change on human health.

Ethics

All authors have contributed equally to the conception and design of the study, the analysis and interpretation of papers reviewed; and drafting the article. J. Lloret coordinated all tasks. All the authors approve its publication.

Data availability

No data was used for the research described in the article, and therefore no data has been deposited into any publicly available repository.

CRediT authorship contribution statement

Josep Lloret: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Alfredo García-de-Vinuesa:** Writing – original draft, Investigation, Formal analysis. **Montserrat Demestre:** Writing – review & editing, Writing – original draft, Project administration, Investigation, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

[1] Millennium Ecosystem Assessment, Ecosystems and Human Well-Being: Synthesis, Island Press, Washington, DC, 2005, p. 155. https://www.millenniumassessment.org/documents/document.356.aspx.pdf.
[2] IPBES, IPBES Global Assessment Summary for Policymakers, 2019. https://www.ipbes.net/news/ipbes-global-assessment-summary-policymakers-pdf.
[3] S.F. Thrush, P.K. Dayton, Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity, Annu. Rev. Ecol. Syst. 33 (2002) 449–473, https://doi.org/10.1146/annurev.ecolsys.33.010802.150515.
[4] L. Airoldi, M. Beck, Loss, status and trends for coastal marine habitats of Europe, Ocean Mar Biol 45 (2007) 345–405.
[5] M. Demestre, S. de Juan, P. Sartor, A. Ligas, Seasonal closures as a measure of trawling effort control in two Mediterranean trawling grounds: effects on epibenthic communities, Mar. Pollut. Bull. 56 (2008) 1765–1773, https://doi.org/10.1016/j.marpolbul.2008.06.004.
[6] C.M. Duarte, Global Loss of Coastal Habitats. Rates, Causes and Consequences, Fundación BBVA, 2019. https://www.biophilia-fbbva.es/wp-content/uploads/sites/3/2019/07/DE_2009_Global_Loss.pdf.
[7] European Marine Board, Linking Oceans and Human Health: A Strategic Research Priority for Europe. Position Paper 19 of the European Marine Board, 2013. Ostend, Belgium.
[8] L.E. Fleming, N. McDonough, M. Austen, L. Mee, M. Moore, P. Hess, Michael H. Depledge, et al., Oceans and human health: a rising Tide of challenges and opportunities for Europe, Mar. Env. Res. 99 (2014) 16–19.
[9] N. Röbbel, Green Spaces: an Invaluable Resource for Delivering Sustainable Urban Health, United Nations, 2021. https://www.un.org/en/chronicle/article/green-spaces-invaluable-resource-delivering-sustainable-urban-health.
[10] R. Aerts, O. Honnay, A. Van Nieuwenhuyse, Biodiversity and human health: mechanisms and evidence of the positive health effects of diversity in nature and green spaces, Br. Med. Bull. 127 (1) (2018) 5–22, https://doi.org/10.1093/bmb/ldy021Aertsetal2018.
[11] M.R. Marselle, T. Hartig, D.T.C. Cox, S. de Bell, S. Knapp, S. Lindley, M. Triguero-Mas, K. Böhning-Gaese, M. Braubach, P.A. Cook, S. de Vries, A. Heintz-Buschart, M. Hofmann, K.N. Irvine, N. Kabisch, F. Kolek, R. Kraemer, I. Markevych, D. Martens, R. Müller, M. Nieuwenhuijsen, J.M. Potts, J. Stadler, S. Walton, S.L. Warber, A. Bonn, Pathways linking biodiversity to human health: a conceptual framework, Environ. Int. 150 (2021) 106420, https://doi.org/10.1016/j.envint.2021.106420.
[12] P.Y. Nguyen, T. Astell-Burt, H. Rahimi-Ardabili, X. Feng, Green space quality and health: a systematic review, Int. J. Environ. Res. Public Health 18 (21) (2021) 11028, https://doi.org/10.3390/ijerph182111028, 20.
[13] L.R. Elliott, Mathew P. White, James Grellier, Siân E. Rees, Ruth D. Waters, Lora E. Fleming, Recreational visits to marine and coastal environments in england: where, what, who, why, and when? Mar. Policy 97 (2018) 305–314.
[14] J. Lloret, S. Gómez, M. Rocher, A. Carreño, J. San, E. Inglés, The potential benefits of water sports for health and well-being in marine protected areas: a case study in the Mediterranean, Annals Leis. Res. (2021), https://doi.org/10.1080/11745398.2021.2015412.
[15] Ma P. White, L.R. Elliott, M. Gascon, B. Roberts, L.E. Fleming, Blue space, health and well-being: a narrative overview and synthesis of potential benefits, Env. Res. 191 (2020) 110169.
[16] M.P. White, S. Pahl, K. Ashbullby, S. Herbert, M.H. Depledge, Feelings of restoration from recent nature visits, J. Env. Psychcol. 35 (2013) 40–51.
[17] M.P. White, I. Alcock, J. Grellier, B.W. Wheeler, T. Hartig, S.L. Warber, L.E. Fleming, Spending at least 120 minutes a week in nature is associated with good health and wellbeing, Sci. Rep. 9 (1) (2019) 7730.
[18] A. Carreño, M. Gascón, C. Vert, J. Lloret, The beneficial effects of short-term exposure to scuba diving on human mental health, Int. J. Env. Res. Pub Health 17 (7238) (2020) 1–17.
[19] H2020, SOPHIE Consortium, A Strategic Research Agenda for Oceans and Human Health in Europe; H2020, SOPHIE Project, Ostend, Belgium, 2020. ISBN 9789492043894.
[20] J. Lloret, R. Abós-Herràndiz, S. Alemany, R. Allué, J. Bartra, M. Basagaña, E. Berdalet, M. Campàs, et al., The roses ocean and human health chair: a new way to engage the public in Oceans and human health challenges, Int J Environ Res Public Health 17 (14) (2020) 5078, https://doi.org/10.3390/ijerph17145078, 2020 Jul 14.
[21] European Environment Agency, An Introduction to Habitats, 2023. https://www.eea.europa.eu/en/topics/in-depth/biodiversity/an-introduction-to-habitats.
[22] E.J. Brunner, P.J. Jones, S. Friel, M. Bartley, Fish, human health and marine ecosystem health: policies in collision, Int. J. Epidemiol. 38 (1) (2009) 93–100, https://doi.org/10.1093/ije/dyn157.
[23] F. Sofi, R. Abbate, G.F. Gensini, et al., Adherence to Mediterranean diet and health status: meta-analysis, Brit. Med. Jour. 337 (2008) a1344.
[24] F. Sofi, The Mediterranean diet revisited: evidence of its effectiveness grows, Curr. Opin. Cardiol. 24 (5) (2009) 442–446.
[25] J. Lloret, Human health benefits supplied by Mediterranean marine biodiversity, Mar. Poll. Bull. 60 (2010) 1640–1646.
[26] J. Lloret, H.-J. Rätz, J. Lleonart, M. Demestre, Challenging the links between seafood and human health in the context of global change, J. Mar. Biol. Assoc. U. K. 96 (1) (2016) 29–42.
[27] A.S. Bernstein, Biological diversity and public health, Annu. Rev. Public Health 35 (2014) 153–167, https://doi.org/10.1146/annurev-publhealth-032013-182348.
[28] J. Lloret, G. Shulman, M. Love, Condition and Health Indicators of Exploited Marine Fishes, Wiley-Blackwell, 2014. http://eu.wiley.com/WileyCDA/WileyTitle/productCd-047067024X,descCd-description.html, 978-0-470-67024-8.
[29] A. García-de-Vinuesa, M. Demestre, J. Lloret, Fatty acids as trophic markers and indicators of the quality of benthic habitats: the example of maerl and crinoid beds in the Northwestern Mediterranean, J. Sea Res. 187 (2022) 102254, https://doi.org/10.1016/j.seares.2022.102254.
[30] S. Biton-Porsmoguer, R. Bou, E. Lloret, M. Alcaide, J. Lloret, Fatty acid composition and parasitism of European sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) populations in the northern Catalan Sea in the context of changing environmental conditions, Conserv Physiol 8 (1) (2020) coaa121, https://doi.org/10.1093/conphys/coaa121.
[31] J. Dalsgaard, S.J. John, G. Kattner, D. Müller, W. Hagen, Fatty acid trophic markers in pelagic marine environment, Adv. Mar. Biol. (2003) 227–318.
[32] P. Murage, H.R. Batalha, S. Lino, K. Sterniczuk, From drug discovery to coronaviruses: why restoring natural habitats is good for human health, BMJ 375 (2021) n2329, https://doi.org/10.1136/bmj.n2329.
[33] D.H. Ngo, T.S. Vo, D.N. Ngo, I. Wijesekara, S.K. Kim, Biological activities and potential health benefits of bioactive peptides derived from marine organisms, Int. J. Biol. Macromol. 51 (4) (2012) 378–383, https://doi.org/10.1016/j.ijbiomac.2012.06.001.
[34] R.R.N. Alves, I.M.L. Rosa, Biodiversity, traditional medicine and public health: where do they meet? J. Ethnobiol. Ethnomed. 3 (2007) 14, https://doi.org/10.1186/1746-4269-3-14.
[35] M. Silva, P. Seijas, P. Otero, Exploitation of marine molecules to manage Alzheimer's disease, Mar. Drugs 19 (2021) 373, https://doi.org/10.3390/md19070373.
[36] M.J. Uriz, D. Martin, X. Turon, E. Ballasteros, R. Hughes, C. Acebal, An approach to the ecological significance of chemically mediated bioactivity in Mediterranean benthic communities, Mar. Ecol. Prog. Ser. 70 (1991) 175–188, https://doi.org/10.3354/meps070175.

[37] M. Menna, Antitumor potential of natural products from Mediterranean ascidians, Phytochem Rev 8 (2) (2009) 461–472, https://doi.org/10.1007/s11101-009-9131-y. Medpan 2023. The system of Mediterranean Marine Protected Areas in 2020.
[38] C. Avila, C. Angulo-Preckler, Bioactive compounds from marine heterobranchs, Mar. Drugs 18 (2020) 657.
[39] A. Carreño, J. Lloret, The vulnerability of fish and macroinvertebrate species with bioactive potential in a Mediterranean marine protected area, Aquat. Conserv.: Mar. Freshw. Ecosys. 31 (6) (2021) 1334–1345.
[40] A. García-de-Vinuesa, M. Demestre, A. Carreño, J. Lloret, The bioactive potential of trawl discard: case study from a crinoid bed off blanes (North-Western mediterranean), Mar. Drugs 19 (2021) 83, https://doi.org/10.3390/md19020083.
[41] N. Hilmi, R. Chami, M.D. Sutherland, J.M. Hall-Spencer, L. Lebleu, M.B. Benitez, L.A. Levin, The role of blue carbon in climate change mitigation and carbon stock conservation, Front. Clim. 3 (2021) 710546, https://doi.org/10.3389/fclim.2021.710546.
[42] D. Krause-Jensen, C. Duarte, Substantial role of macroalgae in marine carbon sequestration, Nature Geosci 9 (2016) 737–742, https://doi.org/10.1038/ngeo2790.
[43] M. Canals, E. Ballesteros, Production of carbonate particles by phytobenthic communities on the Mallorca Menorca shelf, northwestern Mediterranean Sea, DeepSea Res II 44 (1997) 611–629.
[44] J. Garrabou, J.B. Ledoux, N. Bensoussan, D. Gómez-Gras, C. Linares, Sliding toward the collapse of mediterranean coastal marine rocky ecosystems, in: J. G. Canadell, R.B. Jackson (Eds.), Ecosystem Collapse and Climate Change. Ecological Studies, vol. 241, Springer, Cham, 2021, https://doi.org/10.1007/978-3-030-71330-0_11.
[45] M.T. Burrows, P. Moore, H. Sugden, C. Fitzsimmons, C. Smeaton, W. Austin, R. Parker, S. Kröger, C. Powell, L. Gregory, W. Procter, T. Brook, Assessment of Carbon Capture and Storage in Natural Systems within the English North Sea (Including within Marine Protected Areas), A North Sea Wildlife Trusts, Blue Marine Foundation, WWF and RSPB commissioned report, 2021.
[46] A.J. McMichael, E. Lindgren, Climate change: present and future risks to health, and necessary responses, J. Intern. Med. 270 (5) (2011) 401–413, https://doi.org/10.1111/j.1365-2796.2011.02415.x, 2011 Nov.
[47] Q. Schiermeier, Mediterranean most at risk from European heatwaves, Nature (2010), https://doi.org/10.1038/news.2010.238.
[48] D. D'Ippoliti, P. Michelozzi, C. Marino, et al., The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project, Environ. Health 9 (2010) 37, https://doi.org/10.1186/1476-069X-9-37.
[49] J. Fosse, S. Klarwein, I. Kosmas, A. Gonzalez, Ecosystem Approach for a Better Environmental Management of Coastal and Maritime Tourism in the Mediterranean Region (Versión 1), Zenodo, 2021, https://doi.org/10.5281/zenodo.5137940.
[50] E. Gacia, C.M. Duarte, Sediment retention by a Mediterranean Posidonia 410 oceanica meadow: the balance between deposition and resuspension, Estuar. Coast Shelf Sci. 411 (52) (2001) 505–514.
[51] Adriadapt, Protection and Restoration of Posidonia Oceanica Meadows, Interreg Italy-Croatia, 2022. http://adriadapt.eu/adaptation-options/protection-and-restoration-of-posidonia-oceanica-meadows/.
[52] A. Amores, M. Marcos, D.S. Carrió, L. Gómez-Pujol, Coastal impacts of storm gloria (january 2020) over the north-western mediterranean, nat, Hazards Earth Syst. Sci. 20 (2020) 1955–1968, https://doi.org/10.5194/nhess-20-1955-2020,2020.
[53] J. Wang, K. Remon Koopman, F.P.L. Collas, L. Posthuma, T. de Nijs, R.S.E.W. Leuven, J.A. Hendricks, Towards an ecosystem service-based method to quantify the filtration services of mussels under chemical exposure, Sci. Tot. Env. 763 (2021) 144196.
[54] R.W. Haile, J.S. Witte, M. Gold, R. Cressey, C. McGee, R.C. Millikan, A. Glasser, N. Harawa, C. Ervin, P. Harmon, J. Harper, J. Dermand, J. Alamillo, K. Barrett, M. Nides, G. Wang, The health effects of swimming in ocean water contaminated by storm drain runoff, Epidem 10 (4) (1999) 355–363.
[55] C. O'Halloran, M. Silver, Health risks and benefits among surfers after exposure to seawater in monterey bay, santa cruz county, California, United States, Front. Mar. Sci. 8 (2021) 714831, https://doi.org/10.3389/fmars.2021.714831.
[56] T. MacTavish, J. Stenton-Dozey, K. Vopel, C. Savage, Deposit-feeding sea cucumbers enhance mineralization and nutrient cycling in organically-enriched coastal sediments, PLoS One 7 (11) (2012) e50031, https://doi.org/10.1371/journal.pone.0050031.
[57] M. Gascon, W. Zijlema, C. Vert, M. White, M.J. Nieuwenhuijsen, Outdoor blue spaces, human health and well-being: a systematic review of quantitative studies, Int J Hyg Env Health 220 (8) (2017) 1207–1221.
[58] B. Eigenschenk, A. Thomann, M. McClure, M. Davies, M. Gregory, U. Dettweiler, E. Inglés, Benefits of outdoor sports for society. A systematic literature review and reflections on evidence, Int J Env Res Public Health 16 (2019) 6.
[59] M. Rocher, B. Silva, G. Cruz, R. Bentes, J. Lloret, E. Inglés, Benefits of outdoor sports in blue spaces. The case of school nautical activities in viana do castelo, Int J Env Res Public Health 17 (22) (2020) 1–14.
[60] A.S. Naomi, Access to nature has always been important; with COVID-19, it is essential, HERD: Health Environments Research & Design Journal 13 (4) (2020) 242–244, https://doi.org/10.1177/1937586720949792.
[61] S. Pouso, Á. Borja, L.E. Fleming, E. Gómez-Baggethun, M.P. White, M.0C. Uyarra, Contact with blue-green spaces during the COVID-19 pandemic lockdown beneficial for mental health, Sci. Total Environ. 20 (756) (2021) 143984, https://doi.org/10.1016/j.scitotenv.2020.143984.
[62] A. Garcia-De-Vinuesa, I. Sola, F. Quattrocchi, F. Maynou, M. Demestre, Linking trawl fleet dynamics and the spatial distribution of exploited species can help to avoid unwanted catches: the case of the NW Mediterranean fishing grounds, Sci. Mar. 82 (2018).
[63] V. Tičina, I. Katavić, L. Grubišić, Marine aquaculture impacts on marine biota in oligotrophic environments of the Mediterranean Sea – a review, Front. Mar. Sci. 7 (2020) 217, https://doi.org/10.3389/fmars.2020.00217.
[64] A. Careño, J. Lloret, Environmental impacts of increasing leisure boating activity in Mediterranean coastal waters, Ocean Coast Manag. 209 (2021) 105693.
[65] H. Carić, P. Mackelworth, Cruise tourism environmental impacts - the perspective from the Adriatic Sea, Ocean Coast Manag. (2014), https://doi.org/10.1016/j.ocecoaman.2014.09.008.
[66] J. Lloret, A. Turiel, J. Solé, E. Berdalet, A. Sabatés, A. Olivares, J.M. Gili, J. Vila-Subirós, R. Sardá, Unravelling the ecological impacts of large-scale offshore wind farms in the Mediterranean Sea, Sci. Total Environ. 10 (824) (2022) 153803, https://doi.org/10.1016/j.scitotenv.2022.153803.
[67] A. Saide, C. Lauritano, A. Ianora, A treasure of bioactive compounds from the deep sea, Biomedicines 9 (11) (2021) 1556, https://doi.org/10.3390/biomedicines9111556.
[68] A.F.C. Leonard, L. Zhang, A.J. Balfour, R. Garside, P.M. Hawkey, A.K. Murray, O.C. Ukoumunne, W.H. Gaze, Exposure to and colonisation by antibiotic-resistant E. coli in UK coastal water users: environmental surveillance, exposure assessment, and epidemiological study (Beach Bum Survey), Environ. Int. 114 (2018) 326–333, https://doi.org/10.1016/j.envint.2017.11.003.
[69] L.M. Gorman, S.J. Judge, M. Fezai, M. Jemaà, J.B. Harris, G.S. Caldwell, The venoms of the lesser (Echiichthys vipera) and greater (*Trachinus draco*) weever fish– A review, Toxicon 6 (2020) 100025.
[70] P.D. Negro, C. Saul, C. Bruno, D.G. Maria, K. Franco, Toxicity of mediterranean scyphomedusae: an overview, Cent. Nerv. Syst. Agents Med. Chem. 16 (3) (2016) 213–217.
[71] E. Berdalet, L.E. Fleming, R. Gowen, K. Davidson, P. Hess, L.C. Backer, S.K. Moore, P. Hoagland, H. Enevoldsen, Marine harmful algal blooms, human health and wellbeing: challenges and opportunities in the 21st century, J. Mar. Biol. Assoc. U. K. (2015), https://doi.org/10.1017/S0025315415001733.
[72] I. Nuez, M. Gazo, L. Cardona, A closer look at the bycatch of medium-sized and large sharks in the northern Catalan coast (north-western Mediterranean Sea): evidence of an ongoing decline? Aquat. Conserv. Mar. Freshw. Ecosyst. 31 (9) (2021) 2369–2380, https://doi.org/10.1002/aqc.3651.
[73] R. Morabito, A. Marino, G. La Spada, L. Pane, G.L. Mariottini, The venom and the toxicity of Pelagia noctiluca (Cnidaria: scyphozoa). A review of three decades of research in Italian laboratories and future perspectives, Journal of Biological Research - Bollettino Della Società Italiana Di Biologia Sperimentale 88 (2) (2015), https://doi.org/10.4081/jbr.2015.5372.
[74] M. Vila, R. Abós-Herràndiz, J. Isern-Fontanet, J. Àlvarez, E. Berdalet, Establishing the link between Ostreopsis cf. ovata blooms and human health impacts using ecology and epidemiology, Sci. Mar. 80 (Suppl. S1) (2016) 107–115.
[75] J. Peyton, A.F. Martinou, O.L. Pescott, et al., Horizon scanning for invasive alien species with the potential to threaten biodiversity and human health on a Mediterranean island, Biol. Invasions 21 (2019) 2107–2125, https://doi.org/10.1007/s10530-019-01961-7.

[76] G. Rensch, H.M. Murphy-Lavoie, Lionfish, scorpionfish, and stonefish toxicity. 2, in: StatPearls, StatPearls Publishing, Treasure Island (FL), 2022 [Internet], https://www.ncbi.nlm.nih.gov/books/NBK482204/.
[77] S. Jal, S.S. Khora, An overview on the origin and production of tetrodotoxin, a potent neurotoxin, J. Appl. Microbiol. 119 (4) (2015 Oct) 907–916, https://doi.org/10.1111/jam.12896.
[78] A. Giusti, M. Guarducci, N. Stern, N. Davidovich, D. Golani, A. Armani, The importance of distinguishing pufferfish species (*Lagocephalus* spp.) in the Mediterranean Sea for ensuring public health: evaluation of the genetic databases reliability in supporting species identification, Fish. Res. 210 (2019) 14–21.
[79] M. Rambla-Alegre, L. Reverté, V. del Río, P. de la Iglesia, O. Palacios, C. Flores, J. Caixach, K. Campbell, et al., Evaluation of tetrodotoxins in puffer fish caught along the Mediterranean coast of Spain, Toxin profile of Lagocephalus sceleratus, Env. Res. 158 (2017) 1–6.
[80] C. Acar, S. Ishizaki, Y. Nagashima, Toxicity of the Lessepsian pufferfish *Lagocephalus sceleratus* from eastern Mediterranean coasts of Turkey and species identification by rapid PCR amplification, Eur. Food. Res. Technol. 243 (2017) 49–57, https://doi.org/10.1007/s00217-016-2721-1.
[81] P. Ubaldi, P. Galli, E. Azzurro, F. Cerri, Invasive species drive human poisoning: the case of the silver cheeked pufferfish Lagocephalus sceleratus (gmelin, 1789), Int J Zool An Biol 5 (6) (2022) 1–7, 10.23880/izab-16000428].
[82] T.M. Glasby, S.D. Connell, M.G. Holloway, C.L. Hewitt, Nonindigenous biota on artificial structures: could habitat creation facilitate biological invasions? Mar. Biol. 151 (2007) 887–895.
[83] C.M. Duarte, K. Pitt, C. Lucas, J. Purcell, S. Uye, K. Robinson, L. Brotz, et al., Is global ocean sprawl a cause of jellyfish blooms? Front. Ecol. Environ. 11 (2013) 91–97.
[84] EFSA, Climate change as a driver of emerging risks for food and feed safety, plant, animal health and nutritional quality, EFSA Supporting Publications 17 (6) (2020), https://doi.org/10.2903/sp.efsa.2020.EN-1881.
[85] J. Martinez-Urtaza, J.C. Bowers, J. Trinanes, A. DePaola, Climate anomalies and the increasing risk of Vibrio parahaemolyticus and Vibrio vulnificus illnesses, Food Res. Int. 43 (7) (2010), 1780-179.
[86] L. Vezzulli, M. Previati, C. Pruzzo, A. Marchese, D.G. Bourne, C. Cerrano, VibrioSea Consortium. Vibrio infections triggering mass mortality events in a warming Mediterranean Sea, Environ. Microbiol. 12 (7) (2010) 2007–2019, https://doi.org/10.1111/j.1462-2920.2010.02209.x. Epub 2010 Mar 29. PMID: 20370818.
[87] F. Le Roux, K.M. Wegner, C. Baker-Austin, L. Vezzulli, C.R. Osorio, C. Amaro, J.M. Ritchie, et al., The emergence of Vibrio pathogens in Europe: ecology, evolution, and pathogenesis (Paris, 11–12th March 2015), Front. Microbiol. 6 (2015) 830, https://doi.org/10.3389/fmicb.2015.00830.
[88] E.J. Archer, C. Baker-Austin, T.J. Osborn, et al., Climate warming and increasing *Vibrio vulnificus* infections in North America, Sci. Rep. 13 (2023) 3893, https://doi.org/10.1038/s41598-023-28247-2.
[89] ZSL, Habitat Loss and Human Health - Understanding the Links between Ecosystem Degradation and Infectious Disease Outbreaks, 2020. Conference, https://www.zsl.org/science/whats-on/habitat-loss-and-human-health-understanding-the-links-between-ecosystem-degradation.
[90] IPBES, Workshop Report on Biodiversity and Pandemics of the Intergovernmental Platform on Biodiversity and Ecosystem Services, IPBES secretariat, Bonn, Germany, 2020, https://doi.org/10.5281/zenodo.4147317.
[91] J. Lloret, M. Demestre, Sánchez-Pardo, Lipid reserves of red mullet (Mullus barbatus) during pre-spawning in the northwestern Mediterranean, Sci. Mar. 71 (2) (2007) 269–277.
[92] I. Everson, Managing Southern Ocean krill and fish stocks in a changing environment, Philos. Trans. R. Soc. Lond. B338 (1992) 311–317.
[93] M.A. St John, A. Borja, G. Chust, M. Heath, I. Grigorov, P. Mariani, et al., A dark hole in our understanding of marine ecosystems and their services: perspectives from the mesopelagic community, Front. Mar. Sci. 3 (2016) 31, https://doi.org/10.3389/fmars.2016.00031.
[94] S. Biton-Porsmoguer, R. Bou, E. Lloret, M. Alcaide, J. Lloret, Fatty acid composition and parasitism of European sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) populations in the northern Catalan Sea in the context of changing environmental conditions, Conserv Physiol 8 (1) (2020) coaa121, https://doi.org/10.1093/conphys/coaa121.
[95] H.C. Holm, H.F. Fredricks, S.M. Bent, D.P. Lowenstein, J.E. Ossolinski, K.W. Becker, W.M. Johnson, K. Schrage, B.A.S. Van Mooy, Global ocean lipidomes show a universal relationship between temperature and lipid unsaturation, Science 376 (6600) (2022) 1487–1491, https://doi.org/10.1126/science.abn7455.
[96] D.R. Smith, H. Brockmann, M.A. Beekey, et al., Conservation status of the American horseshoe crab, (*Limulus polyphemus):* a regional assessment, Rev. Fish Biol. Fisheries 27 (2017) 135–175, https://doi.org/10.1007/s11160-016-9461-y.
[97] R.W. Byard, Traditional medicines and species extinction: another side to forensic wildlife investigation, Forensic Sci. Med. Pathol. 12 (2016) 125–127, https://doi.org/10.1007/s12024-016-9742-8.
[98] Hac, High Ambition Coalition for Nature and People, 2021. https://www.hacfornatureandpeople.org/home.
[99] European Commission, COM(2020) 380 Final. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, EU Biodiversity Strategy for 2030, 2020.
[100] Medpan 2023, The System of Mediterranean MPAs in, 2020. https://medpan.org/en/system-mediterranean-mpas-2020.
[101] European Commission, Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora, 1992. https://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm.
[102] European Council, Nature Restoration, 2023. https://www.consilium.europa.eu/en/policies/nature-restoration/.
[103] S.S. Myers, L. Gaffikin, C.D. Golden, R.S. Ostfeld, K.H. Redford, T.H. Ricketts, W.R. Turner, S.A. Osofsky, Human health impacts of ecosystem alteration, Proc. Natl. Acad. Sci. U.S.A. 110 (47) (2013) 18753–18760, https://doi.org/10.1073/pnas.1218656110.
[104] J.D. Gourevitch, A.M. Alonso-Rodríguez, N. Aristizábal, et al., Projected losses of ecosystem services in the US disproportionately affect non-white and lower-income populations, Nat. Commun. 12 (2021) 3511, https://doi.org/10.1038/s41467-021-23905-3.
[105] S.F.W. Taylor, M.J. Roberts, B. Milligan, et al., Measurement and implications of marine food security in the Western Indian Ocean: an impending crisis? Food Sec 11 (2019) 1395–1415, https://doi.org/10.1007/s12571-019-00971-6.
[106] C.Y. Chan, N. Tran, S. Pethiyagoda, C.C. Crissman, T.B. Sulser, M.J. Phillips, Prospects and challenges of fish for food security in Africa, Global Food Sec 20 (2019) 17–25, https://doi.org/10.1016/j.gfs.2018.12.002.