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Review Article

Impact of Climate Change on Marine Biodiversity: Current Challenges and Future Perspectives

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Abstract: Marine ecosystems have been affected by natural and human-induced pollution. In recent decades, land and sea levels have risen due to increases in temperature and CO_2 concentrations, as well as the accumulation of other toxic chemicals. The distribution and diversity of marine species have been affected by acidification, eutrophication, and anaerobic conditions, inhibiting the interaction process and increasing coral mortality and bleaching. Both cold- and warm-water coral reefs serve as food, shelter, and habitat for many important plant and animal species that have been severely impacted by ocean warming. Some marine plants, including mangroves and seagrasses, have been severely affected by ocean warming. However, the response of marine genotypes, i.e., mangroves, seagrasses, fishes, mammals, turtles, etc., varies depending on the type of environmental extremes and the nature of climate change. The species with lower immunity are vulnerable to ocean warming. Many researchers have studied that both marine flora and fauna are in danger if proper management and strategies are not developed. Here we discussed the negative impacts of climate change on marine ecosystems and also highlighted the new methods being used to protect marine species. In addition, various protocols developed to protect marine biota in the context of rising temperatures are briefly discussed along with future guidelines for marine ecosystem security. We suggest that marine biodiversity can be conserved through the establishment of marine protected areas and that novel epigenetic studies are needed to improve the genetic protection of marine species under abiotic stress and to minimize the risks associated with various anthropogenic activities.

Keywords: Acidification, Climate change, Epigenetics, Marine Ecosystem, Management and Policies, Ocean Warming

1. INTRODUCTION

The area extending 200 m below sea level is called the deep-sea region and is one of the most significant areas for countless important living organisms [1]. About 71 % of the total Earth's surface is covered by the ocean which is one of the most important factors in controlling climate [2]. Fundamental primary compounds and other carbon and nutrients are formed in this area. For this reason, it is a suitable habitat for many seabirds, plants, fish, and other marine species. The warmth in this region is directly related to greenhouse gases [3]. Due to some anthropogenic activities and other

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environmental changes, the marine ecosystem is harshly affected. Both direct and indirect human activities affect marine ecosystems. Similarly, natural and anthropogenic factors are responsible for environmental degradation. Sometimes the climate is affected by natural forces like volcanic eruptions, thunderstorms, and many others. A large part of the deep sea is affected by these harmful factors [3]. The increased contamination continues to cause degradation with negative impacts on food security, food safety, and marine biodiversity [4].

The negative impacts of human activities on the ocean ecosystem are increasing day by day [2]. Some of these changes have occurred rapidly in the oceans in recent decades [5]. Measuring these impacts on marine ecosystems is difficult because of their complexity and the diversity of many species [6]. Over the past 30 years, world temperature has increased by up to 0.2 °C/decade due to toxic greenhouse gases [7]. By 2015, world temperature has increased by about 1 °C due to high concentrations of toxic greenhouse gases (GHGs). The additional energy has been absorbed by the oceans. In addition, the heat of the uppermost layer of the Globe Ocean has increased by up to 14 × 1022 J since 1975, which corresponds to an increase in the temperature of the uppermost layer of 0.6 °C [2]. A further increase in Earth's temperature is estimated if 130-160 Pg of permafrost carbon is released into the air by 2100. Ocean pH is slowly decreasing at a rate of 0.02/decade over the past 30 years [8]. The temperature rise is affecting the terrestrial ecosystem and melting excess ice that is directly entering the water bodies, increasing the volume and stratification of the oceans [9]. The production of a large amount of hydrogen peroxide leads to anaerobic conditions and causes mass mortality [10]. Low light intensity and high ocean temperature significantly reduce photosynthetic efficiency [11].

Reports from Intergovernmental Panel on Climate Change (IPCC) showed that emissions of toxic GHGs into the environment are rapidly increasing [12], even after the Paris Agreement, to reduce world temperature to 1.5 °C by 2100 and secure life on Earth [13]. Scientists have predicted that the warming effect will continue for about half a century [14]. This climate change poses serious threats to wildlife biodiversity as well as other living things, including humans [12, 15]. About 1/3 of human CO_2 emissions enter the oceans, leading to higher acidity (26 %) of the upper layer. This increase was expected to be 100 % or more by 2100 [12].

Abiotic stress has severe effects on all plant and animal species [16-19]. The biodiversity of various marine ecosystems has been disturbed due to global temperature rise [20]. Nitrogen is one of the main pollutants that directly or indirectly increases the temperature of marine and terrestrial ecosystems, thus affecting biodiversity. N_2O increases eutrophication and thus disturbs aquatic biodiversity [21]. The variability of coastal marine species is affected by the increase in ocean temperature [22]. The accumulation of algal toxins leads to the death of many aquatic species [23]. The toxic effects of various direct and indirect pollutants on the marine ecosystem are shown in Figure 1. To date, there is a lack of comprehensive literature on the effects of climate change on the marine ecosystem. Therefore, in this review, we focus on the negative impacts of climate change on marine biodiversity. Here we discuss the impacts of

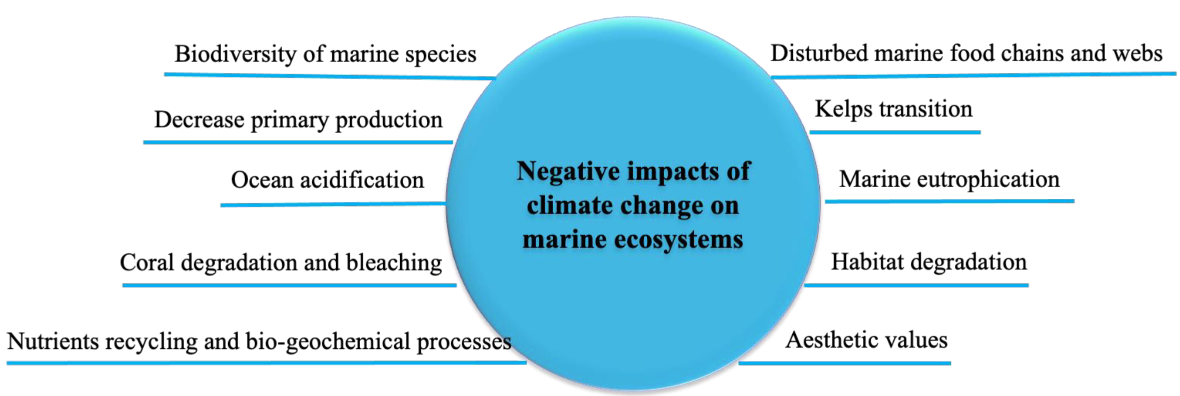

Fig. 1. Negative impacts of direct and indirect pollutants on marine ecosystems

climate change on plants, animals, and other marine species.

2. NEGATIVE IMPACTS OF CLIMATE CHANGE ON SPECIES DISTRIBUTION AND DIVERSITY

The change in climatic conditions may lead to the migration of wildlife [5]. Temperature growth and high salinity in the polar ocean disrupt the distribution of important taxa and ecosystems [24, 25]. High water temperatures can cause genetic divergence in both tropical and subtropical areas [26]. The frequency of small plants is crucially affected by these environmental changes [27]. Under these conditions, the marine reservoir system can protect the static organism [28]. Such a system is also useful in promoting population connectivity [29]. The reservoir system enriches genetic variability by increasing the size of the population and also provides an optimal environment [30]. In 2003, a high rate of the shoot mortality rate of important Posidonia oceanic was recorded by Marba and Duarte [31].

In accordance with previous reports, the increase in acidity in water bodies poses a serious concern to marine organisms [32, 33]. Declines in populations of plankton and other marine species, such as mollusks and calcareous algae, among others have been noted [34]. Some marine plants encompassing mangroves and seagrasses, help to minimize CO_2 emissions and increase pH; thus, these act as a defense system for some important marine calcifying organisms [35, 36]. These species are highly threatened and rapidly becoming extinct [37]. Therefore, the protection of this wetland from harmful human activities is necessary [38]. The conservation of the marine ecosystem helps to increase the population of teleost fishes. This type of fish plays a key role in the inorganic carbon cycle [39]. According to Graham and Harrod [40], ocean warming affects the genetic variability and function of many important ecosystems. It affects all levels of life, i.e., individuals, population, and community.

The rise in sea temperature also increases the severity of the disease. The effects of Vibrio shiloi on the coral *Oculina patagonica* increase with the rise in temperature [41]. Sometimes, ocean warming contributes to the release of some toxic chemicals and causes serious health problems [42]. High temperatures also disrupt the chemical defense system of many marine animals [43]. Climate change in the ocean can also disrupt the biodiversity of local species [42]. Such warming leads to the extinction of cold-water boreal species [44]. Lower pH and highly dissolved CO_2 affect the biodiversity of the Mediterranean Sea. Acidification affects coralline red algae that serve as habitat and coral reef formation [45]. The immigration or transfer of invasive alien species disrupts existing species in many ways, such as displacing native species, losing genetic diversity, and affecting both habitat and community structure [46, 47]. Many invasive bivalves have negative impacts on native species [48]. The jellyfish *Rhopilema nomadica* has multiple negative impacts on marine ecosystems [49]. The Atlantic Percnon gibbesi has spread into the Mediterranean Sea and uses algae in large quantities for its energy production. It also competes with other native species for food and shelter [47].

Arctic species are so sensitive to abiotic factors that their abundance decreases significantly during Arctic summers [50, 51]. However, these responses vary with different factors such as nutrient availability, temperature increase, and ambient inconsistency [52]. Shellfish and the breeding process of other fishes are highly affected by high-temperature stress [53], the drop-in ocean pH [54], and the process of deoxygenation [55]. Pollution of the ocean from land and sea level rise is affecting the performance of reefs [56].

3. EFFECT ON PRODUCTIVITY AND OXYGEN DEMAND

The temperature rise can disorder normal metabolic and photosynthetic activities [57]. It also unsettles prey-predator ratios and reduces the overall mass of plant and animal species. The warming of the upper layer degrades the ability to mix nutrients and produce important products. The high stratification rate reduces oxygen levels and creates anaerobic conditions that lead to high mortality rates [57]. Fishing mortality rates have been increased by the unavailability of optimum oxygen demand [58] or by decreasing the total mass of phytoplankton and the low availability of essential nutrients [59]. General circulation models have indicated that dropping oxygen levels, along with other factors such as eutrophication and overfishing, are a problem for marine ecosystems. A high mortality rate has been found in the deep lower parts of the oceans off the west coasts of North America [60] and southern Africa [61].

The lower oxygen concentration in the ocean disturbs multicellular organisms [62]. This concentration has decreased since 1950 due to the increase in ocean temperature [63]. The increase in atmospheric CO_2 concentration decreases the amount of O_2 [64]. Mobile species can survive at low oxygen levels, but inactive organisms are sensitive to low O_2 or die [65].

4. IMPACT ON CORAL AND CORAL REEFS

Coral reefs have been in severe decline due to human activities. In the last 200 years, the destruction of coral reefs has multiplied due to overfishing and water pollution [66-68]. Warm-water reefs have decayed by about 50 % in tropical locations over the past 30-50 years [69-71]. Cold-water reefs have also declined at a similar rate due to many factors such as cable and pipeline connections, trash accumulation, sampling, reef exploitation, and more [72, 73]. The biggest problem is the development and advancement of technologies used to exploit marine ecosystems [74].

The cold habitats for plants or animal species and coral reefs are endangered and there is a possibility that these may become extinct in the future due to ocean warming [57]. Coral reefs are very vulnerable to ocean warming and acidification [75]. In the last three decades, many coral reefs have been lost because of ocean pollution, overfishing, and temperature rise. It is noteworthy that if this temperature rise is not controlled, it may lead to a significant loss in coral reef production by 2050 [50, 76]. Therefore, temperature stress inhibits coral growth and calcification capacity [77] and promotes degradation and susceptibility to storms [78]. The decline in coral reef formation has a direct impact on fish production, which thus leads to poverty and food insecurity. This alteration may also decrease the population of some important fish species [79, 80]. Continuous and sudden changes are occurring in ocean ecosystems, which are interlinked with the disruption of the normal life of many vital marine species. Coral reefs are major sources of food, shelter, and habitat for multiple marine organisms. In the deep sea, these reefs are the main habitats for numerous fishes. It must be highlighted that the rapid extinction of these coral reefs can cause serious problems for about 500 million people who rely directly on them for food, income, shelter, and other purposes. In some cases, this can cause regional insecurity [81].

The response of corals varies according to the type of environmental stress. The mutualistic relationship between warm water reefs is influenced by the physical/chemical changes in the environment. Thermal fluctuation or the presence of toxic compounds such as cyanide can distress this synergistic relationship [81, 82]. Similarly, coral bleaching has a damaging propensity to the progressive interaction between corals (Scleractinian) and Symbiodinium. Temperature surges over prolonged periods can promote mortality and bleaching [82, 83]. Bleaching of corals lessens their energy requirements and obstructs normal physiological function [84]. Previous studies have shown that changing climatic conditions can directly influence coral mortality and bleaching [85]. However, a high mortality rate was found in the early 1980s due to ocean warming caused by human activities [68]. The lack of symbiotic relationships among coral tissues caused serious threats due to starvation, failure of reproductive output and decrease in photosynthetic efficiency, poor competition, and diseases [68, 82, 86].

5. IMPACT ON THE MICROBIOME AND OTHER INTERACTION PROCESSES

Climate change is causing an increase in temperature and acidification, which affect the physiology and interactions of marine species. These climate changes have serious implications for kelp and its relevant microbiome [87]. The change in the structure and function of the microbiome is important in terms of environmental change. Seagrass species divide into similar rhizospheric communities [88]. Root structure and function have shown lowered exudates and thus lowered microbial populations in *Halophila ovalis, Halodule uninervis*, and *Cymodocea serrulate* [89].

One of the recent shotgun genomic studies has revealed that this process fosters the mutualistic interaction of *Saccharina japonica* with the associated microbiome [90]. Some bacteria release toxic compounds that reduce the growth of other microorganisms on the surface of the alga [91]. At low salinity, some bacteria attach to species (*Ectocarpus*) and enhance their adaptive capacity [92]. The change in climatic conditions affects 1729 fish, 124 marine mammals, and 330 seabird species from 6 marine regions. Unfortunately, the world's very rich marine biodiversity is being seriously affected by ocean warming [74].

6. IMPACT ON MARINE SPECIES DISTRIBUTION AND BIODIVERSITY

Human activities are disrupting chemical processes, plant and animal species, and ocean temperatures [93]. Global warming affects the marine ecosystem in two ways. First, sea level rise reduces the area of wetlands [94]. These effects are particularly pronounced for mangroves [95]. Second, high temperature causes many important plant and animal species to shift to the pole by disrupting their habitat [96].

Regime shift has been observed in marine systems [93]. Regime shifts have been investigated in many studies, but these studies are limited to specific areas such as Florida Bay and the Baltic Sea [9]. In one of the condensed studies by Rocha *et al.* [97], 15 regime shifts were recorded and an efficient database was developed. These researchers have used the term "drivers" for all-natural or human-induced factors that affect our marine ecosystem through direct or indirect sources. The direct source affects the marine ecosystem processes while the indirect source affects the direct drivers [98]. Regime change is due to a variety of factors, with an average of 12 factors. One of the most important factors is the decline of mangroves [99]. The second most important factor is the eutrophication of the marine ecosystem [100], followed by changes in corals [101].

Temperature increases of up to 4 °C is disrupting populations and other important features of marine ecosystems [102]. Warming of the marine system is affecting algal and seagrass species, which are a source of protein and food for many marine species. A large number of these species are being lost or relocated to polar regions. Genetic adaptability is slow due to increasing human pollution. Both epigenetic and non-genetic processes are required for proper adaptation and have direct effects on the phenotype, stability, and fitness of a species. Morphological variations are related to several physiological traits, reproductive success, and relationships with other organisms. The full study is based on the morphophysiological responses of algae and seagrass, which are important for appropriate conservation under climate change conditions [103]. High temperatures cause the extinction of many herbivore species and also disrupt the algal population. Moreover, it affects the success rate of many marine species [104].

An increased temperature causes the photosystem II (PS II) response and inhibits photosynthesis [105]. Increased ocean temperatures decrease total chlorophyll content and lead to coral bleaching along with the browning of seagrasses [106]. Similarly, ocean warming decreases both chlorophyll and carotenoid content of dwarf eelgrass (*Zostera noltii*). Temperature stress causes chlorophyll degradation and decreases the ratio of chlorophyll "a" and "b" [103, 107]. It also affects gametogenesis and the fertilization process of *Laminaria digitata* [89]. Ocean warming also causes the death of *P. oceanica* seeds [108]. High ocean temperature disrupts seedling performance. Moreover, it retards growth and increases leaf necrosis, mortality, and respiration efficiency of *P. oceanica* seedlings in the northwestern Mediterranean [109]. Temperature above 29 °C has caused the death of *Z. japonica* seedlings [110].

Frainer *et al*. [111] characterized the effects of climate change on 52 Arctic fish species of the Baret Sea for 13 key functional traits. They found that many functional traits were being replaced by some boreal species traits that were large, have longer lifespans, and were often piscivorous. Overfishing and maximum temperatures are two major extremes affecting many marine species. The poleward movement of marine species in response to warming is higher than in terrestrial ecosystems due to the reduced availability of physical shelter [80]. In addition, the lack of suitable habitat and other antagonistic interactions promote temperature-driven poleward movement [112]. Under these conditions, the response to this movement varies among genotypes. Some genotypes are strongly affected by this change compared to other species [113]. This type of movement is more pronounced in mid to high-latitude warm-water species and therefore disrupts their important function and genetic variability [114].

However, the genotype response varied depending on the type of stress. Some genotypes showed themselves immune to global warming, while others remained sensitive and exhibited a low survival rate. For example, some fish species change their movements and move in both horizontal and vertical directions and have the ability to reproduce. Others, however, do not change direction and these species are expected to become extinct soon [115]. High CO_2 decreased the feeding ability and survival rate of crabs at a pH drop (0.3 units). At high CO_2, muscle consumption decreases by 50 %, and mortality increases (>50 %). The whelks showed resistance to elevated temperature and CO_2 stress. Abalone mussel growth decreased with increasing CO_2 levels. In the presence of crabs, the feeding of abalone was decreased and increased in warm water. Abalone mussel growth was significantly reduced by high CO_2 and low pH [116].

7. EFFECTS ON OTHER ECOSYSTEM FUNCTIONS

Temperature has a direct effect on the kinetic energy of molecular processes, such as the transport of materials to the membrane and enzymatic activities [117]. A slight change in temperature affects metabolic processes that directly impact various ecosystem functions and population growth [118]. Some organisms can acclimatize to these environmental changes within a limited temperature range. Once the limits are exceeded, the organism can no longer adapt, resulting in increased mortality, decreased fitness, and depleted population growth. Animal metabolism is also dependent on optimal temperature [117], in particular, prey-predator relations are affected by the increment in temperature [119]. Respiration rate reduces with increasing temperature; therefore, organisms require more calories to survive [5, 120]. Mesocosm investigations have shown that temperature elevation from 21 °C to 27 °C cutbacks biomass of the food web and plants and animals [121]. The size of phytoplankton also decreases due to warming [5].

8. OTHER EFFECTS

Climate change has positive, additive, or detrimental effects on certain marine species [34]. It becomes more dangerous by other factors such as overfishing, increases in nutrient levels in waters, and habitat alteration [122, 123]. However, the large population allows for reducing the likelihood of extinction at specific and general levels [124]. Under these conditions, marine reserves help to maintain the diversity of life and reduce the mortality rate of highly varied populations [125], thus enhancing the recovery process. Such reserves minimize the risk of outbreak and reduce prey growth [125, 126]. Variability among living organisms and the profusion of life has a direct impact on the ecosystem [127]. When maximum diversity is present in a reef ecosystem, it triggers more mass assemblages. In addition, more diverse communities may be less disturbed by maximum temperature stress [128]. The skeleton of corals releases calcium carbonate, which serves as a habitat for fish and other marine animals. These carbonated structures prevent biological and physical erosion. These reef ecosystems are believed to be the natural habitat for about 25 % of fish species [129].

The change in climatic conditions is troublesome to the normal processes of many important marine organisms by negatively affecting the habitats of marine species such as corals, seagrasses, oysters, and many others. Due to high temperatures, the mortality rate of corals is continuously increasing, by decreasing the presence and density of coral reefs and other species [130]. Deforestation of mangroves is growing rapidly and a loss of 10-20 % of mangroves was expected by 2100. This has a drastic implication for other marine ecosystems [131]. Sea ice or coral reefs play a prominent role in the genetic diversity of the marine ecosystem. It is fundamental for various activities of birds and animals and provides habitats for reproduction, migration, and other functions [132]. Due to climatic change, the penguin population is declining rapidly [133].

Climate change plays a central role also in affecting biological events [134]. Of note, these inconsistencies have been determined for gene expression [135], and in allele frequencies of the short-lived species [136]. Musculature development is also linked to temperature [137] which has a straightforward effect on the movement of organisms, disrupting their speed and potential to compete with prey [138]. In a broader perspective, warming can damage physical behavior and increase the mortality rates of species [139]. It also disturbs community size and biomass [140]. Ocean warming distracts the growth rates of many marine species [141]. The formation of juveniles and larvae stages is linked with temperature rise [142]. Juvenile marine species are highly sensitive and cannot tolerate extreme temperatures [143]. Climate change in the oceans has direct effects on host vulnerability, the production of various pathogens, and the production of more disease vectors. An example of some of the diseases includes extreme temperatures causing diseases described in reef-building corals [144]. Another example is the increase in the severity of the deadly infectious disease (red abalone) in California [145]. One of the serious threats to the ocean ecosystem is the changes in geochemical processes due to the increase in acid concentration. This type of change leads to the loss of habitat, species distribution, community composition, and other interactions described elsewhere [146].

9. IMPACTS OF CLIMATE CHANGE ON GLOBALLY IMPORTANT MARINE ECOSYSTEMS

High-temperature stress has significantly impacted both plant and animal species of the Arabian Gulf [147, 148]. Continued climate change is disrupting the Gulf's marine biodiversity. The high salinity and temperature stress determine the tolerance of species [149]. The occurrence and diversity of species in the Gulf marine ecosystem are low [150, 151], but from a biological perspective, these species have many values [152]. The environmental extremes such as the increase in world temperature and sea level, decrease in oxygen levels and other human activities such as overfishing, oil exploration, etc. are disturbing the biodiversity of this region [153, 154].

Marine species of the Gulf are more tolerant to heat stress compared to other parts of the world [155, 156]. The temperature increase has been determined to be up to +0.57 °C in the Gulf between 1950 and 2010 [157] has affected many marine species [158]. The temperature increase (35-37 °C) has more than quintupled the frequency of coral bleaching since late 1990 [159]. These impacts are very severe and in recent decades about 70% of the reefs in this region have disappeared within a few decades. Such mass mortality has a direct impact on other fish species [160]. Loss of hawksbill sea turtle habitat is expected in various parts of the Gulf. The rate of extinction is highest in the southwestern part of the Gulf, off the coast of Saudi Arabia, Qatar, and the UAE. The fisheries of Iran and Qatar may be more susceptible to climate variability [161].

Mediterranean Sea has a rich marine diversity that is affected by climate change [162]. The Mediterranean ecosystem has been reported with greater effects by habitat alteration, environmental change, and pollution, overexploitation of key species, introduction of unknown species into pre-existing biota, and by coastal urbanization [42, 163]. Environmental changes affect marine organisms in a variety of ways. Species with low biodiversity are more exposed to these threats and may become locally extinct [42, 164]. Heat and drought stress also this region [164, 165]. In 1999 and 2003, climate change led to the mass mortality of many species of benthic invertebrates [166].

Climate change has serious impacts on all small island states through temperature and sea level rise and changes in rainfall frequency. The effects of sea level rise are extremely dangerous for coastal ecosystems. The presence of large numbers of people on the coast disrupts normal sea levels, flooding, erosion, and the availability of trash disrupts small Caribbean Islands. These changes directly affect the habitats of many marine species and also lead to ecosystem degradation. Such environmental changes in the Caribbean Island increase disease and the production of various parasites, as well as the immigration of new species into the native biota [57, 162]. Many fish species are seriously threatened in Caribbean marine systems. The increasing biomass of algae also affects different ecosystems. Algal blooms reduce the availability of nutrients and increase ocean temperatures [162]. In addition, the opossum shrimp is greatly affected by the increase in temperature by causing anaerobic conditions in the Irish glacial relic Mysis salemaai. High temperature degrades habitat quality and slows down the survival rate of mammal species

[115]. The high sea temperature increases the alien invertebrates and fish species of the Israeli Mediterranean Sea. In contrast, populations of native fish and endangered species are declining [167].

10. RISK MANAGEMENT IN A CHANGING MARINE ECOSYSTEM

Greenhouse gas concentrations in the atmosphere can be controlled in many ways, including the use of renewable energy, increasing energy production capacity, carbon sequestration and safe storage, and enhancing natural carbon resources [15]. Most policies are based on the country's response to climate change [165], while ocean-based policies receive little attention. Therefore, ocean-based policies are mandatory to prevent ocean warming, control acidification, lower sea levels, and protect habitat degradation.

Climate changes induced by the ocean system are a major concern for policy makers and managers. The lack of effective planning and policy reduces the available resources for different marine species. "No regret" policies are necessary to keep the oceans safe for all marine species. Deforestation of important plant species like mangroves should be controlled to maintain the optimum temperature of the oceans. There is a need to manage or efficiently use available natural resources and prevent the release of toxic greenhouse gases into the upper or lower layers of the ocean [5, 168] described that humans can disrupt the marine ecosystem in five ways, namely by increasing acidity, raising sea level, increasing storms, disrupting the occurrence and diversity of species, and lowering oxygen levels. They emphasized that not only the release of CO_2 should be minimized as per the 2015 Paris Agreement greenhouse gas emissions, but also some other management and implementation steps are needed to protect marine flora and fauna.

With the increasing pressure on the marine ecosystem, it is now important to develop effective planning and policies to improve and safeguard ocean/deep-sea biodiversity. But still, there is a lack of proper strategies and good governance to tackle such issues and enhance the life system of many important marine organisms. In many parts of the world, governments have not given full authority to environmental protection agencies, which is one of the major problems for marine ecosystem security [169]. Preference is given to anthropogenic activities at certain experimental sites, e.g., fishing/mining. However, natural or other human activities that affect the ocean ecosystem are not preferred [170, 171]. Clear evidence of the lack of adequate management is the fact that 64 % of the ocean area is beyond national jurisdiction (ABNJ) [171]. In particular, there is no single authority for the protection of the deep sea that is committed to its safety and biosecurity [172].

An important step towards safeguarding marine biodiversity is the establishment of Marine Protected Areas (MPAs). MPAs will protect many important and diverse marine organisms by protecting their habitats and increasing their abundance. Thus, MPAs will contribute to the conservation of many important marine organisms. This system requires effective planning, management, and implementation strategies [173, 174]. Specific conservation strategies, including fully and strongly protected areas, help and maintain marine biodiversity. According to the Convention on Biological Diversity and Sustainable Development Goal 14, coastal states are far beyond their target, having committed to protecting 10 % of the waters [175]. Some recent studies suggest that the target for MPAs should be 30 % to optimally protect marine ecosystems [176]. The MPA system needs to identify the gaps and should close them within deadlines. This process can be further improved through dialogs and the development of a clear agenda to safeguard the lives of marine species. But this process is not very successful due to the lack of human resources, funding sources, availability of equipment [177], and lack of discussion and help from local people. After a healthy dialog between marine researchers and managers, they concluded that not only MPAs but also efficient fisheries management strategies are important for about 70-90 % of the oceans [178].

CO_2 concentrations in the air increased to 406 ppm by November 2017 [179]. The Paris Climate Agreement of 2015 [180] set the main goal to limit the global temperature increase to below 1.5 °C. To achieve this goal, regular and efficient methods of removing atmospheric C are required [181]. According to Johnson *et al*. [182], the North

Atlantic deep-water area and open oceans will be severely affected in the next 20-50 years. More and more efficient oceanographic data are important to review and calculate the species. In addition, more research is needed to review the changes in the deep-sea ecosystem and response times. They recommended precautionary measures and minimization of harmful human activities to the ecosystem that directly affect the deep-sea system. Vulnerability and participatory assessments are important to minimize the risk of extinction of many important marine species [161]. Abiotic techniques must be used to remove CO_2 from seawater [183, 184]. Marine spatial planning techniques must be used to conserve or save a large proportion of marine species [185]. Regime change requires international rules and regulations to minimize the risk to the marine ecosystem [97]. The possible solution to protect the marine ecosystem from direct and indirect pollution is shown in Figure 2 modified by Gattuso *et al*. [33].

Epigenetically driven variability plays a vital role in optimizing species in the face of changing environmental conditions [186, 187]. DNA polymorphism helps in slow acclimation processes under changing climatic conditions [188]. Epigenetic mechanisms increase speciation, acclimation, and plasticity under extreme environmental conditions [189]. In addition, the methylation process aids in species adaptation [190]. The network enhances DNA methylation by regulating metabolic pathways at elevated temperatures (–1.5 °C vs. + 4 °C) [191]. Similarly, DNA methylation occurs at the larval stage when temperature increases up to 2 °C in the European seabass [192]. Acidification aids in the morphologically based adaptation of the coral *Stylophora pistillata* [193]. DNA methylation occurs in red, green, and brown algae, as well as diatoms [194, 195]. In addition, CpG islands and jumping genes enhance adaptation traits [196]. In seagrass (*Zostera marina*), jumping gene disruption occurs, forming a new promoter and splice sites, reactivating gene function, and enhancing acclimation to high temperatures [197]. Clonal growth together with a mutation in somatic cells plays a role in the adaptation and fitness of marine species to climate change [198].

11. CONCLUDING REMARKS AND FUTURE PERSPECTIVE

High CO_2 and ocean warming have serious implications for the biota of marine ecosystems, including important plant and animal species. Ocean warming disrupts the morpho-biochemical and physiological processes of marine species. The effects on corals, which serve as shelter, habitat, and nutrient sources for many important marine species, are particularly severe. If these changes continue at the same rate, a large number of marine species will become extinct in the near future. Therefore, it is necessary to protect wetlands from anthropogenic activities, avoid toxic greenhouse gasses, and promote the efficiency of CO_2 precipitation in terrestrial ecosystems. In addition, serious steps must be taken to minimize man-made pollution. Thus, it is the responsibility of every individual, institution, government, and non-governmental organization to develop effective planning and policies for the safe protection of marine species. Strict codes and “No regret” policies should be implemented all over the world to protect the biodiversity of the various marine ecosystems.

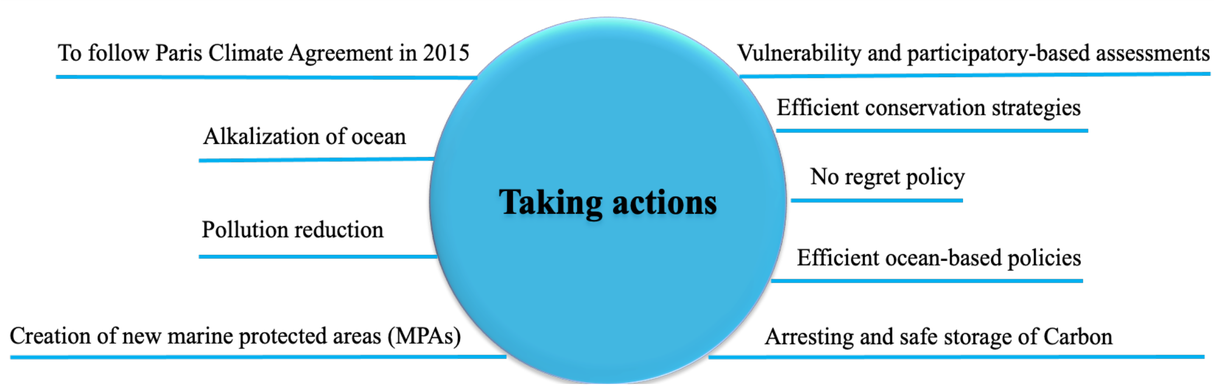

Fig. 2. Salient actions to protect marine ecosystems

12. CONFLICT OF INTEREST

The authors declared no conflict of interest.

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