The Importance of the World’s Oceans in Climate Change Resilience

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Abstract: The oceans play a critical role when it comes to climate change resilience. Its ecosystem services help to sequester carbon, regulate climate, generate oxygen, boost biodiversity, and provide resources for the entire planet. However, the oceans are being disproportionately affected by climate change, as they have absorbed the majority of anthropogenic global warming-related heat, protecting the atmosphere from additional warming. As the oceans absorb this heat, seawater temperatures rise, causing other detrimental effects like deoxygenation and acidification that affects marine life and ecosystems. In order to properly address climate change, the impacts on the oceans must be carefully considered, as the health of the oceans significantly affects the health of the entire Earth.

Keywords: Oceans • Climate change • Ecosystem services • Resilience • Carbon sequestration • Ocean warming • Deoxygenation • Acidification

1. Introduction

The world's oceans, which cover approximately 75% of the Earth's surface and contain almost 98% of the Earth's total water, provide crucial ecosystem services that influence and benefit the entire world (1). The oceans produce the majority (approximately 50-80%) of the oxygen (O_2) we breathe, even more than the Amazon Rainforest and all other forests combined (2). The oceans also provide extraordinary biodiversity and countless resources such as food, minerals, fuel, medicine, and economic opportunities. Most importantly, perhaps, is the ability of the oceans to regulate the global climate and contribute to climate change resilience; the oceans act as a carbon sink, absorbing excess carbon dioxide (CO_2) that would otherwise contribute to additional atmospheric warming. In fact, because of its large surface area, large volume, and low albedo (reflection coefficient), the oceans have absorbed over 93% of anthropogenic global warming-related heat trapped in the Earth's atmosphere since 1971, significantly reducing the 'perceived' warming effect on land (3, 4).

Despite these critical benefits, the oceans are being disproportionately impacted by climate change, to the point that its ecosystems and their services are being severely threatened. Rising sea temperatures are endangering the lives of countless marine species (both floral and faunal) via deoxygenation and acidification (5). These threats, which often interact in synergistic ways, create positive feedback loops that continually worsen the impacts. Ultimately, the burning of fossil fuels lies at the heart of these issues and must be reduced to mitigate climate change. The following paper first discusses several ecosystem services provided by the oceans: carbon sequestration and climate regulation, oxygen generation, biodiversity, and resource provisioning. Then the three main climate-related threats to the ocean are discussed: rising temperatures, deoxygenation, and acidification.

2. What the Oceans Provide: Ecosystem Services

The benefits that humans and the environment obtain from ecosystems are known as ‘ecosystem services’ (6). It is important to view eco*systems* as a systematic concept, accounting for the whole of all integrated systems, both ecologically and human-related; just as important is considering all environmental, social, and economic aspects. Ecosystem services (Fig. 1) can be divided into four main categories: provisioning (e.g., food, raw materials), regulating (e.g., climate regulation, water cycle), supporting (e.g., photosynthesis, nutrient cycling), and cultural (e.g., recreation, aesthetics) (7, 8). Because of these services, marine ecosystems, including everything from coastal zones and coral reefs to open ocean and the deep-sea, are some of the most heavily exploited ecosystems on Earth (9). Several marine ecosystem services are discussed in detail below.

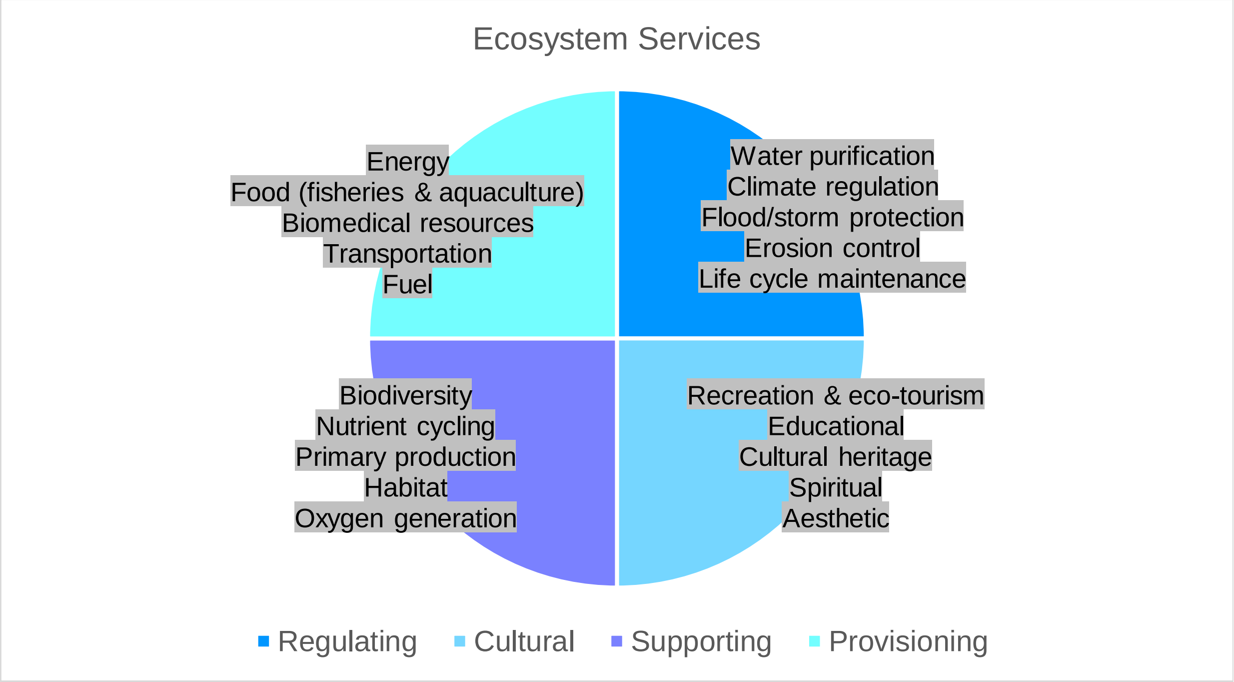

Figure 1: Examples of marine ecosystem services.

2.1. Carbon Sequestration and Climate Regulation

CO_2 is considered to be the most important greenhouse gas (GHG) (next to water vapor) due to its high relative abundance in the atmosphere and its abilities in regulating the global heat budget (10). CO_2, among other GHGs (e.g., methane, nitrous oxide, ozone), exerts a natural greenhouse effect on the atmosphere, keeping the Earth warm while still allowing some heat to escape back into space (11). However, the current atmospheric levels of GHGs—amplified by industrialization and the burning of fossil fuels—have skyrocketed, creating a human-enhanced greenhouse effect, trapping more heat inside the atmosphere than normal (12).

The ability of the oceans to sequester (i.e., absorb, store, and/or remove) much of this CO_2 in organic material (e.g., plankton, plants) has mitigated the perceived effects of global warming on land (Fig. 2) (13). Approximately one quarter of anthropogenic CO_2 emitted every year is captured and stored by the oceans, reducing its concentration and heat-trapping effects in the atmosphere (14, 15). Studies show that without the capacity of the oceans to absorb this heat, the Earth would have already experienced 36°C of warming (as opposed to the 0.55°C in reality) since the second half of the 20th century (5). Indeed, the oceans play a crucial role in climate regulation, limiting the levels of GHGs in the atmosphere and preventing additional heat from being trapped.

2.2. Oxygen Generation

One of the most important functions of the oceans is oxygen production. The oceans generate the majority of the O_2 that we breathe (Fig. 2), most of which is produced by oceanic plankton as well as plants, algae, and some photosynthetic bacteria (2). In fact, the cyanobacterium Prochlorococcus, one of the smallest photosynthetic organism on Earth, produces approximately 20% of all O_2 in the atmosphere alone (17). This production is essential, as O_2 is fundamental for all aerobic life (e.g., all plants and animals, including humans) on Earth; however, O_2 also helps the cycling of other biogeochemically important elements, including nitrogen, phosphorus, iron, and manganese which are critical for sustaining life (18).

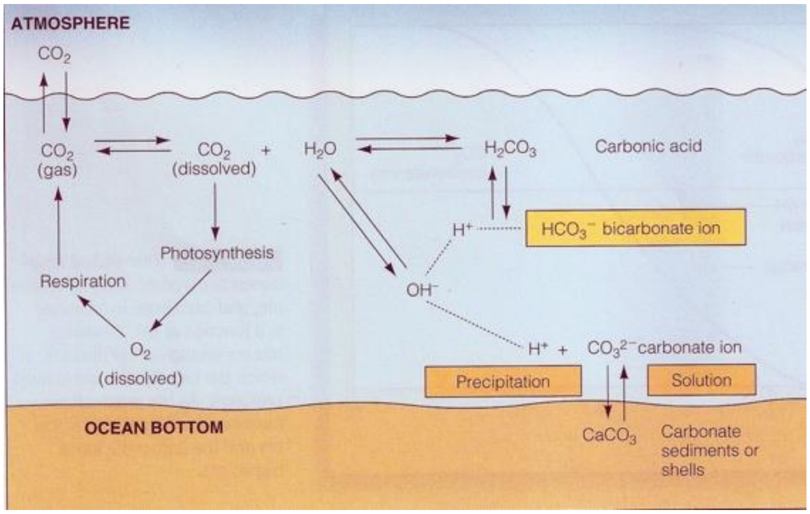

Figure 2: The carbon cycle in the ocean (16).

2.3. Biodiversity

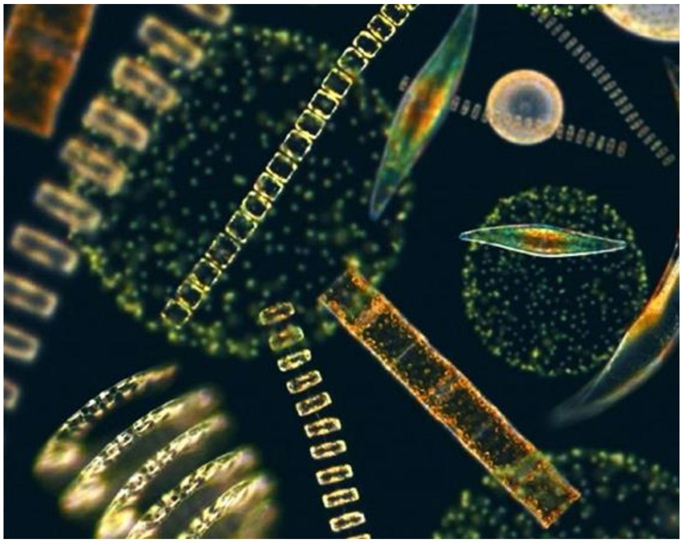

Figure 3: Mix of oceanic photosynthetic plankton (primarily diatoms and dinoflagellates) (19).

Perhaps unsurprising due to its vastness and volume, the oceans constitute over 90% of all habitable space on Earth (20). Consequently, there are between 500,000 and 10 million marine species—much of this uncertainty comes from the fact that over 80% of the oceans remain unexplored and unmapped, and only 6.5% of the seafloor has been surveyed (as of 2011) (21-23). Of these species, viruses, bacteria, archaea, single-celled eukaryotes, and small planktonic animals (Fig. 3) represent the foundation of marine ecosystems and food webs, with organismal numbers reaching higher than all the stars in the universe (24, 25).

Marine biodiversity supports ecosystem functioning, including trophic cycling, nutrient regeneration, carbon sequestration, and habitat and breeding grounds provisioning (26). Without features like these, both marine and terrestrial ecosystems would deteriorate making life on Earth inhospitable for many creatures, including humans (27). More than half of marine species may face extinction by 2100 if current trends continue, with some studies projecting the complete collapse of all seafood-producing species by 2048 (20, 28). Biodiversity is an essential component to all ecosystems, without which almost all other ecosystem services would halt.

2.4. Resources and Provisioning

There are many types of ocean resources that marine ecosystems support and provide. Indeed, fish, shellfish, and other seafoods provide key dietary and economic sustenance in many regions of the world. For example, global aquaculture production has risen 527% between 1990 and 2018, and approximately 10% of the global population (predominantly in the global South) depends entirely on fisheries for their livelihoods (29). Additionally, vast amounts of renewable energy can be drawn from the oceans, including via waves, tides, salinity gradients, submarine geothermal resources, and algae biomass (30, 31).

Fuel resources are also extracted from the ocean on the large-scale via offshore drilling. Typically, petroleum lying underneath the seabed is drilled for uses such as vehicle gasoline and jet fuel, heating oil, petrochemicals, tar, and plastics (32). The seafloor also boasts significant mineral resources in the form of polymetallic ferromanganese nodules, cobalt-rich ferromanganese crusts, and seafloor massive sulfides. Submarine mineral deposits such as these represent some of the largest known sources of many minerals—including some critical minerals—and present great opportunity for extraction (33). Furthermore, the use of marine genetic resources has been transformative in industries developing pharmaceuticals, biotechnology, genetic engineering, cosmetics, and wider scientific research (34).

3. Climate-Related Threats to the Ocean

As climate change accelerates, these important ecosystem services are becoming endangered—there are many threats that jeopardize the health and functioning of the world's oceans. The hazards discussed below do not encapsulate all the currently known threats to the oceans; however, they were selected based on their relevance to climate change. Rising temperatures, deoxygenation, and acidification (the "deadly trio") are three interacting stressors that are linked to each of the five mass extinctions on Earth (35). Indeed, these threats risk significant impacts to the health of the oceans and the entire world, many of which science is only beginning to understand.

3.1. Rising Temperatures

It has been shown that the global ocean surface temperature has risen on average by 0.13°C per decade since 1900 (Fig. 4); furthermore, we are likely to see an additional 1-4°C increase in mean global ocean temperature by 2100 (5). This

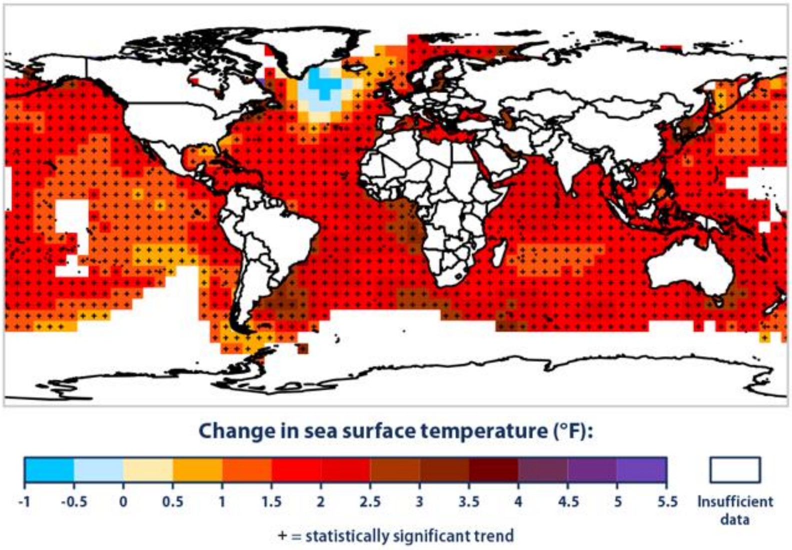

Figure 4: The change in average sea surface temperatures around the globe from 1901 to 2020 (36).

kind of severe warming is likely to produce the most significant changes in marine biodiversity that the Earth has seen in 3 million years (37).

Rising ocean temperatures from the absorbing of GHGs affects all marine species and ecosystems in countless different ways (Table 1). Marine species will likely experience high levels of mortality, loss of breeding grounds, and mass migrations in the search for suitable environmental conditions (5). Coral reefs, which are the most biodiverse marine ecosystem and provide habitat and feeding grounds for 25% of marine species, are also threatened from coral bleaching and temperature-related mortality (38). Increased ocean temperatures cause corals to expel their colorful symbiotic algae and food source, turning them white; if corals remain bleached over a period of several weeks, they die due to lack of food (39). Other vegetation and structural organisms that protect coastlines from sea-level rise and erosion (e.g., mangroves) will be affected, increasing the frequency and severity of flooding; similarly, warmer ocean waters will exacerbate problems with extreme weather (e.g., hurricanes, droughts) (5).

Consequences of a Warming Ocean

- Loss of breeding and feeding grounds (marine, coastal, and terrestrial)
- Impacts on breeding success
- Changes in trophic patterns and strategies
- Shifts in sex ratios
- Shifts in seasonality and consequently prey-predator mismatch
- Poleward shift of fish and other motile sea life
- Changes in geographical species range leading to potential increases in fishing bycatch
- Increased occurrence of invasive species and local extinctions
- Decreased size of organisms from food and nutrient limitations
- Reduced fecundity
- Changes in entire ecosystems and community structure
- Extreme weather and storms
- Increased spread of marine diseases (risks transmission to humans)
- Harmful algal blooms
- Coral bleaching
- Resource (e.g., food) insecurity for humans

Table 1: Consequences of a warming ocean, adapted from (4, 38).

As ocean warming accelerates, not only will these impacts intensify, but additional stores of carbon in the deep ocean are likely to resurface. For example, approximately 2.5Gt of frozen methane hydrate are stored on the seafloor;

increased warming may release this methane into the atmosphere, contributing to a positive feedback loop of even more warming (4).

3.2. Deoxygenation

As the oceans warm, they will continue to undergo deoxygenation, or the reduction of dissolved O_2 levels in the oceans. Compared to cooler water, warm water holds less O_2, is more buoyant, and raises the O_2 demand from organisms; this leads to the reduced circulation of oxygenated surface water with deep, naturally less oxygenated water, causing less O_2 to be available for marine life (41). In another sense, fertilizer run-off, sewage and animal waste, and nutrient deposition promotes the excessive growth of algae and other plant life; harmful algal blooms thrive in nutrient-rich water, and if these growths become dense enough, they deplete the O_2 in the water, leading to widespread fish and other marine organism kills (38, 42, 43). This trend, known as eutrophication, typically affects coastal areas; however, deoxygenation has implications in overall ocean productivity, carbon and other nutrient cycles, and other marine and deep-sea habitats (40). Since the 1950s, the world's oceans have lost roughly 2% of its dissolved O_2 and is expected to lose another 2-7% by 2100 if trends continue (18, 40). Moreover, there have been distinct regions of hypoxic/anoxic ocean—often coastal—where O_2 reductions as high as 33% have been recorded since the 1960s (Fig. 5) (38).

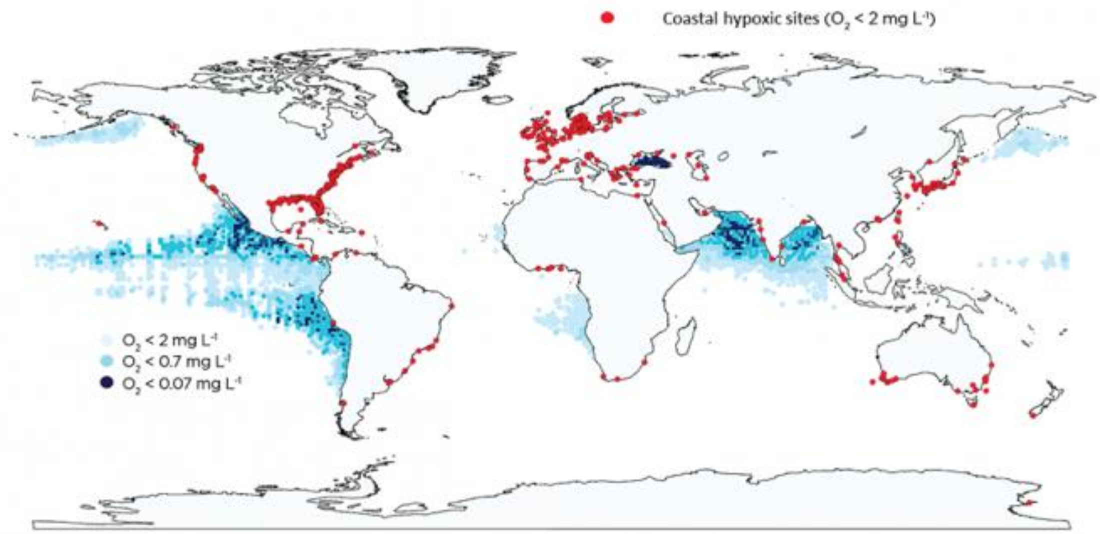

Figure 5: Coastal and global ocean deoxygenation (40). More than 500 coastal sites and several million cubic kilometers of open ocean have been classified as hypoxic (O_2 < 2 mg/L) or low oxygen.

3.3. Acidification

Ocean acidification is caused by elevated levels of CO_2 in the ocean. When CO_2 dissolves in seawater, it undergoes chemical reactions (Fig. 2) to form carbonic acid, thereby increasing the acidity (lowering the pH) of the water (38). While it is beneficial that the ocean can absorb CO_2, limiting atmospheric warming, this increased acidity has detrimental effects on sea life. Perhaps most paramount is the impact on shell-forming sea life. In an acidic environment, carbonate-containing species (e.g., corals, oysters, mussels, starfish, some planktons) experience growth-hindering and fatal shell dissolving (45, 46). Increased acidity can have vast impacts on noncalcifying species and ecosystems as well, including effects that alter behavior, performance, metabolism and reproduction (47). The average acidity of the ocean has already increased by 30% (decline of 0.1 pH units) since the Industrial Revolution (Fig. 6); the pH is expected to decline an additional 0.3 pH units by 2100 if trends continue (45).

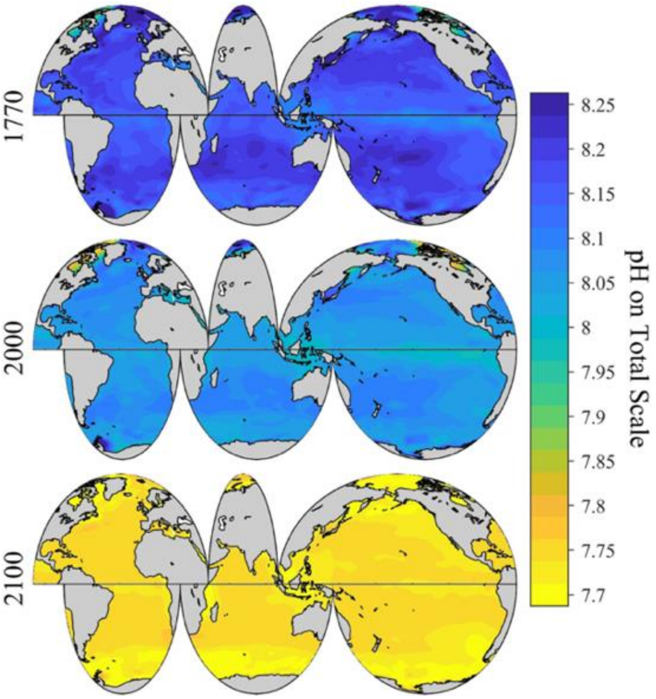

Figure 6: The annually averaged spatial distribution of surface seawater pH historically (1770), currently (2000), and in the future (2100) as predicted by the IPCC RCP8.5 scenario (44).

As mentioned, the threats discussed above are not exhaustive of all known threats to the oceans. For example, the warming of seawater also accelerates the melting of sea ice and glaciers, causing sea level rise which threatens coastal wildlife and habitats, human infrastructure and well-being, and risks saline intrusion in terrestrial ecosystems among other vulnerabilities (38). Another significant problem is ocean pollution, which can take the form of plastic and other physical debris; nutrients, toxins, and other chemicals; and noise and light. Each of these types of pollutions exert unique but harmful effects on marine ecosystems that have impacts the world over (35, 38, 48). Over-exploitation (e.g., for fish and minerals) also threatens the oceans in countless ways, many of which are still unknown (29, 33, 49). All of these hazards must be carefully weighed when considering the health of the oceans.

4. Conclusion

Indeed, the ocean is the largest and one of the most important ecosystems on the planet. Ecosystem services derived from the oceans, including carbon sequestration, climate regulation, oxygen generation, biodiversity, and resource provisioning benefit humans and all ecosystems around the globe. However, as we continue to burn fossil fuels and release CO_2 and other GHGs into the atmosphere, the oceans will continue to be threatened from rising temperatures, deoxygenation, and acidification.

There is widespread concession among scientists that without healthy oceans, the Earth itself cannot be healthy. More serious consideration must be given to analyzing and protecting the functions of the oceans, while preventing, mitigating, and adapting to these climate-related hazards. We may soon reach a "tipping point" where mitigation actions of climate change are no longer possible or effective, and repercussions will be felt all over the planet—not just in the oceans. To prevent these threats, the understanding of the vast marine ecosystem must be improved. The necessary ecological, social, economic, and moral transitions to mitigate and adapt to climate change must also be established if we wish to preserve human society on Earth.

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