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ARTICLE

Oceans and COVID-19: Perspectives, Reflections, Recovery and Regulatory Frameworks

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ABSTRACT

COVID-19 pandemic has created an unprecedented public health crisis, taken about 1.4 million lives so far, infected almost 70 million people around the world, battered the global economy and paralyzed the normal activity. This situation is evolving so rapidly that the data on numbers of infections and deaths are changing daily and the economic impacts are difficult to evaluate at this stage and probably will not be exactly known in the near future. It is important to determine the genesis of the outbreak to understand the root causes of COVID-19 and to prevent such pandemics from occurring in the future. It is believed that the virus originated in a seafood market in Wuhan (China) that was also trading in wildlife for human consumption. Such practices are associated with the habitat degradation and biodiversity loss, leading to an imbalance of the natural ecosystems. The zoonotic spillover of this infectious outbreak is a reflection of the impairment of natural systems. Scientific and anecdotal evidences demonstrate the significance of marine critical habitats in combating and containing human diseases. There are many other ways in which the oceans can help in human health. In addition to providing an analysis of the COVID-19 outbreak, this paper also suggests knowledge-based and informed measures that need to be applied to prevent a repeat of such catastrophic events while highlighting the role of oceans in this context. Plans and strategies for recovering the global economy and ensuring its resilience will require incorporating nature-based solutions and ecosystem restoration. The sustainability of the ocean is a key consideration in the development of a framework for post-COVID-19 recovery and this aspect is the major focus of this paper.

1. Introduction

The novel coronavirus outbreak that originated in Wuhan, China, in December 2019 has become a global pandemic (COVID-19). It has created an unprecedented public health crisis, taken 1.4 million lives so far, infected 70 million people around the world, battered the economy, plunged the world into recession and paralyzed normal living activities. Less highlighted is the challenge that this

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pandemic has posed to the oceans and the global goals of development (Sustainable Development Goals, SDGs). Even before the broader transformations required to achieving the objectives and targets of SDGs (2016-2030) were recognized, COVID-19 took the world by storm, shutting down economies, confining people to homes and disrupting daily life. There are short-term, medium-term and long-term consequences of this pandemic. Governments released bailout payments and stimulus packages and mobilized resources for public health security. The enforced lockdowns and the consequential restrictions are gradually being relaxed but "post-lockdown" is not synonymous with "post-COVID-19" as long as the coronavirus is prevailing. This virus transmits easily from person to person, infects healthcare staff despite their special protective gear and remains active on hard surfaces and in aerosols, which are signs of its adaptability and potential of becoming endemic in human populations. Until large populations survive the infection and have antibodies, and effective vaccines immunize the population against the infection, the COVID-19 threat will persist. Thus, a return to normal lifestyles in all their facets that prevailed before the viral outbreak is not an imminent prospect.

Without the prescribed precautions, further outbreaks are inevitable. Social distancing and other protective measures have reduced infections to lower levels and flattened the curve in several countries but the virus is around and billions of people remain vulnerable. The fact that Malaysia and some other countries have not seen high rates of infection at the levels of the USA, France, Italy, UK, Latin America and Asia means that most people still remain vulnerable without having antibodies to fight the disease. We do not know how effective the vaccine will be and how long the immunity will last.

This pandemic will make it more difficult to achieve the targets of SDGs, but an in-depth analysis of the Goal requirements motivates prioritization of investments in selective actions within each Goal. While SDG3 (Good Health and Wellbeing) specifically deals with this matter, others concerned with poverty reduction, fighting hunger and malnutrition and sanitation have a bearing on human health. In this context, the role of oceans should be recognized and appreciated and efforts directed towards boosting the resilience of marine ecosystem for the benefit of human health and general wellbeing.

COVID-19 crisis is a timely reminder to reflect on the ocean as a fundamental life-support system that can benefit humanity when faced with major challenges. Oceans cover 70% of the Earth's surface and contain 97.5% of the total amount of water on the planet. Goods and services supporting the formal and informal sectors of marine economy ("blue economy") are collectively valued at $2.5 trillion a year, constituting the 7th largest economy in the world (in terms of Gross Domestic Product) that is supported by ocean assets worth $24 Trillion [1]. The first-sale value of fish amounts to US$401 billion [2]. If the assessment of the World Economic Forum is given credence, more than 3 billion people depend on the oceans for their livelihoods. Fish provides 3.3 billion people with 20% of the animal protein [2]. The per capita fish consumption averages 20.5 kg. Fishing activity, which is one sub-sector of the ocean economy, declined by about 6.5% as a result of restrictions enforced by governments to break the cycle of infection [3]. Post-COVID-19 course of action will have to tackle these complex issues that are inter-related and call for a holistic response to place the world on a recovery roadmap.

This paper considers the genesis of the pandemic and places the role of oceans in an appropriate perspective, and also suggests knowledge-based measures for sustainable solutions.

The impact of COVID-19 extends far beyond the number of people infected and killed by the virus. It has produced ramifications across the world and these are redefining the economic, political and social landscapes [4]. Tackling these consequences calls for a rational policy sequencing [5] based on comprehensive analysis of sectoral variations in the COVID-19- related areas, so as to facilitate the sector-specific responses [6] through policy reviews and structural transformations. In this context, it is appropriate to link these issues with the role of oceans in mitigation strategies. This global common is neither immune to the COVID-19 crisis nor short of solutions to mitigate its impacts and, therefore, deserves due recognition in efforts towards harmonizing human systems and natural ecosystems. This unprecedented situation calls for in-depth analysis of interrelated issues and implications of mitigation measures.

2. Genesis of Novel Coronavirus Outbreak Linked to the Seafood Market

COVID-19 is a subject of intense discussion in the media of mass communication and social media. While this exposure has played a significant role in public awareness, some misconceptions still remain in the public mind. Not all viral coronavirus postings can be accepted as facts. There is a dire need to filter these messages and select those facts that are backed by science. It is true that the

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pathogen was first detected in late 2019. This triggered a series of responses, the timelines of which have been reported by the relevant institutions [7]. Although the exact origin of the coronavirus is still being debated, the overwhelming evidence is that the first human infection occurred in the Huanan seafood market in Wuhan [8]. It should be emphasised that the infection did not occur as a consequence of seafood consumption but from wild animals. This seafood market covers a vast area where livestock are kept alongside dead animals and live wild animals are openly traded for human consumption. The available evidence suggests that this novel coronavirus originated from bats and passed through an intermediate animal, probably a snake, a pangolin or a dog (still unconfirmed), before infecting a human host. Based on genomic analysis, two scenarios have been proposed [9]. Firstly, the virus evolved into its current pathogenic state in an intermediate animal and thus already had features that made it pathogenic to humans and spread rapidly in the population. Secondly, the non-pathogenic form of the virus directly entered the human beings and acquired the pathogenic state. In the absence of any substantial structural changes in the virus reported since its outbreak, it is evident that it is already well adapted to the human body system.

It should be understood that these viruses are nucleoprotein bodies (in some cases with an additional lipid envelop) in search of cellular machinery of host cells to reproduce. They are capable of reprogramming and using host cell resources to make copies of themselves. If the virus has indeed originated from bats, it is possible that the consumption of this flying mammal or an intermediate host led to its exploring a new (human) host through a process called as the "zoonotic spill-over". If the primary and intermediate hosts are under stress due to excessive exploitation and habitat degradation then their internal environment may not be ideally conducive to the viral pathogen which would opportunistically explore other hosts, including humans. Hence, when species are removed from their natural populations in large numbers, the ecosystem is disturbed, the relationship between the pathogens and their natural hosts is disrupted, and the pathogens tend to seek new hosts among other animals, and this spillover ends in humans.

Likewise, if wildlife taken out from their natural habitats is held in close contact with other species, then the species not naturally known to harbour the coronaviruses could become potential hosts. Obviously, the wild animals maintained in captivity in small enclosures are under stress and become vulnerable to the viruses. The virus can also be transmitted to farmed animals if they are in close proximity to infected wildlife in markets and thus become an easy route to human consumers even though they do not consume such wildlife.

This pandemic has also exposed the inhumane treatment of animals as well as continued exploitation of wildlife despite international agreements for the conservation of all levels of biodiversity. Probably, the seriousness of the message contained in these and other highly scholarly scientific findings could not reach the stage of translation of the recommendations under the Convention of Biological Diversity (CBD) and SDGs. Ironically, the COVID-19 pandemic is a significant alarm signal for non-compliance of the international biodiversity policy. The convention on the "Biological Diversity Strategic Plan 2011- 2020", which laid down the "20 Aichi Biodiversity Targets", is nearing its term. There have been obvious weaknesses and grey areas in governance, as a result of which, habitat destruction and depletion of certain species targeted for human consumption have remained the major drivers of the global biodiversity crisis and degradation of natural ecosystem functions. One such function is the control of infectious diseases. Scientists have developed conceptual constructs of ecosystem thresholds and have examined trends that demonstrate the link between biodiversity loss and the emergence and transmission of infectious diseases [10,11]. COVID-19 prevalence is a reflection of disruption of the complex interactions in the web of life comprising pathogens, vectors and hosts. It should be emphasized that biodiversity of habitats, species and their genes provides stability to the ecosystem, which is essential for both ecological and human health. The depletion or deletion of one species changes the way other species mutually interact. A broader issue surrounding the Covid-19 crisis is that "justice for the environment" means improving and maintaining a healthy environment for the benefit of society and all other life forms. When boundaries of resilience of the Earth's natural systems are breached and ecosystems are pushed to tipping points, nature cannot continue to sustainably provide the essential services on which humanity depends for its welfare [12]. The fact that 50% the world's gross domestic product is dependent on natural resources deserves emphasis [13]. Humans have not accorded justice to the environment and the consequences are now becoming evident. Progress in a post-COVID-19 recovery will involve transitioning from linear economies to circular economies, starting with development of sustainable sea-

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food systems but not limited to this sector.

3. COVID-19 and the Oceans

A survey of COVID-19-related publications reveals that inadequate attention has been given to the ocean perspectives despite their relevance. Apart from the role of oceans in seafood supply and mitigating the impact of climate change and diseases linked to this phenomenon, the oceans have a direct role in combating human pathogens. A ground-breaking work [14] provided evidences that show that seagrass meadows (Figure 1) remove pathogens of humans, fishes and invertebrates from seawater. Role of these flowering marine plants is supplemented by the coastal vegetation represented by mangroves (Figure 2). Many researchers have highlighted how the destruction of biodiversity and natural capital has perpetuated many new pathogens. In adopting a broader perspective, it has been comprehensively elaborated that the changes in ecosystems influence the behavior of human pathogens and the degree of disease prevalence in the society [15]. COVID-19 crisis should promote research into the fundamental causes that give rise to deadly viruses and focus on conservation strategies of "natural capital" and the "global commons" which have been plundered and degraded for generations. Undoubtedly, the biggest global common is the ocean. The pandemic is a reminder that eliminating something (coronavirus) that looks lifeless, unable to grow and reproduce on its own, can be so daunting. The simple chemical complexes of the virus that use host cells to assume the proportions of a global pandemic and emerge to become a formidable threat to humanity should strengthen our resolve for preventive actions.

Figure 1. Seagrasses combat human pathogens

Figure 2. Mangroves build resilience in seagrass meadows

Oceans provide us high-quality seafood rich in protein and other nutrients that nourish our body, improve health and strengthen the capacity to fight diseases while reducing inflammation. According to the latest estimates as much as 84.5 million tons of fish was harvested from the ocean in 2018 [16]. The fish supplies have a major share in the first sale value amounting to US$ 401 billion [2]. The seafood is also free of the infections such as Middle-East Respiratory Syndrome (MERS), Swine Flu (H1N1), Severe Acute Respiratory Syndrome (SARS) and Bird Flu (H5N1) or the human version of the "Mad Cow" known by the name Creutzfeldt-Jakob Disease (vCJD). There is no evidence linking COVID-19 to seafood, and this virus does not infect marine animals [17]. Further, many marine organisms are sources of bioactive compounds that are suitable for development of functional foods that improve health beyond the basic nutrition and reduce the risk of disease. There is a large number of marine bio active ingredients that meet the criteria of functional foods, including polyunsaturated fatty acids (eicosapentaenoic and docosahexaenoic), minerals, trace elements and vitamins, and anticancer substances. Selenium present in measurable amounts in shrimps, lobsters, crabs and oysters is a proven antioxidant and has immunity-boosting properties that support the immune function and provide resistance against viral infections [18-20]. Also, there are potent compounds possessing antibiotic properties that can act against a range of bacteria [21]. Further, there are several polysaccharides derived from marine microalgae and seaweeds that have been shown to possess antimicrobial, antiproliferative, anti-inflammatory and immunomodulatory properties [22]. The screening of natural products derived from marine life has yielded a large number of compounds that are potential antiviral drugs [23,24], and many have demonstrated effectiveness against bacteria [25,26], fungal infections [27] and parasites [28]. In fact, there

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are many pharmacological products already available in the market including the alternative antiviral medicines [23].

Post-COVID-19 research should motivate more interest in marine bioprospecting, marine cultures, antimicrobial trials and marine drug development. The scope of exploring oceans for possible drug discoveries is significant because of the complex environmental conditions that marine organisms have to deal with to survive and thrive. They develop strategies and mechanisms that involve producing chemical metabolites for inter- and intraspecific signalling, deterrence against predators, inhibiting the adverse activities of surrounding life forms and producing safeguards from pathogenic microbial forms [29]. Chemical compounds produced metabolically (secondary metabolites) are known to possess bioactivity and medicinal properties [30]. Viruses pose a special challenge due to a limited number of targets in their structure, rapid rate of evolution of their genes and emergence of drug-resistance pathways and mutations that result in new strains [31]. Furthermore, viruses are difficult to culture and most laboratories are not equipped to undertake this sophisticated and risky trial that can be undertaken in living cells. For a virus such as COVID-19, the risk is manifold because the full extent of the dangers and the exact nature of immune system needed to defend it are unknown. In discussing the scope of marine bioprospecting for products of pharmacological significance, the need for international cooperation in this area of research through a policy review for accessibility to marine biodiversity hotspots and benefit-sharing has been recently highlighted [32].

The rapidity with which the coronavirus has spread and its pathogenicity are responsible for the present increasing infection rates and death tolls. Vaccines take time to develop and be tested and to become commercially available. Hence, populations at large remain vulnerable and depend on preventive measures such as isolation and social distancing to remain healthy. The risk of infection will continue until the majority of people (70-90%) become immune either after safe recovery with antibodies or immunity through vaccination. This breaks the chain of transmission, and slows down the pandemic because there are not enough infected carriers to transmit the pathogen to others.

The search for complex bioactive compounds in marine organisms must, therefore, continue. Because of their complexity, there is a possibility of discovering some novel compounds that can combat the unknown pathogens and to a certain extent protect populations until such time that effective and clinically validated solutions evolve. Meanwhile, scientists and media of mass communication can also dispel the traditional belief in the healing and curative properties of products of wildlife origin such as shark fins, dugong body parts and sea turtle eggs, for which there are no scientific evidences to support specific medicinal benefits from their consumption.

In the case of COVID-19, the wise course of action, therefore, is for individuals to stay healthy by protecting the immune system, observing social distancing, using face masks and practicing prescribed hygienic procedures such as hand sanitizing. Generally, good nutrition and a healthy immune system offer protection from many health problems but are no guarantee against COVID-19. Prevention guidelines should continue until effective vaccines are available to the population. Countries that have not seen a high rate of infection means that most of the population remains vulnerable without antibodies protection. There is a need to continue practicing the measures for protection from COVID-19.

There are many uncertified products available in the market portrayed as a means of preventing and curing COVID-19. These are not effective against COVID-19 and their use may even be harmful to the body immune system [33-35]. By contrast, marine bioactive compounds developed by intensive research, analysis and trials could to be somewhat effective if guidelines for their use are followed. Their potency and effectiveness can be put on trial as a fast track approach to combating infections as new vaccines emerge.

The potential of corals in treating human diseases is currently under investigation. The target of these studies is the chemical defence system of these reef-building animals which are sessile and which chemically shield them from many predators in the sea (Figure 3).

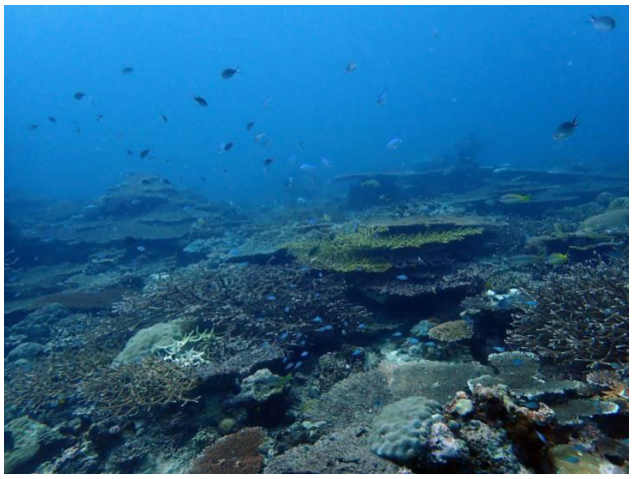

Figure 3. Many marine species in coral reefs are sources of bioactive compounds that can combat pathogens

Oceans also have a highly significant role in mitigating climate change that is known to increase infectious dis-

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ease occurrence and transmission [36].

Interesting observations have been canvassed in the media on how the lockdown of cities and drastic curtailment of commercial activities have provided "healing" to the ocean. There is accumulating evidence which shows that halting of industrial fishing operations by deep sea fishing fleets due to lockdown and market closures and quarantine procedures that required social distancing, have eased pressure on fisheries stocks. Interruption of commercial shipping operations and other industrial activities have also provided some reprieve to the marine ecosystem. Considering that 80% of worldwide trade (in total volume) is handled by the maritime industry [37], the effects of human activity reduction are likely to be significant [38]. However, sightings of rare or semi-rare forms of marine life are anecdotal at this stage but are sufficiently significant to reflect the extent of ecological footprint of anthropogenic activities that encroached on the marine wildlife habitats. It is premature to present scientific data underlying ecosystem conditions as related to COVID-19 lockdowns, but early signs suggest marked improvements can be expected.

However, there are also negative impacts on the oceans due to COVID-19, such as the widespread disposal of used personal protective equipment (PPE), particularly masks, gloves, visors and gowns, which has become an additional threat to the oceans that are already reeling under the enormous weight of global plastic waste [39]. Marine enforcements, especially in Marine Protected Areas (MPAs), are also constrained during lockdowns and this could have allowed "Illegal, Unreported and Unregulated (IUU)" activities to occur. The extent of these is difficult to ascertain due to the suspension of monitoring. Closure of MPAs has led to a drastic decline or complete disruption of nature tourism, leading to decline in income which is an important source of revenue for conservation agencies and livelihoods of local communities. Suspension of on-going research needed for the restoration of marine biodiversity means delay in data collection required for informed management decisions. There is a delay or postponement of key UN meetings such as the "Biodiversity Conference - 15th 'Conference of the Parties' (COP15) and the 'Convention on Biological Diversity' (CBD)", scheduled for 2020 as a landmark year for conservation. This means less time is available for reviewing the achievements of the "Strategic Plan for Biodiversity" (2011-2020) and for chartering the future courses of action on issues as critical as resource mobilization and capacity-building among others.

Commercial maritime activities will be restored as this pandemic is brought under control. These can be shaped according to the criteria outlined in a recent publication for developing the "blue economy" [40]. Weather the pre-COVID-19 "business-as-usual" scenario will prevail or new policies will be formulated for making a radical departure for real transformation towards sustainability, remains speculative. The urban paradigm that has long prevailed until the COVID-19 outbreak has led to concentration of industrial activities and human settlements along the coast lines. Currently, 40% of the world's population of 7.8 billion lives within 100 km of coasts. Many environmental impact studies, especially through modeling, have justified coastal zone urbanization by presenting "ecofriendly" mitigation measures and attractive infrastructure designs. Ironically, these metropolises have suffered the most from the coronavirus infection [41] and also are facing the onslaught of climate change impacts. Urban planners should, therefore, consider the risks involved in developing high-density clusters along coastlines. The practical viability of virtual online activities including business meetings and trade and product promotions can be effectively conducted remotely, without clustering people into limited spaces dictated by the dysfunctional systems of planning. This reduces traffic jams, accident risks and greenhouse emissions, and spares open spaces from turning into pandemic hotspots.

Given the experience with conservation interventions, it might help to some extent to continue the momentum for pushing the ocean ecosystem agenda for policy support. The central argument is that the SDGs cannot be achieved without a healthy ocean [42] and the world is risking human health and wellbeing by placing ocean health at risk. This explains the significance of SDG14: Life Below Water (Conserve and Sustainably Use the Oceans, Seas and Marine Resources for Sustainable Development).

To help protect the ocean, 193 Member States of the United Nations agreed to conserve 10% of their coastal and marine environment by 2020 (this year) following the requirements of CBD through MPAs as an effective spatial, ecosystem-based management tool [43]. The world is trailing far behind despite this being the Aichi Target 11 of CBD as well as Target 5 of SDG14. This is a significant target to achieve since current research shows that at least 30% of the oceans must be protected to meet the goals of global conservation [44] and the multiple resources they provide to society.

The post-2020 global biodiversity agenda before "CBD COP15" will have to be based on the achievements and extent of delivery of the CBD "Strategic Plan for Biodiversity 2011 - 2020" and adopting the post-2020 global biodiversity framework. The latter should be structured to ensure protection of 30% of the world's oceans by 2030

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via effectively regulated networks of MPAs in which destructive or resource-depleting extractive activities are not allowed. Efforts should be made to link the post-2020 global biodiversity framework with the SDGs and identifying indicators for assessment. This will contribute to our efforts towards science-informed policy responses consistent with the United Nations proclamation of Decade of Ocean Science for Sustainable Development (2021 - 2030).

Also, specific policies should evolve under the purview of "blue economy" and "blue growth" to fast-track solutions to pending and emerging problems. This is a matter of utmost urgency as lockdowns worldwide ease and economies recover. Fortunately, there is an unprecedented clamour among scientists, environmentalists and rational thinkers to leverage their knowledge for supporting "blue-green growth" as a "new normal" in a post-COVID-19 world. The global environment is at a crossroads and far-sighted decisions are urgently needed to build resilience in natural systems, to protect oceans, to make a rapid transition into sustainable pathways for a long-term human welfare and to combat infections and enhance human quality of life. The recovery roadmaps suggested earlier [40,45,46], can be considered in terms of building a strong and sustainable ocean economy post COVID-19. Future developments have to be balanced, covering land-based "green economy" as well as ocean-based "blue economy". Lopsided considerations that in the past ignored the potential of oceans have to be corrected by a comprehensive cost-benefit analysis. An example is that of food supply. Land-based food crops use scarce land and the dwindling resources of freshwater, and need fertilizers and pesticides to maximise output, whereas seaweed farming (Figure 4) for food does not need any of these commodities. COVID-19 recovery plans should envisage sector-wise transformations in ocean-based activities. The unsustainable fisheries practices should progress towards "Ecosystem Approach to Fisheries Management" (EAFM). Aquaculture systems put pressure on marine resources by commercial-scale production of fish meal and fish oil and because their effluents create environmental and human health issues. These should follow aquaponics, "Integrated Multi-Trophic Aquaculture" (IMTA) and other ecological farming methods. Likewise, rebuilding of fishery stocks can be achieved by responsible stock enhancement and sea ranching. Conservation of marine biodiversity by expanding and enforcing MPAs can increase fishery harvests. These and other areas requiring "blue growth" and "blue economy" are summarized in Figure 5. For these sectors, the appropriate application of digital technologies associated with "Industrial Revolution 4.0" (IR 4.0) will be helpful in boosting knowledge-based "blue growth" and expanding the "blue economy". These technologies supplement the successful application of existing practices or replacement of those constraining "blue growth". An example is "Big Data" technology that can assist conservation of natural capital, especially oceans, where there is an enormity of data to process for timely decision-making and for preventing and containing pandemics.

Figure 4. Seaweed farming is among the low-carbon sectors of blue economy. Farmers in Balambangan region of Borneo traditionally harvest seaweeds from marine farms

Figure 5. Areas requiring attention for developing a sustainable blue economy

4. New Normal and the New World Order

The "seismic" impact of COVID-19 in terms of the human infection and death tolls has caused economic

disruptions and social upheavals which have projected a "New World Order". Overall a 3% contraction of the world economy in 2020 was projected by the International Monetary Fund (IMF). The need for a collective response to this pandemic is paramount. International cooperation is needed to contain it and a global endeavour is necessary to pre-empt its recurrence in the future. Viruses do not respect borders and in such mitigation efforts, a global consensus must be achieved according to ethical guidelines without the constraints of sovereign rights. The "New World Order" should have agreements to examine national policies with international ramifications and should have objective tools to seek accountability beyond the purview of vetoes in matters concerning global human health. Also, there should be structured systems of responsibilities and accountabilities to be applied worldwide. Further, the world requires a global consensus on an action blueprint and a systems approach. While institutions and instruments have been developed by the United Nations, the COVID-19 outbreak exposes their weaknesses in terms of practicality in enforcement. This should trigger "disruptive" approaches that can reject the ineffective prevailing systems.

A post-COVID-19 world order should be based on the concept of a "collective future" for humanity and guided by the principles of oneness. A roadmap in the form of UN SDGs is already available for implementation. Under this framework, a robust global disease surveillance program, with a mandate to operate worldwide, can assist in achieving global health security. Epidemics arising in any part of the world can pose threats globally. Responses to health emergencies cannot succeed if a new world order ignores this issue of fundamental importance. Unfettered access should be provided to UN institutions to monitor specific areas of concern for compliance as a matter of routine. This will also benefit the global population by eliminating potential origins of infectious diseases, give early warning of outbreaks and mobilize resources wherever and whenever these are needed.

Through international cooperation, national institutions can obtain essential resources for epidemic control and for preventing its spread beyond epicentres, through a transparent framework of monitoring and action. SDG17 (Partnership for the Goals) envisages steps for strengthening implementation and revitalization of the global partnership for sustainable development. World needs to develop new mechanisms for achieving these objectives in the hindsight of COVID-19.

COVID-19 pandemic has shaken the world socially and economically unlike any other disaster in recent decades. Concerned that COVID-19 is a threat multiplier, three emergencies - health, social and physical development - that might add to the pre-existing inequalities and vulnerabilities have been identified [47]. The extent to which different countries address these will depend on their socio-economic status, political efficiency and governance frameworks. In general terms, the following issues need to be addressed in the aftermath of COVID-19 (Table 1).

Table 1. Suggestions for a post-COVID-19 action plan

S.no.	*Suggested actions*
1.	Review targets of SDGs with greater emphasis on epidemiological issues, while devising effective implementation and monitoring methods.
2.	Prioritise research on knowledge gaps in identifying the critical control points for zoonotic spill-over from wildlife to control its wider transmission.
3.	Develop national policies for strengthening emerging areas such as marine bioprospecting for pharmaceuticals and protection of ecosystem services; research should move beyond screening to drug development.
4.	Develop sustainable seafood production systems as a substitute for terrestrial wildlife exploitation to minimize the risk of infectious outbreaks from the potential zoonotic spill-overs.
5.	Invest more resources in self-reliance and supply chains especially pertaining to seafood to buffer stocks from unanticipated problems inherent in global and local supply chains.
6.	Digitalise the economic sectors such as seafood supplies.
7.	Invest in "blue-green" architecture for coastal and marine infrastructure via design innovations.
8.	Harness the potential of "Big Data" technology to identify vulnerabilities in society for devising strategies for addressing the weaknesses and sustainable management of the natural capital of oceans.

5. Systems Thinking for Sustainability

The role of higher education institutions in the post-COVID-19 response and recovery is critically important since the roadmaps for recovery will be knowledge-based and driven by "systems thinking" which is basically a holistic analysis and understanding of the entire complex system that has multiple linkages and interactions. This approach encourages exploration of the inter-relationships, perspectives and boundaries of a problem systematically that cannot be solved by examining one element or an aspect of a complex issue. A systems thinking approach is relevant to topics of sustainability that require seeing the "big picture" in order to identify multiple leverage points that can be addressed to achieve a positive transformation which can be considered adaptive management [48]. An interdisciplinary approach is necessary for a holistic analysis, especially when issues require defining the complexity of connections of the oceans with pandemics. Currently, more advanced interdisciplinary research in this area is

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essential at institutions of higher education.

Many universities have acquired or enhanced basic digital capabilities as a result of COVID-19 restrictions and lockdowns in order to continue to undertake their primary roles by using online platforms for lectures, meetings and conferences. These systems will be reviewed when the feedback from the audience will be available to indicate the depth of their engagement through online delivery and how this compares with the conventional face-to-face delivery. It is possible that the teaching and learning portfolio will be a mix of "conventional" and "on-line" strategies as the universities are called upon to provide appropriate education and training to address the changing employment market trends. A radical shift towards digitalization and online education will create a new education paradigm in conjunction with openness, transparency and plagiarism control. In addition, the effectiveness of such systems can effect a transformative change in the promotion of sustainability. A detailed account has been presented [49] on the role of institutions of higher education in a rapidly changing educational landscape.

Digitalization demands expensive infrastructure. At a time when global economies are entering recessions and bordering on depression and unemployment is ballooning, there are serious national budgetary challenges that need prudent fiscal management and new strategic directions backed by a "systems thinking" model.

For food producing sectors such as fisheries and aquaculture, there can be no abrupt departure from the time-tested methods of production but some associated activities can undergo digital transformation. These sectors have suffered from lack of adequate attention towards start-ups and disruptive innovations. In a "new normal" environment, R & D investment should ensure that funded projects yield productive sustainable outcomes and meet the requirements of SDGs.

Nature-inspired designs of development can bring significant changes to education with sustainability perspectives. It stimulates a dynamic new way of imparting education in sustainable development, STEM, creative problem-solving and systems thinking [50]. Such a holistic study paradigm is inclusive and engaging which can inculcate a quest for self-learning and creative and "out-of-the-box" thinking even beyond the confines of the classroom.

There is scope for reforming existing sectors as well as opening new ocean-based industries to absorb both graduates and low-pay workers to empower economic and social recovery, while sustaining natural capital. The higher education sector will have to invest in developing critical masses of experts in "blue-green" growth to focus on sustainable ocean-based economy in response to the post-COVID-19 recovery. These institutions have to demonstrate how blue growth and development can proceed while ensuring that the natural marine assets continue to provide resources and services for societal wellbeing. This involves structural innovation to underpin sustained growth and generate new employment and economic opportunities. The obsolete old model of growth that eroded the natural capital and resilience of the global commons, leading to water scarcity, biodiversity loss, resource bottlenecks, environmental degradation and climate change has to be rejected [51]. The new model will unambiguously prove economic dividends from investments in low-carbon, resource efficient, clean production and consumption, resilience and circularity and other attributes of sustainability in the development projects and sustainability programs.

Thus, the strategic teaching and learning plans of universities will have to change to include inbuilt systems of rationalization and accountability at all levels. This is necessary if the higher education system is to remain viable and be able to maximize its contribution to post-Covid-19 recovery. In addition, universities should continue to invest in on-line professional activities such as webinars particularly when these are focused on conservation and sustainability issues. This saves time and budget, and reduces impact on the environment. It can continue while some of the budgetary allocation that is normally utilized for such purposes can be diverted to ocean conservation projects.

It is essential that the higher education institutions are involved in national development plans since they can pursue problem-solving research transcending the disciplinary boundaries and participate in community enhancement projects. For maritime countries, community-based projects related to ocean conservation and protection will bolster interest in resilient and sustainable blue economy.

The term "disruptive" should not remain confined to research in the areas of ocean sciences and technology, and seafood security but must also find purposeful applications in the entrepreneurial programs of the universities to facilitate the post-COVID-19 recovery. It will need a radical shift from the culture of inflating the conglomeration aimed at achieving scores for which there are no immediate social innovation outcomes to the focused human resources that can help the society and economy in the increasingly uncertain future, especially for the graduates.

The ocean is classic global commons that represents an interconnected system of this planet's marine water which comprises most of the hydrosphere. It offers multiple solutions. Humanity knows many of them, gives little attention to others and is ignorant of the potential of several

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ocean services due to knowledge limitations. Events such as the COVID-19 shed light on the knowledge gaps that need to be filled. A topic of vital importance is green architecture for innovative designs for environment-friendly coastal and marine infrastructure. It is not only for new development projects but also for design modifications in the existing coastal infrastructure that faces the vagaries of nature and exposes people living and working in high densities to a greater vulnerability to viral diseases. High density urban areas have been particularly badly affected by COVID-19 due to concentration of people living and working there (with no physical or social distancing considerations!), their connectivity to transport to destinations outside their boundaries and healthcare facilities [52]. These areas do not measure up to "smart city" ranking and have become an outdated model of development. Especially in coastal areas, the "smart city" concept should include "green metrics" and be classed as "Green Smart Cities" in post-COVID-19 recovery. Introducing nature-based strategies into coastal infrastructure such as greenways, green alleys, esplanades, precincts and resort islands that can incorporate marine habitat restoration, will bolster resilience and enhance the concept of sustainable living. Traditional coastal communities living harmoniously with marine ecosystems have been practicing sustainable living for generations (Figures 6-8). The seas and oceans have sustainably provided these communities with the food and raw materials they need. High-end infrastructure, such as tourist resorts, will require a robust and comprehensive "green architecture" plan to be created and implemented.

Figure 6. Mangrove-integrated fish farming practised by traditional coastal community in Tuaran, Sabah, Malaysia

Figure 7. Fish catch is higher where mangroves are in a healthy condition

Figure 8. Environment friendly traditional seaweed farming using discarded plastic bottles as floats by the indigenous coastal communities in Banggi island

Ports and harbours should introduce the concept of "living shorelines" in the form of coastal vegetation and wetland areas so as to control erosion and stabilize seafronts, while providing habitats for marine species and wildlife and recreational spaces for human use [53]. Oxygen-rich clear air, shade, carbon sequestration, pollution mitigation, and a healthy environment, are inherent components of such infrastructures. Human resources development in these fields will enhance employment opportunities, provide income stability, strengthen community welfare and change public perception in favour of sustainable living. Further, "green architecture" and "sustainable development" concepts should be introduced into school and higher education curricula, in conjunction with related practical sessions in appropriate environments. Perhaps, nature-inspired outdoor teaching of certain course contents will help shape the architecture of educational programs that will go beyond the green architecture of the

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coastal infrastructure to encompass the essence of sustainable development.

6. Conclusions

COVID-19 has plunged the world into an unchartered territory with a great deal of uncertainty as to the structure and stability of the "new world" which will emerge. It has overwhelmed the healthcare system of even the richest and the most industrialized countries by the sheer number of people seeking medical assistance. Global economies are in a free fall and supply chains are in disarray. The world is in urgent need of visionary strategies and a strong resolve for transformative actions to protect public health and economies, and to sustainably manage the "global commons".

It is of major concern that such catastrophic event might be repeated without bringing dramatic changes to existing systems based on a holistic understanding of the present situation, coupled with a globalized system of pathogen surveillance. Although current SDGs have been tested by the severity of the pandemic, their objectives and targets still offer solutions to the prevailing crisis, in terms of the need to reassess our development priorities, focusing on human health, food security, livelihood and emphasizing the importance of natural capital.

The shockwaves and fallout of COVID-19 should motivate mitigation opportunities which could improve public health, lead to greater self-reliance, give certainty to supply chains and enhance levels of environmental conservation coupled with supporting a blue economy. Institutions of higher education can seize this opportunity to prioritizing research, focussing on these key issues and pursuing natural sustainability innovations.

The natural capital provides resilience and a means for buffering pandemic shocks, and it must be preserved by establishing ecological boundaries and identifying tipping points that contribute to preventing major reoccurrences. The shrinking of "safe spaces" threatens biodiversity which is the fabric of stability. While concerns for the preservation of biodiversity are widespread, transition into action is limited since multiple strategies are involved. These include: a) more investment in linking biodiversity to issues that concern the general public in daily life such as food security, health and wellbeing and the economy, and b) globalizing nature conservation monitoring and disease surveillance systems. COVID-19 has clearly emphasised the need to reassess national priorities in areas of critical importance such as "blue growth" and "blue economy".

Post-COVID-19 recovery should be knowledge-based and driven by a "systems thinking" process. Institutions of higher education need to respond to COVID-19 by undertaking significant restructuring of curricular and research so as to be resilient, relevant and be able to contribute to rebuilding the post-COVID-19 world. Post-COVID-19 recovery is an opportunity for all responsible institutions to facilitate transformative actions towards re-establishing the relationship of humanity with the natural world and particularly with the marine environment. Further, with respect to an ocean-focused policy, there should an element of ocean accounting in national statistics of individual countries comprising the value of marine goods and services, the impact of "blue growth" on the economy, the socio-economic condition of local communities and appropriately positioning oceans towards delivery of the "2030 Agenda for Sustainable Development".

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