Environmental Concerns in Marine Ecology and Strategies for Sustainable Development

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Abstract. Since the commencement of the Industrial Revolution, there has been a gradual and consistent escalation in the level of carbon dioxide emissions, thus causing a drastic alteration in the global climate. As the most substantial ecological environment system on Earth, the marine ecological environment system has also undergone substantial impacts as a result of these climatic changes. Despite its vast size, minor environmental dilemmas were not emphasized initially, leading to momentous qualitative changes caused by the quantitative ones; consequently, human face critical concerns related to marine ecological environment today. The intent of this study is to delineate corresponding sustainable development approaches for the persisting environmental issues under the theoretical framework of sustainable development. Initially, the causes of climate change are discussed, and the undeniably significant role humans have played is examined. Subsequently, alterations in climate change affect various segments of the marine ecosystem differently concerning seawater hydrological conditions, consequently producing a series of chain reactions that ultimately affect the overall marine ecological environment. Various sustainable development strategies have been proposed under the theoretical framework of sustainable development to address the multiple minor problems that contribute to the overall marine ecological environment issues. This study endeavors to present an extensive summary of the marine ecological environment issue in its entirety; however, it should be followed by further in-depth analysis and consolidation of the ecological environment issues of disparate links in the ecosystem, thereby increasing the effectiveness of the targeting approach. This paper expects that through this study, the specific impact of climate change on the marine ecological environment and the direction that human society must work towards to achieve improvement would be made more evident.

Keywords: Global climate change, marine ecological environment, sustainable development.

1. Introduction

At present, there is a noticeable transformation occurring in the global climate, primarily characterized by a rise in temperature and accompanied by alterations in natural patterns and factors attributable to human activities. The extent to which human activity contributes to this process of global warming is still subject to some ambiguity. However, it is undeniable that the global climate system is currently experiencing unprecedented and drastic changes. As the largest ecosystem on Earth, the marine ecosystem has always been recognized as the primary producer of oxygen and the major absorber of carbon dioxide, thus playing a crucial role in the regulation of the global environment. Currently, the marine ecological environment is the system that is most adversely affected by climate change and holds significant potential for impacting the global climate system.

It is now feasible to prognosticate forthcoming climate alteration patterns and potential impacts via Model Intercomparison Projects (MIPs), which proffer integrated prognostication outcomes. The quantification of divergences among models, spanning from low to high prediction ranges, is a vector for enhancing models and a destination for future long-term advancement. The most crucial MIP at present is the Coupled Model Intercomparison Project (CMIP), which has been upgraded and reiterated to the sixth iteration of Earth System Models (ESMs) for experimentation purposes. The output of these model consequences may be employed to propel other pertinent models to scrutinize how climate alteration will impact specific human sectors or natural ecological processes. There exist diverse categories of Marine Ecosystem Models (MEMs) as designated in Table 1 [1].

Table 1. List of global MEMs Participating in the study and differences relative to CMIP5 analysis [1]

MEM	Model type	Key forcing variables used	Differences between CMiP5 and CMiP6 MEM structure	Taxonomic groups included
APECOSM	Composite (size-and traid-based; functional group structure)	Carbon concentrations, particulate organic matter, zonal and meridional currents, turbulent mixing, temperature, water density, dissolved oxygen concentration, light irradiance. All fields 3D and monthly.	The APECOSM model was executed on the indigenous ORCA1 grid employing the native IPSL-CM suite of forcing fields. The 3D outputs were subsequently subjected to vertical integration and interpolation onto the 2D Fish-MIP 1° x 1° grid. Marginal refinements entail meticulous calibration of certain parameters.	Epipelagic fish, migratory mesopelagic fish, resident mesopelagic fish
BOATS	Si ze-based	Mean temperature 0–75 m, NPP	None	All commercially fished species, both finfish and invertebrates
DBEM	Species distribution model	Surface and bottom O_2, pH, salinity and temperature. Ice cover, current velocity, NPP, NPP pico and NPP diat. All variables on a yearly basis.	None	956 species of exploited fishes and invertebrates
DBPM	Composite (size-and trait-based)	Surface and bottom temperature, phytoplankton carbon groups	None	All benthic and pelagic marine animals weighing between 1 mg and 1 tonne.
EcoOcean	Composite (trophodynamic and species distribution model)	SST, seafloor temperature, column average temperature,	Improved representation of species contributions to ecosystem	Includes 51 functional groups representing the whole spectrum

		phytoplankton carbon groups	dynamics; improved responses of the marine food web to stratified environmental drivers	of marine organisms from bacteria to whales, and integrates explicit information for 3,400 species of vertebrates, invertebrates and primary producers
Eco Troph	Trophic-level-based	NPP, SST, integrated mesozooplankton carbon	None	Implicitly all groups, including pelagic and demersal fishes and invertebrates
FEISTY	Composite	Seafloor temperature, seafloor detritus flux, mean temperature 0~100 m, integrated mesozooplankton carbon 0~100 m	None	Small pelagic fish, large pelagic fish, demersal fish, benthic invertebrates
Macroecological	Size-based	NPP, SST	None	Implicitly all marine organisms from 1 gram to 1 tonne
ZooMSS	Composite (size-and trait-based; functional group structure)	Chlorophyll-a, SST	None	Flagellates, cilliates, omnivorous copepods, carnivorous copepods, larvaceans, salps, chaetognaths, euphausiids, jellyfish, fish

The purpose of this article is to summarize the current impacts of climate change on marine ecological environments and propose specific sustainable development strategies in response to these effects and the current socio-economic development situation. It is hoped that this will provide a helpful summary and compilation for future development.

2. Factors Contributing to Climate Change

2.1. Natural Factors

The natural contributing factors to the Earth's climate can be primarily attributed to two aspects: fluctuations in solar radiation and volcanic activity. Beyond the regular, periodic changes in surface radiation resulting from solar activity on a smaller temporal scale, alterations in the Earth's orbit itself can influence the overall amount of solar radiation received by the planet. There exist three types of recurring variations in the Earth's orbit around the sun: firstly, the eccentricity of the elliptical Earth orbit which fluctuates on a 10-year cycle; secondly, the angle between the Earth's axis and the ecliptic plane which oscillates between 21.6-24.5 degrees on a 41,000-year cycle; and lastly, the annual variation in the time of perihelion (the time when the Earth is closest to the sun) which shifts on a 23,000-year cycle [1].

Another natural factor contributing to the Earth's climate is the significant release of carbon dioxide, sulfide aerosols, and dust as a result of volcanic activity. These substances are carried into the stratosphere through atmospheric circulation and greatly affect the total amount of solar radiation received by the Earth, enhancing the reflection and scattering of the atmosphere and inducing cooling in the lower atmosphere.

2.2. Human Factors

Following the advent of the Industrial Revolution, there was a marked acceleration in human exploitation and utilization of the natural world concomitant with rapid industrialization. Yet, despite the ongoing evolution of knowledge and cognitive faculties, humans either inadvertently or intentionally transgressed the objective laws governing the natural ecosystem. This deleterious trend persists, as despite the acknowledgment of the detrimental impact of greenhouse gas emissions from fossil fuels on the global climate environment, the current global energy structure remains excessively reliant on fossil fuels, a limitation borne of technological progress.

In addition to the materials difficult to degrade and organic pollutants that are produced with technological advancement, the most significant impact of human activities on the global climate system is the emission of greenhouse gases. Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCS), perfluorocarbons (PFCS), and sulfur hexafluoride (SF_6) are the six greenhouse gases emitted by human activities [2]. The utilization of fossil fuels by humans has altered the global carbon cycle process, leading to a larger output than input from carbon reservoirs. Despite carbon dioxide not being the most potent greenhouse gas, the vast volume of CO_2 emissions makes it one of the primary causes of the current greenhouse effect. As of now, the amount of CO_2 released by human activities is comparable to that of a super volcano and is 100 times the total amount emitted by all volcanic eruptions.

3. Impact of Climate Change on the Oceans

3.1. Hydrological Conditions of Seawater

3.1.1 Acidity

During the last century, there has been a notable surge in the concentration of carbon dioxide, leading to substantial alterations in the carbon dioxide-carbonate exchange system between the atmosphere and the surface of the ocean. This phenomenon has resulted in an upsurge in the levels of CO_2, H^+, and HCO_3^{2-} in seawater, alongside a decline in CO_3^{2-} concentration, leading to ocean acidification. At present, the pH of seawater has dwindled from approximately 8.21 pre-industrial revolution to about 8.11, marking a decrease of about 0.1 units, and if this trend persists, it is projected to plummet to 7.7 by the year 2100 [3].

Seawater characterized by diminished pH levels bears a lower rate of dimethyl sulfide (DMS) production, a substance that amalgamates with atmospheric agents to produce aerosols or minute atmospheric dust, which in turn generate nuclei for cloud formation. Clouds, through their inherent scattering and refraction of sunlight, serve as a countermeasure against the heating effect of solar radiation on Earth. An attenuation in DMS production consequently reduces the prevalence of clouds, causing an exacerbation of global warming, as increased CO_2 concentrations in the air caused by ocean acidification contribute to the promotion of a positive feedback cycle.

3.1.2 Seawater temperature

Ever since the advent of the Industrial Revolution, the profuse discharge of greenhouse gases has triggered the greenhouse effect, thereby culminating in a discernible surge of 0.6℃ in the earth's surface temperature, a 100-year increment of 0.6℃ within the mean temperature of the sea surface, and a hike of 0.31℃ in the average temperature of the ocean's surface layer at a depth of 300 meters, with a concomitant rise of 0.06℃ in the average temperature of the water column spanning a depth of 3000 meters [3, 4].

The research conducted on small pelagic fish in the open ocean alludes to the potential endangerment of cold water fish species in light of global warming. Additionally, there exists the possibility that warm water fish species may come to occupy the ecological niche of their colder counterparts in the future. Simultaneously, alterations in water temperature have the capacity to modify the physical dispersal patterns of these aquatic species, thereby creating an environment conducive to the invasion of non-native species as a result of global warming [5].

3.1.3 Sea level

Antarctica boasts more than 90% of the global freshwater reserves, and even a meager 1% of its thawing has substantial implications on the overarching oceanic milieu. Presently, there are no efficacious methodologies to alleviate greenhouse gas emissions; instead, endeavors can merely decelerate the pace of climate change to a moderate extent. As temperatures persist in escalating universally, concomitant with the surge of sea-surface temperatures, polar sea ice, snow, ice sheets, and permafrost are dwindling, leading to a rise in sea level. As per extrapolations, in the event of a continued increase in carbon dioxide emissions, the projected rise in sea levels could potentially reach 2 meters and 5 meters by the years 2100 and 2150, respectively [6]. The impact of such an outcome on numerous coastal cities worldwide would be monumental, resulting in catastrophic effects such as inundation, erosion, and impairment to infrastructure. Alarming mitigating measures, including efforts to reduce carbon dioxide emissions and develop carbon capture technology, are of paramount importance to address the pressing issue of climate change, lest we confront increasingly dire and irreversible ramifications.

3.1.4 Currents

Research into prehistoric climate and marine organism fossils has indicated the occurrence of an exceedingly warm epoch approximately 55,000 years ago in the Paleogene era. During this time, the directional flow of deep ocean currents in the Pacific and Atlantic Oceans was antithetical to that observed in contemporary times [7]. Deep ocean currents are categorized as density currents, and the influx of freshwater resulting from the melting of polar sea ice has the potential to attenuate the North Atlantic warm current. This has the propensity to impact the heat transfer between the northern and southern hemispheres, potentially resulting in notably frigid winters in the northern hemisphere.

Alterations in oceanic currents can have a substantial impact on the global distribution of nutrients and heat. Empirical evidence suggests that critical changes in the flow velocity of ocean currents have occurred since the 1990s, with some regions exhibiting no modification or a deceleration while the average velocity of oceanic currents has been increasing steadily. The underlying cause of this phenomenon is likely to be the intensified wind speeds in some regions of the globe, resulting in larger waves. Such changes are believed to be the outcome of a combination of natural environmental factors and global climate change. The specific repercussion of the rate of flow alterations in ocean currents on the marine ecosystem remains indeterminate. Nevertheless, it is pertinent to note that when the velocity of environmental change surpasses the evolutionary adaptation rate of organic life forms, a perilous decline in species diversity is inevitable.

3.2. Marine Ecosystems

The extensive impact of global climate change on marine ecosystems is undeniable. The elevation of seawater temperature has a favorable effect on the growth and development of most phytoplankton. However, the response of different species to temperature varies considerably, leading to significant changes in the ecological niche of surface phytoplankton in the context of global warming. Moreover, the increase in sea temperature will inevitably enhance the metabolism of most marine organisms, accelerate energy consumption rates, and potentially affect species growth, development, and population reproduction. The indirect impact of rising sea temperatures will exacerbate ocean stratification and augment the extent of oxygen-deficient zones, further impacting marine ecosystems.

Considering that calcium carbonate forms the fundamental constituent of coral reefs, the phenomena of acidification and warming serve as aggravating factors, leading to a detrimental effect of coral bleaching and consequent degradation of the biodiversity within coral reef regions. In the most severe of instances, this may result in the complete collapse of the entire coral reef system [3].

Importantly, despite the increase in surface phytoplankton numbers with rising temperature, the primary productivity of the ocean will decrease, ultimately impacting the overall stability of the ecosystem. Meanwhile, global warming has disrupted the seasonal succession and growth of marine phytoplankton. This process involves altering the growth cycle of one species, gradually impairing the reproductive capacity of phytoplankton and thereby affecting their biomass. This, in turn, has greatly hindered the availability of fishery resources, the growth of seaweed, and higher-level organisms in food chains. The rise in global sea levels is also a significant threat to the habitat of biological amphibians, for instance, rising coastlines can suffocate many turtle eggs on sandy beaches, leading to devastating consequences for the survival and reproduction of this species.

4. Strategies for Sustainable Development

The underlying cause of global warming can be attributed to alterations in solar radiation and anthropogenic activities. While the impact of the sun on the Earth is difficult to accurately ascertain, the rate of temperature escalation observed over the past century represents an unprecedented surge in comparison to the preceding ten thousand years, with human influence being the undeniable factor. The inconsiderate industrial and agricultural practices of humankind, coupled with the excessive utilization of fossil fuels, wanton deforestation, and land reclamation activities have contributed to the release of copious amounts of greenhouse gases, including CO_2, thereby disrupting the equilibrium of the Earth's carbon cycle. Consequently, the natural ecosystems have been rendered incapable of absorbing the surplus greenhouse gases, leading to their residual accumulation in the atmosphere [8].

4.1. Climate

To tackle the issue of climate change, there exist two prominent approaches for mitigating greenhouse gas emissions. Firstly, the optimization of the present energy structure entails a shift away from the fossil-based energy consumption industry towards the promotion and development of new energy industries like geothermal, wind, and photovoltaics. These emerging industries exhibit great potential to significantly decrease, if not entirely eliminate, greenhouse gas emissions, hence slowing down the current global warming trajectory. Secondly, safeguarding the natural environment and restoring ecosystems can also serve as a measure to counteract climate change by preserving both plant and animal species, which comprise the carbon sink. This is crucial given that the destruction of natural ecosystems has resulted in a significant reduction in the number of species, leading to the release of carbon that was originally stored by these species into the atmosphere [9]. Consequently, the restoration of the entire ecosystem can enhance the efficiency of carbon sequestration.

The climate system operates as a comprehensive entity, and as such, a solitary action can often have considerable ramifications. Though the current sustainable development solutions tend to entail certain unfavorable repercussions, it is imperative to judiciously evaluate the advantages and disadvantages while implementing such strategies. This entails taking into account not only the impacts of specific measures, but also the potential knock-on effects on other aspects of the climate system, thereby avoiding a domino-like sequence of events. Hence, it is pivotal to avoid a zero-sum game and forestall the adoption of patchwork solutions that may give rise to unanticipated challenges during the course of the problem-solving process.

4.2. Ocean

4.2.1 Cleaning the ocean

The contemporary ocean environment is facing a progressively severe pollution dilemma. Specifically, microplastics have permeated our daily drinking water and have been detected even in polar areas. To combat this burgeoning issue, it is advisable to decrease the utilization of plastics in everyday life and to opt for more biodegradable materials instead. Furthermore, the advancement of waste disposal technology is necessary to abate the secondary pollution that arises during waste management processes. Additionally, the enhancement of sewage treatment technology is imperative to mitigate the discharge of recalcitrant pollutants and nutrients into the ocean [10].

In the contemporary milieu wherein the dearth of substitutes for fossil fuels persists, it is imperative to urgently augment the security of offshore oil prospecting and transportation, whilst concurrently reinforcing countermeasures for emergencies. Moreover, it is incumbent upon us to explore new reservoirs of energy to ameliorate our reliance on fossil fuels and arrest the source of marine ecological contamination stemming from oil leakage.

4.2.2 Utilization of Marine Biological Resources

The exponential expansion of the human populace has resulted in an incessant escalation of sustenance requisites, thereby engendering a state of overcapacity in both offshore aquaculture and offshore fishing. It behooves us to foster the development of offshore aquaculture in a methodical and scientific manner, lest it should precipitate pollution and jeopardize the biodiversity of the offshore ecosystems. As for offshore fishing, it is imperative to augment the enforcement of fishing moratoriums, and restrict the extent and magnitude of fishing activities.

5. Conclusion

In recent times, climate change has emerged as a pivotal research theme within the realm of global ecological and environmental changes. Climate issues oftentimes harbor significant, lasting impacts on the environment. As a crucial piece of the global ecological environment, the marine ecological environment assumes instrumental importance in bettering the contemporary global ecology.

The primary cause inciting alterations in the marine ecological environment is traced back to oscillations in pH and temperature. Modifications in pH cause an upsurge in the acidity of subregions and the entire ocean, inducing ocean acidification, which destabilizes the balance of carbonates present in seawater. Temperature changes directly result in a steep rise in the temperature of the seawater, ushering in a host of related environmental predicaments. Elevated temperature levels further spawn the melting of glaciers in the polar regions, leading to an ailment of massive ice melting, reduced seawater salinity, and indirectly impacting the movement of oceanic currents. These currents, in turn, function as a crucial conduit of heat transfer across the northern and southern hemispheres of the ocean, having a direct bearing on the climate, giving rise to more extreme weather patterns.

Given the present human technological capacities, anticipating immediate betterment of the global ecological environment is a far-fetched notion. At present, political and economic measures can be implemented to slow down the process of global warming and feasibly enhance the current state of environmental demerit to a certain degree. The purpose of this manuscript is to clarify the prevailing issues surrounding the marine ecological environment, and suggest directed sustainable development tactics to mitigate these exigencies.

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