**Consequence of climate change on fisheries and aquatic system**

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 **INTRODUCTION**

 The Intergovernmental Panel on Climate Change1 (IPCC) has been regularly disseminating information on climate change and its political and economic ramifications since 1988. These updates provide a thorough synopsis of the generally recognised body of knowledge regarding the causes, effects, and science of climate change. This chapter provides an overview of the main effects of climate change on the dynamics of aquatic systems (oceans, seas, lakes, and rivers), with a focus on the aspects that relate to aquatic food production, such as fisheries and aquaculture. It draws heavily on the 5th IPCC Assessment Report (AR5) and recent scientific literature. While more detailed information on the impacts of climate change on these food production systems is available in subsequent chapters of this publication, this chapter focuses specifically on providing basic information on the underlying drivers of climate change and on how they translate into biophysical changes in aquatic systems.

**OBSERVED CHANGES IN THE CLIMATE** **SYSTEM**

The IPCC AR5 concluded that the warming of the climate system was undeniable and that many of the observed changes since 1950 are unprecedented compared with earlier decades to millennia. This conclusion was based on the analysis of these data, notwithstanding the uncertainties associated with knowledge and data gaps. Since the middle of the nineteenth century, the average surface temperature of the Earth has grown by more than 0.8 °C, and it is currently warming at a rate of more than 0.1 °C every decade (Hansen et al., 2010). Even though data dependability and degree of accuracy differ between continents, heat waves are increasingly often lately (Hartmann et al., 2013). The increase in the atmospheric concentration of GHGs including CO2, methane CH4, and nitrogen dioxide NO2 is thought to be the main cause of this warming. GHGs are in charge of sustaining life on Earth by acting as a heat blanket surrounding the planet (IPCC, 2014). Since the industrial revolution, GHG emissions have grown exponentially, resulting in the highest atmospheric concentrations of these gases in the past 800 000 years. For instance, atmospheric CO2 levels rose from 278 ppm in the middle of the eighteenth century to approximately 400 ppm now (Ciais et al., 2013). The IPCC AR5 also came to the conclusion that it is very likely that human activity, specifically the coupling of GHG emissions with gas and oil burning, deforestation, and intensive agriculture, is the primary driver of the warming that has been observed since the middle of the 20th century. Only 1% of the extra heat brought on by human-caused climate change is kept in the atmosphere; 93% of it has been absorbed by the world's oceans. The melting of ice and snow absorbs the final three to four percent. Because of this, the ocean acts as a vast heat buffer, and even modest changes in the equilibrium of heat between the ocean and atmosphere would have a significant impact on world air temperatures (Reid, 2016). In addition to its thermal capacity, the ocean has also sequestered about 25 percent of the CO2 released as a result of anthropogenic activities (Le Quéré et al., 2018), playing a crucial role in the regulation of the Earth’s climate.

 The hydrological cycle is significantly impacted by the climate's warming. The amount, quality, and seasonality of water resources are impacted by variations in precipitation, temperature, and climatic patterns, as well as the melting of snow and ice, which inevitably modifies aquatic habitats. In high-latitude places, permafrost is already melting and thawing, and in high-elevation regions, it is forcing glaciers to recede, with implications for downstream water resources (IPCC, 2014). The melting of the Arctic sea ice has the potential to interrupt or impede the worldwide ocean conveyor belt in marine systems (Liu et al., 2017; also see ocean circulation section below)

 For the vast majority of underprivileged and vulnerable communities, fish is a key source of sustenance. One of the most traded food items in the area, the industry also employs a large number of men and women. The fish trade helps many developing nations' economies grow overall and serves as a significant source of cash flow for paying off foreign debt, running national governments, and importing food for home consumption, which improves national food security and diversifies diets. Natural climate changes, especially those on a medium (decadal) scale, have always had an impact on fisheries and the effectiveness of their management. The atmosphere and the ocean will continue to warm over the next 50–100 years, sea level will rise due to thermal expansion of water and melting of glaciers, ocean pH will decline (become acidic) as more carbon dioxide is absorbed, and circulation patterns could change at local, regional and global scales. The impact of climate change on fisheries can be classified as physical, chemical and biological change.

**Physical Changes**

 **Water Surface Temperature Rise**: The control of the world's climate is greatly influenced by the oceans. Due to their heat capacity being around 1000 times greater than that of the atmosphere, they are able to absorb a sizeable portion of the heat that is emitted globally. Such variations in ocean temperature have the potential to alter the regional aquatic habitats' dynamics. Fish migration patterns may shift as a result of changes in ocean dynamics, and landings may decline, particularly in coastal fisheries.

**Sea Level Rise** Sea levels have already increased by 10 to 20 cm globally during the 20th century, primarily as a result of thermal expansion, and by 2100, the Intergovernmental Panel on Climate Change predicts that sea levels will have risen by 9 to 88 cm globally. Sea level rise may change the salinity of estuarine habitats, flood wetlands, and lessen or completely remove the amount of submerged vegetation in coastal areas, negatively affecting species that depend on these coastal habitats for recruitment and reproduction. Sea ports, existing fishing facilities like jetties, and fish storage facilities located on the coastal fringes slightly above the mean high tide line may also be more frequently susceptible to tidal and storm inundation as a result of rising sea levels.

**Chemical changes**

**Increasing Water Salinity**

Water salinity can alter as a result of climate change in a number of ways. Oceans near the poles have become fresher while those in the tropics have become more salinized. It is expected that anthropogenic climate change would cause an increase in the salinity of several freshwater environments. By impairing the organisms' capacity for osmoregulation, such physical alterations will have a detrimental effect on the population of both plankton and larger prey fish species. Salinity is regarded as one of the most crucial factors affecting how long species survive in estuarine ecosystems. It can either directly affect the creatures or indirectly affect them by damaging their habitat, especially their breeding and rearing grounds.

**Ocean Acidification**

 The majority of anthropogenic CO2 emissions may be able to be absorbed by oceans. In water, CO2 dissolves and irreversibly changes into carbonic acid. The world's oceans are becoming much more acidic as a result of this chemical process. Ocean habitats are negatively impacted by seawater's increased acidity due to dissolved CO2. Changes in physiological functions such as decreased growth of calcified structures, otolith development, and fertilisation success are examples of direct consequences. Modifications in predator or prey abundance, impacts on biological ecosystems like coral reefs, and adjustments to nutrient recycling are examples of indirect effects.

 The term "acidification" describes a long-term decrease in the pH of the ocean (usually decades or longer) that is mostly due to the uptake of atmospheric CO2. Other chemical additions to or subtractions from the ocean may potentially be the reason. The component of pH lowering brought on by human activity is referred to as anthropogenic ocean acidification. The oceans take in more CO2 when atmospheric CO2 concentrations rise. This results in a decrease in the pH of the water and the mineral saturation state, as well as an increase in the partial pressure of CO2 (pCO2) near the ocean surface. Climate change and aquatic systems, Chapter 1 There are 11 types of calcium carbonate (CaCO3), which is crucial for any aquatic life that produces shells (Portner *et al*., 2014). Ocean acidification has increased since the start of the industrial period; the pH of ocean surface water has lowered by an average of 0.1, which translates to a 26 percent increase in acidity (IPCC, 2014; Jewett and Romanou, 2017). Coastal waters have a more variable pH than open ocean waters and have greater pCO2 levels. Water acidification is made worse by lower salinity (caused by ice melt and/or excessive precipitation), which dilutes the concentration of buffering chemicals. There are regional variations in the rate of acidification of surface waters: Arctic waters are acidifying quicker than the world average because cold water can absorb more acid, and acidification is already 50% higher in the Northern Atlantic than in the Subtropical Atlantic, Arctic waters are acidifying faster than the global average because cold water can absorb more CO2. In the California Current, corrosive conditions events (in terms of Ωar state) have increased in frequency, severity, duration and spatial extent (**Harris, DeGranpre and Hales, 2013).** Future projections show that this decrease in pH will occur throughout the world oceans, with the largest decreases in surface waters occurring in the warmer low- and mid-latitudes. However, it is the already low Ωar waters in the high latitudes and in the upwelling regions that are expected to become aragonite unsaturated first

**Biological Changes**

**Changes in primary productivity**

Ocean acidification has increased since the dawn of the industrial period, with the pH of the ocean's surface dropping. It is believed that the availability of enough and the right kind of food is crucial for the survival of fish larvae during the planktonic stage. Therefore, in addition to effects of changes in production, climate-induced changes in the distribution and phenology of fish larvae and their prey can also have an impact on recruitment and production of fish stocks. Increased stability of the water column has reduced mixing, deep-water nutrient upwelling, and entertainment into surface waters due to an increase in surface-water temperature and a regional decrease in wind velocity. The result has been a decline in primary production.

Primary production: The marine food web's foundational mechanism, phytoplankton production regulates the energy and food accessible to higher trophic levels and, ultimately, to fish. Global marine primary production forecasts due to climate change are questionable, with models predicting both rises and decreases of up to 20 percent by 2100 (Taucher and Oschiles, 2011). (Bopp *et al*., 2013). This is due in part to the fact that changes in light, temperature, and nutrients are integrated by primary production, but it is also a result of the lack of clarity over how sensitive tropical ocean primary production is to climate change. It is unclear specifically how El Nio episodes in the tropical Pacific will be impacted by climate change. Primary production in freshwater lakes has been observed to increase in some Arctic (**Michelutti et al., 2005)** and boreal lakes, but to decrease in Lake Tanganyika in the tropics (O’Reilly et al., 2003). In both cases the changes were attributed by the authors to climate change **(IPCC, 2014).**

**Changes in Fish Distribution**

One of the most frequently noted ecological reactions of marine species is a change in fish distribution. Fish species are thought to alter their latitudinal and depth ranges in response to environmental changes like changing water temperatures. Fish migration patterns may shift as a result of changes in ocean dynamics, and landings may decline, particularly in coastal fisheries. Since marine fisheries are a significant source of food, changes in the overall quantity or geographic distribution of fish that are accessible for catching could have an impact on food security.

**CONCLUSION**

This chapter provides background material and establishes the context for the following chapters by summarising theme information on climate change and its effects on aquatic systems. Given that aquatic systems make up more than two-thirds of the surface of the Earth, the amount of evidence currently available on the effects of climate change is very limited, and many of the ideas and presumptions are still up for debate. However, it is undeniable that oceans play a crucial part in regulating the climate as well as in absorbing heat and the increased CO2 levels brought on by our activity. According to model predictions, ocean warming, greater stratification, and rising emissions will diminish the ocean's potential to absorb CO2 in the future (Gattuso *et al*., 2015). Freshwater systems have a close relationship to climate since they can both affect atmospheric processes that are relevant to climate and serve as indicators of climate change. Due of the numerous anthropogenic impacts that freshwater systems are exposed to, the IPCC judged them to be among the most imperilled on the world. As a result of hydropower infrastructure, irrigation water consumption, and agricultural land use, water bodies are fragmented, flow regimes are changed, and floodplains and wetlands are gradually cut off from the rivers that support them. These stresses are anticipated to remain dominant as human demand for water resources increases, along with urbanisation and agricultural growth, in addition to climate change (Settele *et al*., 2014).Operations of fishing and farming activities are also expected to be affected, whether by short-term events such as extreme weather events or medium to long-term changes such as lake levels or river flow that could affect the safety and working conditions of fishers and fish farmers. Food control procedures will undergo major reshaping to protect consumers from potential increase in contaminants and toxin levels resulting from changes in water conditions.

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