Impacts of climate change on the aquatic ecosystems

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Abstract

The main purpose of this review is to understand the sensitivity of marine and water ecosystems to climatic changes, it is crucial to understand the impact and the consequences of these climate-induced shifts for ecosystem structure. The physical and chemical conditions present in different marine and freshwater regions are changing with time, and that climate and CO2 can have substantial effects on organism physiology, populations of individual species, and community composition and biodiversity. Somewhat less is known about the consequences of these climate-induced shifts for ecosystem structure and aggregated ecosystem functions, such as energy flow from primary production through to upper trophic levels, connections across habitats via dispersal and transport, sequestration of organic carbon, and biogeochemical cycling. Climate change is modifying the distribution and productivity of marine and freshwater species and is already affecting biological processes and altering food webs.

Keywords: Climatic Change; Ecology; Aquatic ecosystems

Introduction

Aquatic ecology is a branch of the science of ecology which is concerned with the study of aquatic ecosystems. This field can be broken into two divisions: freshwater ecology and marine ecology (Fig.1). Given that most of the Earth is covered in water, understanding aquatic ecosystems is very important, especially since water is critical to the survival of all life on Earth. Without water, Earth would be a very different place, and there probably wouldn't be any ecologists around to study it. An aquatic ecosystem is an ecosystem in a body of water. Communities of organisms that are dependent on each other and on their environment live in aquatic ecosystems. The two main types of aquatic ecosystems are marine ecosystems and freshwater ecosystems.

Marine ecology is the branch of ecological science concerned with organisms that live in or near the ocean, their behaviors, and their interactions with the environment. The scope of studies in marine ecology can range greatly, from examining unicellular microorganisms to researching global effects of pollution and human activity. Scientists might observe a specific population of organisms, identifying their behaviors and relationships, or investigate entire marine habitats to see how different living and nonliving factors contribute to the overall ecosystem.

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structure.

![Aquatic Ecosystems](image)

**Figure 1.** Aquatic ecology is a branch of the science of ecology which is concerned with the study of aquatic ecosystems; ecosystem is a portmanteau word - that is, a word made by jamming two other words together.

**Materials and Methods**

Marine ecosystems cover approximately 71% of the Earth's surface and contain approximately 97% of the planet's water. They generate 32% of the world's net primary production. (Primary production is the production of chemical energy in organic compounds by living organisms. The main source of this energy is sunlight but a minute fraction of primary production is driven by lithotrophic organisms using the chemical energy of inorganic molecules.

![Components of Ecosystems](image)

**Figure 2.** Components of ecosystems are rarely in balance, and this is often causing for alarm. This destabilizes the entire surrounding ecosystem, and birds and animals that prey on the fish either die off or migrate to areas with more food.
Regardless of its source, this energy is used to synthesize complex organic molecules from simpler inorganic compounds such as carbon dioxide ($\text{CO}_2$) and water ($\text{H}_2\text{O}$). The following two equations are simplified representations of photosynthesis (top) and (one form of) chemosynthesis (bottom):

$$\text{CO}_2 + \text{H}_2\text{O} + \text{light} \Rightarrow \text{CH}_2\text{O} + \text{O}_2$$
$$\text{CO}_2 + \text{O}_2 + 4 \text{H}_2\text{S} \Rightarrow \text{CH}_2\text{O} + 4 \text{S} + 3 \text{H}_2\text{O}$$

In both cases, the end point is reduced carbohydrate ($\text{CH}_2\text{O}$), typically molecules such as glucose or other sugars. These relatively simple molecules may be then used to further synthesize more complicated molecules, including proteins, complex carbohydrates, lipids, and nucleic acids, or be respired to perform work. Consumption of primary producers by heterotrophic organisms, such as animals, then transfers these organic molecules (and the energy stored within them) up the food web, fueling all of the Earth's living systems.

They are distinguished from freshwater ecosystems by the presence of dissolved compounds, especially salts, in the water. Approximately 85% of the dissolved materials in seawater are sodium and chlorine. Seawater has an average salinity of 35 parts per thousand (ppt) of water. Actual salinity varies among different marine ecosystems.

Figure 3. A classification of marine habitats

Marine ecosystems can be divided into many zones depending upon water depth and shoreline features. The oceanic zone is the vast open part of the ocean where animals such as whales, sharks, and tuna live. The benthic zone consists of substrates below water where many invertebrates live. The intertidal zone is the area between high and low tides; in this figure it is termed the littoral zone. Other near-shore (neritic) zones can include estuaries, salt marshes, coral reefs, lagoons and mangrove swamps. In the deep water, hydrothermal vents may occur where chemosynthetic sulfur bacteria form the base of the food web.

In the oceans, almost all photosynthesis is performed by algae, with a small fraction contributed by vascular plants and other groups. Algae encompass a diverse range of organisms, ranging from single floating cells to attached seaweeds. They include photoautotrophs from a variety of groups. Eubacteria are important photosynthesizes in both oceanic and terrestrial ecosystems, and while some areas are phototrophic, none are known to utilize oxygen-evolving photosynthesis. A number of eukaryotes are significant contributors to primary production in the ocean, including green algae, brown algae and red algae, and a diverse group of unicellular groups. Vascular plants are also represented in the ocean by groups such as the sea grasses.
Classes of organisms found in ecosystems include brown algae, dinoflagellates, corals, cephalopods, echinoderms, and sharks. Fishes caught in marine ecosystems are the biggest source of commercial foods obtained from wild populations.

**Results and Discussion**

**Environmental problems**

Concerning ecosystems include unsustainable exploitation of ocean, marine and freshwater resources (for example overfishing of certain species), pollution, climate change, and building on coastal areas (EPA, 2007; David, 2010).

**Impacts of climate change**

Climate warming affects regional wind patterns and thus ocean circulation in multiple dimensions. A strengthening of midlatitude westerlies in the Southern Hemisphere promotes spin-up of subtropical circulations and a poleward shift in the Antarctic Circumpolar Current. The main effect is an increasing global average temperature. The average surface temperature could increase by 3 to 10 degrees Fahrenheit by the end of the century if carbon emissions aren't reduced. This causes a variety of secondary effects, namely, changes in patterns of precipitation, rising sea levels, increased extreme weather events, the expansion of the range of tropical diseases, and the opening of new marine trade routes.

Direct effects of changes in ocean temperature and chemistry may alter the physiological functioning, behavior, and demographic traits (e.g., productivity) of organisms, leading to shifts in the size structure, spatial range, and seasonal abundance of populations. These shifts, in turn, lead to altered species interactions and trophic pathways as change cascades from primary producers to upper-trophic-level fish, seabirds, and marine mammals, with climate signals thereby propagating through ecosystems in both bottom-up and top-down directions. Changes in community structure and ecosystem function may result from disruptions in biological interactions. Therefore, investigating the responses of individual species to single forcing factors, although essential, provides an incomplete story and highlights the need for more comprehensive, multispecies- to ecosystem-level analyses.

**Impacts of climatic changes on oceanic, marine and freshwater species**

Humans influence climate primarily through fossil-fuel, industrial, agricultural, and other land-use emissions that alter atmospheric composition. Long-lived, heat-trapping greenhouse gases (CO₂, CH₄, N₂O, tropospheric ozone, and chlorofluorocarbons) warm the planet's surface globally (Gastescu, 1993; IPCC, 2007), whereas shorter-lived aerosols can either warm or cool regionally. Direct radiative warming is amplified through a series of positive climate feedbacks (e.g., water vapor and sea ice); best estimates of projected global mean surface temperature increase over the twenty-first-century range from approximately 1.8°C to 4.0°C (Aaheim and Schjolden, 2004), depending on emission. Fossil-fuel CO₂ emissions for the past decade have been at the high-end of Intergovernmental Panel on Climate Change (IPCC, 2007) scenarios owing to rapid economic growth in developing countries. Moreover, the climate system exhibits considerable inertia, and temperatures will likely continue to increase decades to centuries after greenhouse gas levels stabilize (Callaway, 2004).

**Direct effects of changes in aquatic temperature and chemistry**

Direct effects may alter the physiological functioning (Few et al., 2007) behavior, and demographic traits (e.g., productivity) of organisms (Hughes et al., 2005), leading to shifts in the size structure, spatial range, and seasonal abundance of populations (Butt et al., 2005). These shifts, in turn, lead to altered species interactions and trophic pathways as change cascades from primary producers to upper-trophic-level fish, seabirds, and marine mammals (Boykoff and Boykoff, 2004), with climate signals thereby propagating through ecosystems in both bottom-up and
Changes in community structure and ecosystem function may result from disruptions in biological interactions (Berkes and Jolly, 2001). Therefore, investigating the responses of individual species to single forcing factors, although essential, provides an incomplete story and highlights the need for more comprehensive, multispecies- to ecosystem-level analyses.

The effects of rising CO₂

Rising of CO₂ do not act in isolation (Azar, 1998). Additional regional pressures on ocean ecosystems include intensive use of fertilizers, coastal and benthic habitat degradation, overexploitation of fish stocks, rising aquaculture production, and invasive species. Coastal hypoxia is increasing and expanding globally. Ecosystem deterioration is intense and increasing, particularly for coastal systems, with 50% of salt marshes, 35% of mangroves, 30% of coral reefs, and 29% of sea grasses already either lost or degraded worldwide. Thus, the integrated and synergistic effects of these multiple stressors on marine ecosystems — both CO₂ and non-CO₂ related — must be considered in total, not as independent issues.

Generally, metabolic rates of ectothermic organisms rise exponentially with temperature, leading to higher rates for most physiological processes, including photosynthesis and respiration, within the range of temperatures that an organism tolerates.

In heterotrophic organisms, warmer temperatures raise basal metabolic rates but can also raise respiratory demand, potentially reducing their aerobic scope for activity (e.g., feeding, predator avoidance, digestion) and leaving less energy for growth and reproduction.

Climate change also causes shifts in ranges as species align their distributions to match their physiological tolerances under changing environmental conditions. Species distributions along environmental gradients can provide key information on how they will respond to climate forcing.

Terrestrial and aquatic food production systems differ in fundamental ways that affect our ability to study and interpret the impacts of climate and to predict the consequences of future changes (WB and FAO, 2008).

Aquatic food production, particularly aquaculture, is adopting some of these characteristics, but capture fisheries continue to harvest wild populations, which often have large ranges and are part of natural ecosystems. Where capture fisheries exert differential selectivity, this may cause adaptive genetic changes in the population. The changes may be undesirable (e.g., selection for small size), but the rate and magnitude of such changes remains uncertain. Production of fish in many aquatic ecosystems varies considerably as a result of interannual and decadal variability in their environment, for which the term “climate variability” is used. For example, annual catches of Peruvian anchoveta (Engraulis ringens), the biggest single-species fishery in the world, ranged from 94,000 tons to >13 million tons during the period 1970 – 2004, with much of the variability resulting from changes in the El Niño – Southern Oscillation (ENSO).

The rate of global warming is dictated mainly by the radiative forcing due to the increase of anthropogenic greenhouse gases and the ocean heat uptake (Charney 1979). Recent estimates of the ocean heat uptake have shown that the world ocean above 2,000 m depth has warmed at a rate of 0.39 Wm⁻² since 1950 (Levitus et al., 2012).

Role of ocean in climate variability and change

The ocean’s heat capacity is about 1,000 times larger than that of the atmosphere, and the oceans net heat uptake since 1960 is around 20 times greater than that of the atmosphere (Levitus et al., 2005 and 2012). This large amount of heat, which has been mainly stored in the upper layers of the ocean, plays a crucial role in climate change, in particular variations on seasonal to decadal time scales. The transport of heat and freshwater by ocean currents can have an important effect on regional climates, and the large-scale Meridional Overturning Circulation (MOC; also referred to as thermohaline circulation) influences the climate on a global scale (Vellinga and Wood, 2002). Life in the sea is dependent on the biogeochemical status of the ocean and is influenced by changes in the physical state and circulation. Changes in ocean biogeochemistry can directly feed back to the climate system, for
example, through changes in the uptake or release of radiatively active gases such as carbon dioxide. Changes in sea level are also important for human society, and are linked to changes in ocean circulation. Finally, oceanic parameters can be useful for detecting climate change, in particular temperature and salinity changes in the deeper layers and in different regions where the short-term variability is smaller and the signal-to-noise ratio is higher.

Rising ocean temperatures and ocean acidification are radically altering aquatic ecosystems. Climate change is modifying fish distribution and the productivity of marine and freshwater species. This has impacts on the sustainability of fisheries and aquaculture, on the livelihoods of the communities that depend on fisheries, and on the ability of the oceans to capture and store carbon (biological pump). The effect of sea level rise means that coastal fishing communities are in the front line of climate change, while changing rainfall patterns and water use impact on inland (freshwater) fisheries and aquaculture.

In the open ocean, rising atmospheric CO$_2$ and the resulting increased oceanic CO$_2$ uptake are the predominant factors driving ocean acidification (Dore et al. 2009). Ocean acidification reflects a series of chemical changes: elevated aqueous CO$_2$ and total inorganic carbon as well as reduced pH, carbonate ion, and calcium carbonate saturation states (Doney et al., 2009). Sea-surface pH is estimated to have dropped by 0.1 pH units since the preindustrial era, a 26% increase in acidity over the past 150 years, mostly in the past several decades. Future projections suggest declines of additional 0.2 – 0.3 pH units over this century (Feely et al., 2009). Polar regions may be especially sensitive because of a transition to under saturated conditions for aragonite in surface water within the next several decades (Steinacher et al., 2009). In eutrophic coastal systems, surface water is usually higher in pH because of primary production, whereas water below the pycnocline has reduced pH because of respiratory demand and CO$_2$ production. Furthermore, changing land use and river flow can alter river alkalinity and, in turn, influence coastal inorganic carbon balance; for example, Raymond et al., (2008) documented a large anthropogenic increase in Mississippi bicarbonate and water fluxes.

Figure 4. Conceptual diagram of human and climate interactions on nutrient-enhanced productivity, Impacts on Marine Ecosystems (Doney et al., 2012).
The impact of climate change on aquatic ecosystems, fisheries and aquaculture

Climate change impacts such as more frequent and severe floods and droughts will affect the food and water security of many people. The impact of climate change on aquatic ecosystems, fisheries and aquaculture, however, is not as well known. This policy brief, a joint partnership between several agencies, highlights this issue to ensure that decision makers and climate change negotiators consider aquatic ecosystems, fisheries and aquaculture.

Climate change is modifying the distribution and productivity of marine and freshwater species and is already affecting biological processes and altering food webs (Figure 4). The consequences for sustainability of aquatic ecosystems, fisheries and aquaculture, and the people that depend on them, are uncertain.

Climate change impacts on fisheries have greatest social and economic significance?

This is a simple question, but a comprehensive answer would require predictions of the geographic patterns of global warming (from global circulation models) and predicted impacts of atmospheric warming on climatic, hydrological and oceanographic processes (from physical models). These changes in physical processes would then need to be linked to ecological processes using coupled physical-ecosystem models.

Fishers are already being affected by changes that are ultimately driven by rising global atmospheric temperatures. For example, coastal fishers in Bangladesh face increased frequency and severity of hurricanes, coupled with the greater penetration of saline water into coastal land due to thermal expansion of the warming oceans.

The principal threats to future fisheries production identified here are expected to act progressively (i.e., a linear response) and to interact with each other. However, marine ecosystems can also respond to changes in physical or biological forcing in a nonlinear way, e.g., when a threshold value is exceeded and a major change in species composition, production, and dynamics takes place. We know that such nonlinear responses occur but do not yet understand how or under what conditions.

Fishing is the greatest threat to future global fish production; however, the impacts of fishing and of climate change interact in a number of ways, and they cannot be treated as separate issues (Figure 5). Fishing causes changes in the distribution, demography, and stock structure of individual species and direct or indirect changes in fish communities and marine ecosystems. These changes have consequences for other ecosystem services (such as nutrient cycling and recreational use) and for sustainability, resilience and ability to adapt to climate change, and other pressures. Future sustainable fisheries depend on effective management of fishing activity, which in turn requires an understanding of the effects of climate change on the productivity and distribution of exploited stocks. Management must take into account the interactive effects of fishing, climate, and other pressures.
Sustainable aquatic ecosystems

A key factor concerning future economic impacts is the need to identify which countries and regions are most vulnerable. Modeling studies have assessed country vulnerability on the basis of exposure of its fisheries to climate change, high dependence on fisheries production, and low capacity to respond. The studies show that climate will have the greatest economic impact on the fisheries sectors of central and northern Asian countries, the Western Sahel, and coastal tropical regions of South America, as well as on some small and medium-sized island states. Indirect economic impacts will depend on the extent to which local economies are able to adapt to new conditions in terms of labor and capital mobility. Change in natural fisheries production is often compounded by decreased harvest capacity and reduced access to markets. Global fish production is forecast to increase more slowly than demand to 2020, and the proportion of production coming from aquaculture is forecast to increase. Therefore, zero growth in capture fisheries production will not threaten total supply unduly, but a decline could affect global fish consumption.

Crucial for climate change adaptation

Healthy aquatic ecosystems are critical for production of wild fish, for some of the ‘seed’ and much of the feed for aquaculture. The productivity of coastal fisheries is closely tied to the health of coastal ecosystems, which provide food, habitats and nursery areas for fish.

Estuaries, coral reefs, mangroves and sea grass beds are particularly important. In freshwater systems, ecosystem health and productivity is linked to water quality and flow and the health of wetlands.

Coastal ecosystems that support fisheries also help protect communities from the impacts of natural hazards and disasters. Mangroves create barriers to destructive waves from storms and hold sediments in place within their root systems, reducing coastal erosion. Healthy coral reefs, sea grass beds and wetlands provide similar benefits. Climate change imperils the structure and function of these already stressed ecosystems.

Adaptation measures

Because of the current and projected climate disruption precipitated by high levels of greenhouse gas emissions by the industrialized nations, adaptation is a necessary strategy at all scales to complement climate change mitigation efforts because we cannot be sure that all climate change can be mitigated. And indeed the odds are quite high that in the long run more warming is inevitable, given the high level of GHGs in the atmosphere, and the (several decade) delay between emissions and impact.

Adaptation has the potential to reduce adverse impacts of climate change and to enhance beneficial impacts, but will incur costs and will not prevent all damages. Extremes, variability, and rates of change are all key features in addressing vulnerability and adaptation to climate change, not simply changes in average climate conditions.

Adaptation measures are well known by managers and decision makers, but political will and action is often lacking. To build resilience to the effects of climate change and derive sustainable benefits, fisheries and aquaculture managers needs to adopt and adhere to best practices such as those described in the FAO Code of Conduct for Responsible Fisheries. These practices need to be integrated more effectively with the management of river basins, watersheds and coastal zones.

Focusing on herbivorous species aquaculture

By focusing on herbivorous species aquaculture can provide nutritious food with a low carbon footprint. Farming of shellfish, such as oysters and mussels is not only good business, but also helps clean coastal waters, while culturing aquatic plants helps remove wastes from polluted waters. In contrast to the potential declines in agricultural yields in many areas of the world, climate change opens new opportunities for aquaculture as increasing numbers of species are cultured; as the sea encroaches on coastal lands; as more dams and impoundments are constructed in river basins to buffer changing rainfall patterns; and as urban waste demands more innovative disposal.
Fisheries and aquaculture needs to be blended into national climate change adaptation strategies. Without careful planning, aquatic ecosystems, fisheries and aquaculture can potentially suffer as a result of adaptation measures applied by other sectors, such as increased use of dams and hydropower in catchments with high rainfall, construction of artificial coastal defenses or marine wind farms.

**Conclusion**

In marine ecosystems, rising atmospheric CO₂ and climate change are associated with concurrent shifts in temperature, circulation, stratification, nutrient input, oxygen content, and ocean acidification, with potentially wide-ranging biological effects. Population-level shifts are occurring because of physiological intolerance to new environments, altered dispersal patterns, and changes in species interactions. Together with local climate-driven invasion and extinction, these processes result in altered community structure and diversity, including possible emergence of novel ecosystems. Impacts are particularly striking for the poles and the tropics, because of the sensitivity of polar ecosystems to sea-ice retreat and poleward species migrations as well as the sensitivity of coral-algal symbiosis to minor increases in temperature. Aggregated effects may modify energy and material flows as well as biogeochemical cycles, eventually impacting the overall ecosystem functioning and services upon which people and societies depend.

**References**
