ENVIRONMENTAL BIOTECHNOLOGY 15 (1) 2019; 1-7 doi:10.14799/ebms302

Nature-Based and Technology-Based Solutions for Sustainable Blue Growth and Climate Change Mitigation in Marine Biodiversity Hotspots

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Key words: blue economy, sustainable solutions, disruptive technologies, development goals

Received in April 2019 Published in May 2019.

ABSTRACT

This paper discusses the urgent need for human interventions in maximizing the promise of blue growth while ensuring sustainability in all its dimensions. It spares no efforts in highlighting the critical nexus between ocean conservation, climate change mitigation and the ecosystem services. The interpretation underscores the threat that unchecked deterioration of marine environment would present for health of the planet and its people. It is evident that the nature-based solutions provide the best options, but the significance of disruptive technologies and innovations cannot be underestimated. However, the decisions pertaining to devising and applying solutions should be informed by scientific reasoning and available evidence. Increasing attention given to blue economy shows the importance of exploring the sustainable solutions by shaping research that helps in identifying the tangible and integrated actions to fast track our progress towards implementing the Sustainable Development Goals.

INTRODUCTION

There is an increasing concern about the impacts of climate change on oceans and seafood supplies. Most of the consequences being highlighted include: acidification, coral bleaching, sea level rise, coastal erosion, saltwater intrusion, coastal inundation, loss of wetlands, oxygen deficit, dead zones, shift in species distribution, disruption of food webs, decline in fish populations, increase in frequency and severity of extreme weather conditions, and changes in water circulation. There is no dearth of scientific evidences showing the multiplier effects of rapidly expanding human population, increasing seafood demand and environmental degradation. It is, therefore, logical to understand that the ocean resilience and ecosystem services that help the human society and the planet are at risk, and the goals of sustainable development seriously challenged. Nature cannot undo the damage done by humans on such a big scale. This calls for human intervention. Oceans form the largest ecosystem, covering 71% of the Earth surface, containing 97% of the plant's water and 96% of the living space. Obviously, there has to be a global mobilization of multidimensional efforts.

One of the most pressing challenges of the twenty-first century is food security, and with land-food systems unable to feed 7.6 billion people due to unsustainable management, soil degradation, desertification and other factors, the oceans are the only frontier left for food production. Food security is among the key services that motivated the emergence of the new area of 'blue growth' which implies the development of coastal and ocean resources within environmental thresholds. Currently, 821 million people are suffering from hunger and malnutrition. Some 3.1 billion people rely on oceans for 20% of their animal protein intake and more than 500 million are employed in ocean-related jobs (IUCN 2017). Oceans form the seventh largest economy in terms of the value of goods and services that they provide (Northrop 2018). Maintaining them in a healthy condition is vitally important for humanity and Earth systems.

This paper discusses the options for intervention for conserving the ocean ecosystem, especially the areas that are rich in marine biodiversity.

TYPES OF INTERVENTIONS

The anthropogenic impacts have reached all parts of the oceans, and this is a matter of serious attention. However, conservation efforts should be prioritized in areas with relatively high biodiversity and large numbers of endemic species (biodiversity hotspots) for maintaining genetic variability and preventing biodiversity loss (Myers et al. 2000; Brooks et al. 2006; Seling et al. 2014). This is the most practical way of reducing species extinctions (Myers 1988) and categorization of areas as ecoregions (Spalding et al. 2007), and is an essential tool for conservation planning in terrestrial and marine ecosystems (Brooks et al. 2006).

Generally, the effects of technology on ocean ecosystem have not always been positive. Despite their vastness and depth the oceans have paid a high price for certain technological developments which have been used on industrial scales. A glaring example is that of mechanized fishing that uses gears capable of dragging fish at the bottom (bottom trawls) and longlines that have altered marine habitats, particularly the benthic zone and reefs. Many such fishing technologies have overlooked the fact that marine ecosystem is complex where interactive systems comprising many species, habitats and external factors collectively shape the marine communities and their populations. Industrial fisheries selectively remove large populations, alter the age, size and genetic structure of fished populations and disturb the trophic relations. Devices that help in detecting fish shoals have helped in increasing catch per unit effort but that has exceeded the regeneration capacity of many targeted species. Obviously, priority has been on investing in technology for increasing production, ignoring the essential requirements for sustainable development of fisheries. It is possible to conduct fishing that spares the pressure of exploitation on juveniles, non-target species and habitats. Some simple modifications in demersal trawl fishing such as increase in mesh size backed by reducing fishing effort when bycatch rates of prohibited species exceed the set limits can make a difference (Graham et al. 2007). The problem multiplies when the so-called baselines are established to represent the ecosystem subjected to intense harvesting for many years (Pauly 1995; Jackson 1997). Controls are difficult to define, and without them, it is not easy to accurately determine the effects of fishing (Roberts 1995). However, it is possible to make assessments in areas outside the intense fishing zones where data on landings and scientific evidences have been collected over several years.

Basically, there are 3 types of interventions to deal with the problems related to changing ocean conditions:

- **Geo-engineering solutions** (also known as climate engineering). Large-scale interventions in the Earth’s systems - oceans, soil and atmosphere- with the aim of mitigating the climate change. Such measures fall in two main categories: Removal of carbon dioxide (CO_2) and limiting the amount of solar radiations (by causing the Earth to absorb less radiations) to offset the effects of greenhouse gases.
- **Nature-based solutions**. Defined by IUCN as “actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits”. These can be in the form of many types of interventions aimed at using nature and natural functions of healthy ecosystems to help protect the vast marine environment and ensure economic and social benefits from ecosystem services.
- **Green disruptive innovations**. This new approach includes nature-inspired recent innovations that can contribute to offsetting the effects of climate change. Disruptive innovations focus on the use of new technology rather than the technology itself. Generally, these are in the form of biomimicry models based on time-tested patterns and strategies that nature uses for sustainable solutions.

Geo-engineering approaches to mitigating climate change are very theoretical and the positive outcomes suggested by their protagonists do not present a holistic picture. There are risks associated with global application of technologies or methods based on simplistic views and assumptions, laboratory tests and computer modelling, and which have never been attempted on a large scale under the field conditions. Their scalability to effectively influence global climate is highly debatable. Some of the proposed approaches suggested require releasing massive quantities of limestone into the sea (to neutralize acidification by the carbonate buffering system that would allow oceans to absorb more CO_2 without undergoing change in the water chemistry), iron fertilization (to stimulate large phytoplankton blooms in the hopes of increasing atmospheric carbon dioxide draw-down) of sea water, deploying solar shields (to block radiations), and storing massive quantities of carbon at the seabed. These suggestions build on certain observed processes in the isolated systems while ignoring the fact that ocean is a complex environment and the level of complexity is such that thorough research investigations are required to avoid risks of such actions. If as a result of further research some practically feasible and verifiable approaches emerge then these can be viewed as additional potential options for limiting climate change or its effects, together with measures for mitigation and adaptation, including reducing energy demand, phasing out the use of fossil fuels, carbon sequestration and low-carbon living.

Nature-based solutions are consistent with the ecosystem approaches. Ecosystem perspectives form a sort of umbrella concept under which these solutions are devised or applied. They embrace nature conservation, are open to diverse sources of knowledge (local, traditional, scientific, technological), seek to promote integrated concept in resource use and governance, involve community participation and benefit-sharing, respect cultural diversities in human interaction with resources, allow inclusiveness in operation of any number of ecosystem service sectors within the limits of resilience and environmental regeneration, and focus on innovations in strategies, designs and practices to address specific challenges in search of sustainable solutions.

There are many nature-based approaches to adopt. Five categories (Figure 1) have been suggested by IUCN (Galland and Dorothee 2009). Some of the most talked-about issues such as integrated coastal zone management, protected area management, green infrastructure, ecosystem-based climate change mitigation and adaptation besides other measures can be considered under these approaches.

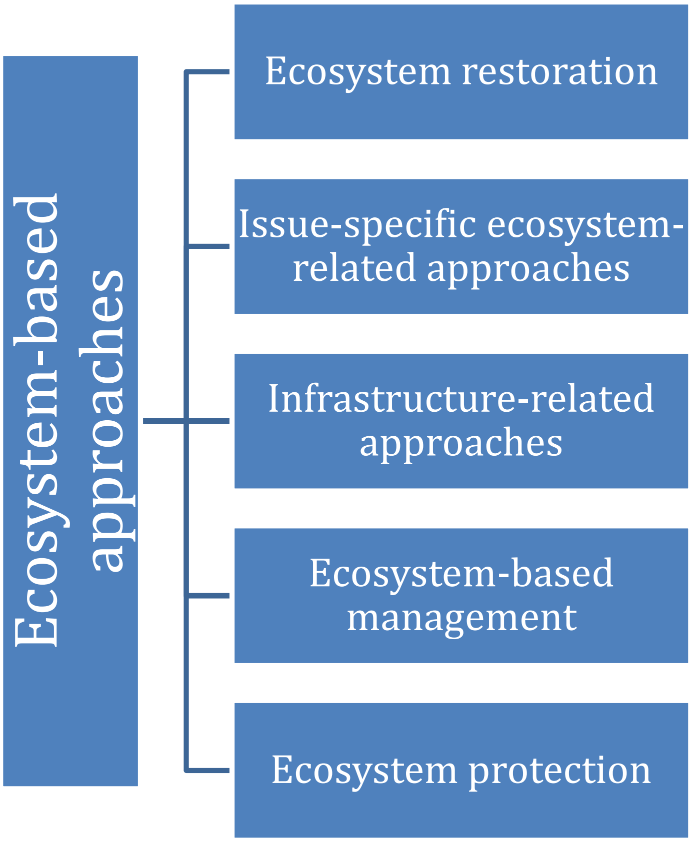

Figure 1. Nature-based solutions

Humans have drawn inspiration from nature in fishing and fish farming since the time when interest in these activities started for food supply. However, industrialization that followed depended heavily on technology which compromised the compatibility of the methods with the ecological balance of the natural systems. Recent years have witnessed a growing interest in learning ways and means that nature uses to solve problems. These pathways provide blueprints that have to be adapted and scaled up as 'biomimicry' models rooted in rationalism. Examples are silvo-fisheries, habitat-inclusive fishing zones (basically, conserving mangroves and seagrasses and allowing fish catch), multiple- use marine protected areas, integrated multi-trophic aquaculture (IMTA), low-carbon sea ranching of benthic species, and Ecosystem Approach to Fisheries Management (EAFM). All these nature-inspired systems function on ecosystem concepts, contain elements of sustainability and seek certainty under uncertain conditions. In a recent work, Sepulveda-Machado and Aguilar-Gonzalez (2015) and Gallagher (2015) have presented some models and case studies that remarkably highlight the importance of conserving blue carbon stocks in sustainable aquaculture.

The last 200 years that characterized the industrial revolution (IR) beginning from the 18th century have changed the fundamental character of the oceans, with some known and mostly unknown implications. This period has been marked by increasing carbon emissions. The first industrial revolution (IR1.0) from 18th–19th centuries mechanized the agriculture, laid the foundation for mining and intensified urbanization. Subsequently, IR2.0 (between 1870 and 1914) saw growth of pre-existing industries and launching of new ones, such as steel, oil, gas and electricity. The IR3.0 that commenced during 1980s and still continues is technically a digital revolution which introduced information and communication tools, computers and internet that advanced the technological capabilities and further increased urbanization. The IR4.0 (or Industry 4.0) which is now taking shape builds on digital revolution with a great deal of innovations in artificial intelligence, robotics, 3D printing, biotechnology, quantum computing and Internet of Things. These can help in conserving and regenerating the marine environment and herald a different and far more effective system of governance. Realizing the potential of IR4.0 for marine environment would require a visionary blueprint for aligning national plans and policies with sustainable economy and society.

It is high time for ocean scientists dedicated to Sustainable Development Goal (SDG) 14 to have a strong voice, propagate ideas, design solution possibilities and generate proof of concepts for the benefits of using disruptive innovations for sustainable development. This will help in greening the IR4.0, and its wider application.

CONSERVATION PRIORITIES FOR MARINE BIODIVERSITY HOTSPOTS

The anthropogenic impacts have reached all parts of the oceans, and this is a matter of serious attention. However, conservation efforts should be prioritized in areas with relatively high biodiversity and large numbers of endemic species (biodiversity hotspots) for maintaining genetic variability and preventing biodiversity loss (Myers et al. 2000; Brooks et al. 2006; Seling et al. 2014). This is the most practical way of reducing species extinctions (Myers 1988) and categorization of areas as ecoregions (Spalding et al. 2007), and is an essential tool for conservation planning in terrestrial and marine ecosystems (Brooks et al. 2006).

Decline in species richness and abundance have been reported to result in altered food web dynamics (Estes and Duggins 1995; Duffy 2003; Costello et al. 2010), and decline in fisheries, ecosystem stability and resilience (Danovaro et al. 2008; Sala and Knowlton 2006). Halpern et al. (2008), Brooks et al. (2006) and Burrows et al. (2011) have attributed these cases to the adverse impacts of three main factors, namely pollution, overfishing and climate change.

As opportunities for increasing land-based production further shrink and potential of marine ecosystem becomes widely recognized, there will be more attention towards protecting the marine ecosystem. This will involve academic institutions, governance bodies and communities, and will most likely enhance obligation of the governments to more effectively implement marine conservation programs under the international agreements, including the Convention on Biological Diversity and Aichi Target 11 for 10% of the marine area to be protected by 2020. It is very unlikely for most countries to achieve this target but building momentum is necessary for actions in this direction.

Creation of Marine Protected Areas (MPAs) is a nature-based tool for protection of overexploited fish stocks, habitats and biodiversity. The importance of MPAs in mitigating and adapting to the impacts of climate change is also being recognized (Roberts et al. 2017).

Restricted range species are concentrated in places that provide them habitats and niches, and these areas are centers of endemism that happen to be major biodiversity hotspots. Roberts et al. (2002) have presented analyses of the geographic ranges of 3235 species of reef fish, corals, snails and lobsters, and observed that between 7.2 percent and 53.6 percent of species belonging to each taxon have highly restricted ranges, rendering them vulnerable to extinction. Many of these places are located in regions where reefs are being severely affected by people, potentially leading to numerous extinctions.

Conservation efforts targeted toward them could help avert the loss of tropical reef biodiversity. Duffy et al. (2016) have presented analysis of the data that widens the importance of MPAs by virtue of their role in conserving marine biodiversity that buffers global fish biomass from climate change and stabilizes fish production in a changing ocean. The authors have urged more synthesis of knowledge and clarity in highlighting the contribution of marine biodiversity to organic productivity and stability in the interest of conservation planning and fisheries management considering the fact that the major drivers of biomass production—temperature, resources, fishing, and biodiversity—are changing rapidly with increasing human population and seafood consumption. Earlier, Mustafa and Hill (2011) made an attempt based on the understanding of the ecological roles of species constituting the web of life in the sea to determine how a gradual decline in biodiversity increases the vulnerability of marine ecosystem. They elaborated that: a) the critical condition of a species in the community increases with biodiversity decline since it cannot entirely replace the ecological roles performed by those deleted from the ecosystem, and b) exclusion of species weakens the ecosystem resilience to stressors. The authors pointed out the difficulty in quantifying this relationship to define the ecosystem thresholds due to variations in the nature of marine ecosystems and species composition. Resilience of the local marine ecosystem in the face of biodiversity loss would depend on biology of the species, their interrelationships, and proportion of keystone species.

Significance of understanding the differences in vulnerability of biodiversity in different regions is a topic of current interest. This is more so for marine biodiversity hotspots such as the Coral Triangle region and MPAs situated there. This region is particularly sensitive to anthropogenic impacts and is vulnerable to warming-induced reduction in species richness for the reasons that: a) warming of water in tropics will be strongest during climate change, and b) many tropical species live near their upper thermal tolerance limits (Nilsson et al. 2009; Jones and Cheung 2015; Stuart-Smith et al. 2015). Marine species have evolved in a range of temperature that is narrower compared to those on land-based ecosystems, so warming of sea water will pose a greater physiological challenge to these species. Graham et al. (2006) have predicted loss of coral habitat and associated reef fish due to warming and other impacts. High biodiversity that provides resilience to the ecosystem will probably offset, to some extent at least, the consequences of climate change in the tropical region (Duffy et al. (2016). Effective enforcement of conservation measures and reducing fishing pressure will be helpful in places like the Coral Triangle in containing the biodiversity crisis. This area occupies 1.6% of the world's oceans and is considered among the most biologically and economically valuable marine ecosystem on Earth (Flower et al. 2013). Its biodiversity sustains livelihood of an estimated 120 million people (CTI-ADB 2014). Obviously, conservation of biodiversity will help stabilize fish yield and food security which is a critically important ecosystem service for this vast population. Seaweed farming is a popular activity in the Coral Triangle and this could also help mitigate the damaging effects of acidification on marine life.

POTENTIAL APPLICATIONS OF DISRUPTIVE INNOVATIONS

Considering the enormity of marine environment and the services it renders, the disruptive innovations can be very helpful in achieving the expected outcomes. These are new uses of recent technological breakthroughs that have the potential to replace earlier approaches to find solutions to the outstanding problems. They can yield significant benefits and can be scaled up as required. This will involve application of technology rather than generating (disruptive) technology itself. Some of the maritime sectors where disruptive innovations can be applied are described below:

Sustainable Fisheries. Fisheries supply about 90.9 million tons of aquatic food annually but almost 20 percent of the catch comes from Illegal, Unreported and Unregulated (IUU) fishing activities. This amounts to a loss of US$ 23.0 billion per year to the legitimate fishermen and the government, and undermines the ocean management efforts (Agnew et al. 2009; FAO 2017). Recent technological developments provide monitoring tools in the form of advanced sensor platforms connected through digital technologies such as high speed 5G and mesh networks.

Overharvesting by industrial fishing amounts to two-thirds of the world catch. Control of unsustainable practices can improve fish catch by 16 million tons, profit by US$ 53 billion, and improve ocean health. Using suitable gadgets, managers can effectively monitor fish stocks and catch, and can track individual fishing boats, spot illegal fishing and enforce regulations.

Pollution Control. Annually, 8 million tons of trash enters the oceans (CEA, 2017). There are 400 dead zones in the sea and their number is increasing (Diaz and Rosenberg 2008). This is due to oxygen depletion by decomposition and other processes. Frequency and severity of harmful algal blooms are increasing. Many species of marine animals suffer and die by ingesting plastic. The toxicants dumped into the sea move through the food chain and can reach human consumers of seafood. The costs in terms of biodiversity loss, decline of ecosystem services and human health are enormous. The ocean monitoring technologies explained above for fisheries management can be deployed to track polluters and control the problem. Future disruptive technologies might make it possible to develop plastic substitute of practical use and to neutralize waste. The problem of plastic pollution of the sea has assumed serious proportions. Experts are working to develop robotic vacuum cleaners that can be operated by solar energy and pick up large quantities of dumped plastic in the ocean.

Protection of Marine Critical Habitats. Marine critical habitats such as mangroves, seagrasses and coral reefs have been degraded. These are nurseries for many marine animals and also provide numerous other marine ecosystem services. Their loss undermines all those services and benefits.

Marine Protected Areas cover only 6.35 percent of the sea (IUCN 2017). Ocean monitoring technologies can help in enforcement of habitat protection measures. Aerial and underwater drones can supplement these efforts. Recently, Varela et al. (2019) created accurate 3D maps of coastal areas using drones and photogrammetry for examining how rising sea level will affect nesting sites of sea turtles. They developed detailed digital models of coastal habitats for developing conservation strategies.

Current level of knowledge of abyssal plain is low due to harshness of the ecosystem there, but it is beginning to be realized that the seamounts arising from seafloor in the form of underwater mountains possess a unique ecosystem that needs conservation. Although these are generally extinct volcanoes that during eruption generated huge amounts of lava, the seamounts attract an abundance of marine life. This is the reason for these submarine geological features to be so productive fishing grounds. Bottom trawling disturbs this habitat where many species are endemic. Furthermore, seamounts also host active hydrothermal vents that are energy hotspots and have high concentrations of reduced chemicals (for example, methane, sulfide, iron) that drive chemosynthetic ecosystem. Life there can be a rich source of bioactive compounds unlikely to be found in any other form of life. Devices equipped with digital technologies can help us explore this ecosystem and address the conservation challenges.

Protecting Endangered Species. Many marine species are declining and the number of species under the Red List is increasing. Loss of marine biodiversity threatens ocean ecosystem and benefits linked to it. Satellite tracking of endangered charismatic species such as marine mammals and sea turtles helps in gaining insights into their ecology and in guiding their conservation. Various tools of IR4.0 can offer real time information about the location of species in the sea and fishing fleets, and also assist monitoring and surveillance vessels operating in the sea for enforcement purposes.

Genomics can also aid in identifying endangered species and their origin in their supply chain for unauthorized trading.

Building Resilience. Climate change has adverse effects on marine environment. These include ocean acidification, dead zones and biodiversity loss among others. This is diminishing the fish stocks and other benefits. Disruptive innovations can increase our capabilities to observe marine biodiversity and monitor changes over time, respond to stressors linked to climate change or directly to anthropogenic interaction, and generate information about the deep sea that has eluded the scientists so far. This will improve our understanding for devising appropriate management interventions. Furthermore, IR4.0 tools such as 3D printed reefs and seagrasses can be used to provide healing touch to the stressed ocean ecosystem. The 3D printing has meant that the reef structure can now boast to be inspired by the natural coral reef and the nearest any artificial reef can go to the pristine structure of the reef.

Products like 3D printed biomimetic (robotic) fish equipped with artificial intelligence systems that mimic the movements of the fish can allow better insights into the fish biology and response to environmental factors.

Control of Coastal Erosion. Coastal erosion is a global problem which is worsening with changing climate. It threatens coastal infrastructure and economies that are closely tied to the sea. The cost is enormous but difficult to calculate. Advanced materials resulting from disruptive innovations can help in providing economically viable, strong and durable means of reinforcing the vulnerable coastlines which can withstand erosional influences of oceanic conditions or the force of some extreme events.

Ecological Aquaculture. With the world's capture fisheries stabilizing at 90.9 million tons per year, aquaculture production is steadily increasing to meet the seafood demand. It contributes 80.0 million tons of fish and when seaweed production is included, the total yield amounts to 110.2 million tons, which exceeds the landings from capture fisheries (SOFIA 2018). The total amount of seafood produced annually (201.1 million tons) supports the average per capita consumption of 20.3 kg. The expanding aquatic farming operations are providing means of livelihood to more than 800 million people around the world. The demand will certainly increase with growth of human population and preference for seafood. In this respect, disruptive technologies can really help in a quantum increase in production on a sustainable basis to achieve the targets of Sustainable Development Goal 14 (Life below water) that stipulates conserving and sustainably using the oceans, seas and marine resources for sustainable development.

Smart aquaculture systems using artificial intelligence for water quality monitoring and management can help in production efficiency and overcoming the shortage of technical manpower in addition to taking timely action in the hatchery or grow-out phases in captivity. Advanced materials can be used to construct more durable deep sea cages. Artificial feeding, cage cleaning and repair can be done by underwater robots with artificial intelligence and automation, and this can spare people from doing risky manual jobs under rough sea conditions. Furthermore, observations on fish growth and health condition in offshore sea cages can be monitored in real time and relayed to the managers. This will enable shifting some coastal aquaculture systems to the deep sea.

Several components of hydroponic, aquaponics and integrated multi-trophic aquaculture systems can be constructed by 3D printers using innovative smart materials. Further research can lead to development of cost-effective and practically feasible methods of renewable energy to save cost and reduce carbon footprint. At some stage, different disruptive technology components can help in transitioning aquaculture into a circular economy model.

Marine Bioprospecting. Marine life is a rich source of bioactive compounds which are of great importance in human health and industrial applications. However, the problems are in identifying source species from the large number of organisms from different phyla, large-scale harvesting of the target species from the sea and changes in the quality of bioactive compounds. Industrial-level harvesting will have adverse consequences for marine ecosystem. It will deplete the population of the target species and disturb other links in the web of life. Developing smart culture systems for the target organisms for mass production and bulk extraction of the required compounds are possible but the culture of many species poses major challenges. In many cases, genomic and genetic engineering technologies can be used without threatening sustainability of the target organisms in the marine ecosystem. DNA extracted from small samples can be cloned into its symbiotic bacterium. This genetically engineered bacterium can synthesize large quantities of the chemical(s) without additional reliance on the harvest from the wild populations. Most of the bioactive compounds are value-added substances which yield good price in the market and better profit for those involved.

CONCLUSIONS

Human well-being is intertwined with the oceans. Marine environment provides natural resources and ecosystem services that support livelihood, supply food, fuel economic growth and create conditions suitable for living on this planet. The climate change that is happening now means oceans are undergoing changes which can potentially undermine their capacity to sustainably provide goods and services needed for human survival. The anthropogenic climate change triggered by massive emissions of greenhouse gases with the advent of industrial revolution is real and scientific evidences are strong to dispute any doubts. It is different from variations that the climate system has been undergoing over a wide range of time scales due to natural causes such as changes in solar energy and volcanic eruptions. Attempts to create scenarios of ‘alternate realities’ that justify business-as-usual ways of life ignore the essential requirements of sustainable development, and are misleading.

Simultaneously with taking measures for reducing the release of greenhouse gases, the world should invest in mitigating its adverse consequences for sustaining the social and environmental benefits, and in developing adaptations. In this context, identifying and conserving priority areas for marine biodiversity and improving general ocean health are steps of critical importance. Oceans require a holistic and informed approach to sustainable management using methods that could be nature-based or technology-based. Technological developments for seafood production from oceans and aquaculture systems have often come at a price to the environment. However, the Fourth Industrial Revolution that is underway holds a great potential for undoing some of the damage that past industrial revolutions have inflicted on the environment. Knowledge generated by diversified approaches can help us take wise decisions, combat the ravages of climate change, fast track blue growth and achieve the targets of sustainable development goals. As much as the technology has impacted the oceans, nature has always been a source of inspiration. There is no reason why new disruptive innovations cannot be inspired by natural processes and shaped according to green perspectives for the blue economy and human welfare. In fact nature-inspired disruptive innovations can help us unlock many more solutions which will accelerate sustainable development.

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