Review

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Ocean Ecosystem Is a Big Player for the Global Climate Change

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The ocean ecosystem plays a central and irreplaceable role in regulating Earth's climate, acting as a major reservoir for heat, carbon, and biological activity. Covering more than 70% of the planet's surface, the oceans absorb the majority of excess heat from global warming and approximately a quarter of anthropogenic carbon dioxide emissions, thereby buffering the pace of climate change. This review article examines the ocean ecosystem as a major driver and moderator of global climate change, integrating physical, chemical, and biological perspectives. It explores ocean circulation, carbon sequestration, marine biodiversity, and biogeochemical feedbacks, while also addressing how climate change is reshaping ocean processes through warming, acidification, deoxygenation, and ecosystem disruption. Rather than treating the ocean as a passive sink, this review argues that the ocean ecosystem is an active and dynamic climate regulator whose resilience is now under threat. Understanding and protecting ocean ecosystems is therefore essential for effective climate mitigation and adaptation strategies.

Keywords: Ocean Ecosystem; Climate Change; Carbon Cycle; Marine Biodiversity; Ocean Circulation

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THE GLOBAL climate system cannot be understood without placing the ocean ecosystem at its center. Oceans dominate Earth's surface, control vast energy exchanges between the atmosphere and the planet, and host complex biological systems that regulate carbon, nutrients, and gases essential for life. For much of modern climate science, the ocean was viewed primarily as a passive heat sink, absorbing excess energy generated by greenhouse gas emissions (Rhein et al., 2013). Over time, however, it has become clear that the ocean ecosystem is not merely a background buffer but an active, dynamic, and highly influential player in global climate change. Its physical movements, chemical reactions, and biological processes shape both the magnitude and trajectory of climate change, while climate change simultaneously alters ocean function in profound and sometimes irreversible ways (Ganopolski & Brovkin, 2019).

One of the most critical roles of the ocean in climate

regulation is heat absorption and redistribution. Since the onset of industrialization, the oceans have absorbed more than 90% of the excess heat trapped by greenhouse gases (U.S. Global Change Research Program, 2017). This massive heat uptake has slowed atmospheric warming, delaying some of the most extreme consequences of climate change on land. Ocean circulation systems, including surface currents and deep thermohaline circulation, redistribute this heat across the globe, influencing regional climates, weather patterns, and seasonal variability (Rhein et al., 2013). Without this heat-buffering capacity, global surface temperatures would already be far higher than observed. However, this protective function comes at a cost, as ocean warming disrupts stratification, circulation, and ecosystem stability.

Ocean circulation itself is a fundamental climate regulator. Large-scale currents such as the Gulf Stream, the Antarctic Circumpolar Current, and the global overturning circulation transport heat, salt, and nutrients across latitudes and depths (Caesar et al., 2018). These movements shape climate patterns far beyond the ocean, influencing rainfall, storm tracks, and temperature extremes on land. The stability of these circulation systems depends on temperature and salinity gradients, which are now being altered by melting ice, freshwater input, and warming waters (Caesar et al., 2018). Changes in circulation can amplify climate feedbacks, potentially leading to abrupt and nonlinear climate shifts. Thus, the ocean ecosystem is deeply intertwined with the physical climate system through circulation dynamics.

Beyond heat, the ocean plays an outsized role in the global carbon cycle. It absorbs approximately one-quarter of anthropogenic carbon dioxide emissions through physical and biological processes (Heinze, 2014; Simmon, 2008). The solubility pump allows CO_2 to dissolve in cold surface waters and be transported to depth, while the biological pump transfers carbon through photosynthesis by phytoplankton and subsequent sinking of organic matter (Heinze, 2014). These processes collectively sequester carbon on timescales ranging from years to millennia. The efficiency of oceanic carbon uptake directly influences atmospheric CO_2 concentrations and the pace of climate change. Any disruption to these processes has global implications.

The biological component of the ocean ecosystem is particularly critical in mediating climate feedbacks. Phytoplankton, despite their microscopic size, account for roughly half of global primary production (Heinze, 2014). Through photosynthesis, they convert inorganic carbon into organic matter, forming the base of marine food webs and driving carbon export to the deep ocean. The composition, distribution, and productivity of phytoplankton communities are sensitive to temperature, light, nutrient availability, and ocean chemistry. Climate-driven changes in stratification, nutrient supply, and circulation can therefore alter biological carbon sequestration, potentially weakening the ocean's role as a carbon sink (Heinze, 2014).

Marine ecosystems also influence climate through the cycling of other greenhouse gases. Oceans are a major source and sink of gases such as methane and nitrous oxide, both of which have strong warming potential. Microbial processes in oxygen-poor waters and sediments regulate the production and consumption of these gases. Expanding oxygen minimum zones, driven by warming and stratification, may enhance emissions of nitrous oxide, creating a positive feedback loop with climate change (Ganopolski & Brovkin, 2019). These processes highlight that the ocean ecosystem affects climate not only through carbon dioxide but through a broader suite of biogeochemical interactions.

Ocean acidification represents one of the most direct consequences of increased CO_2 uptake. As carbon dioxide dissolves in seawater, it forms carbonic acid, lowering pH and altering carbonate chemistry. This process threatens calcifying organisms such as corals, shellfish, and some plankton species, which rely on carbonate ions to build shells and skeletons (Fabry et al., 2008). These organisms play key roles in marine food webs and carbon cycling. Coral reefs, in particular, act as biodiversity hotspots and influence local carbon and nutrient dynamics. Their degradation reduces ecosystem resilience and alters the capacity of coastal systems to respond to climate stress (Fabry et al., 2008).

The loss of biodiversity within ocean ecosystems has cascading effects on climate regulation. Diverse ecosystems tend to be more stable and efficient in maintaining biogeochemical processes. Overfishing, habitat destruction, pollution, and warming reduce biodiversity, simplifying food webs and weakening ecosystem function (Ganopolski & Brovkin, 2019). For example, the decline of large marine predators can alter trophic dynamics, affecting plankton populations and carbon export. The erosion of biodiversity thus undermines the ocean's capacity to regulate climate, reinforcing the view that ecosystem health and climate stability are inseparable.

Cryosphere–ocean interactions further illustrate the ocean's central role in climate dynamics. Melting glaciers and ice sheets contribute freshwater to the ocean, altering salinity and circulation patterns (Caesar et al., 2018). Sea ice loss reduces albedo, increasing heat absorption and accelerating warming. At the same time, polar oceans play a critical role in deep water formation and carbon sequestration. Changes in these regions have disproportionate global impacts, linking ocean ecosystems directly to some of the most sensitive components of the climate system.

Coastal and shelf ecosystems, including mangroves, seagrasses, and salt marshes, are increasingly recognized as vital climate regulators through so-called "blue carbon" storage (Mcleod et al., 2011). These ecosystems sequester carbon at rates comparable to or exceeding those of terrestrial forests, storing it in sediments for long periods. Despite occupying a small fraction of ocean area, they contribute significantly to carbon burial and shoreline protection. Their destruction releases stored carbon and reduces future sequestration potential, transforming them from climate mitigators into emission sources. Protecting and restoring coastal ecosystems is therefore a climate strategy as much as a conservation goal (Mcleod et al., 2011).

Climate change is simultaneously reshaping ocean ecosystems in ways that may reduce their regulatory capacity. Warming leads to species range shifts, altered phenology, and increased frequency of marine heatwaves. These changes disrupt

established ecological relationships and biogeochemical cycles (Ganopolski & Brovkin, 2019). Deoxygenation, driven by warming and nutrient loading, stresses marine life and alters microbial processes. Together, these stressors threaten to push ocean ecosystems beyond tipping points, where gradual change gives way to rapid and potentially irreversible transformation (Ganopolski & Brovkin, 2019).

The feedbacks between ocean ecosystems and climate change are complex and often nonlinear. For example, warming may initially enhance phytoplankton growth in some regions but ultimately reduce productivity through nutrient limitation (Heinze, 2014). Similarly, increased stratification may stabilize surface waters while limiting deep nutrient mixing. These competing effects make it difficult to predict the net response of ocean ecosystems to continued warming. However, the direction of risk is clear: degrading ocean health weakens climate regulation, while protecting ecosystems strengthens climate resilience (Ganopolski & Brovkin, 2019).

Human activities increasingly intersect with ocean–climate interactions. Shipping, offshore energy, deep-sea mining, and aquaculture all influence ocean ecosystems and their capacity to regulate climate. At the same time, climate change affects the economic and social systems that depend on the ocean, including fisheries, tourism, and coastal communities. Recognizing the ocean ecosystem as a climate player reframes these activities as components of a coupled human–natural system, where decisions in one domain reverberate through the climate system (Ganopolski & Brovkin, 2019).

Scientific advances have improved understanding of the ocean's role in climate, yet significant knowledge gaps remain. Observational coverage is uneven, particularly in the deep ocean and polar regions. Many biological and chemical processes operate at scales that are difficult to measure and model. Integrating ecosystem dynamics into climate models remains a major challenge, limiting the ability to predict long-term feedbacks (Ganopolski & Brovkin, 2019). Addressing these gaps requires sustained investment in ocean observation, interdisciplinary research, and international collaboration.

Policy discussions about climate change have historically focused on atmospheric emissions and terrestrial systems. While these remain critical, insufficient attention has been paid to the ocean ecosystem as an active agent in climate regulation. Protecting marine biodiversity, reducing pollution, managing fisheries sustainably, and limiting warming are not secondary environmental goals but central climate actions (Ganopolski & Brovkin, 2019). Failing to incorporate ocean ecosystems into climate strategies risks undermining mitigation efforts and increasing vulnerability to climate impacts.

In conclusion, the ocean ecosystem is undeniably a major player in global climate change. It absorbs heat, sequesters carbon, regulates greenhouse gases, and influences climate patterns on regional and global scales. At the same time, climate change is altering ocean ecosystems in ways that threaten their regulatory capacity (Ganopolski & Brovkin, 2019). This reciprocal relationship means that the future of Earth's climate is inseparable from the future of the ocean. Recognizing the ocean ecosystem as an active, living component of the climate system demands a shift in scientific, political, and societal perspectives. Protecting ocean health is not optional—it is fundamental to stabilizing the global climate and sustaining life on Earth (Ganopolski & Brovkin, 2019). ■

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