DOI: 10.54254/2755-2721/56/20240051

Impacts of global warming on marine ecosystems: Ocean acidification and fish catches

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Abstract. The temperature of the earth has been increasing since the industrial revolution. In recent years, global warming has become more and more severe, so as to the warmer ocean. This paper focus on the response of the oceans to the global warming in physical, chemical, and biological. Under the current climate of global warming, the oceans play a huge mitigating role as thermal containers. And the oceans are also the largest carbon sink in the world. This leads to a serious pollution, ocean acidification, which may change the physical and chemical processes of the ocean and affect the environment of marine life. In the meantime, we point out that the nature internal variability also has great impact on the marine ecosystem, like fish catches. If we learn more the mechanisms of the internal variability, there would be less uncertainty of the ocean changes. Overall, we show a general picture of the effect of the ocean warming to our readers and try to give some constructive suggestions to the policy maker.

Keywords: Global Warming, Ocean Acidification, Fish Catches.

1. Introduction

1.1. Global Warming

The temperature of the Earth has been rising since the Industrial Revolution. The main reason for this is the increased concentration of greenhouse gases in the atmosphere, which absorb the infrared radiation emitted from the Earth's surface and act as a shield at the Earth's surface, preventing the heat radiated from the Earth's surface from escaping freely into space as it did in the past, making it warmer than it would otherwise be [1]. According to the Global Climate Status Report 2021 published by the World Meteorological Organization (WMO), the period from 2015 to 2021 is the warmest seven years on record. The global average temperature in 2021 being approximately 1.11 ± 0.13°C warmer than the pre-industrial average of 1850 – 1900 and global CO_2 emissions breaking record at 407.8 ± 0.1 mg/L in 2018 [2]. And according to the IPCC Sixth Assessment Report (AR6), human activities have undoubtedly contributed the most to atmospheric, oceanic, and terrestrial warming since the pre-industrial era. The effects of global warming are irreversible, such as the loss of sea ice, the shrinking and melting of glaciers and ice caps, and the rise in sea level [3]. These effects have led and will continue to lead to a more significant increase in the frequency and intensity of extreme events, such as storms, wildfires, floods, extreme droughts, etc.

In this current climate of global warming, the oceans play a huge mitigation role as heat containers. Because of the relatively high specific heat capacity of water, it can absorb huge amounts of heat with relatively little increase in temperature. Therefore, a large amount of heat content is stored in the ocean. This extends the time scale of the response of the climate system, especially the Earth's surface temperature, to external forcing. It is estimated that over the last few decades, more than 90% of the heat energy from global warming has accumulated in the oceans. Data show that the average heat gain rate across the ocean depth from 1993 to 2021 was approximately 0.64 to 0.80 watts per square meter [3]. Figure 1 shows the seasonal heat energy in the top half mile of the ocean compared to the 1955 – 2006 average, which shows that the heat content in the global ocean has been above average since the mid-1990s.

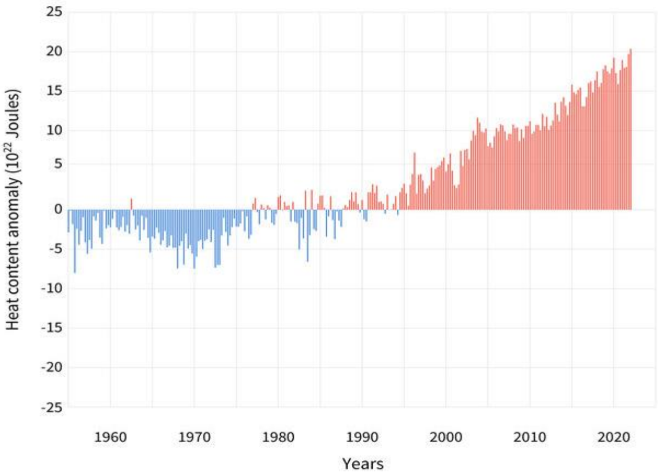

Figure 1. Ocean Heat Compared to Average [3].

1.2. The Importance of Marine Ecosystems to the Climate System

The amount of salmon in a given area is often linked to long-term climate changes. The North Pacific Ocean goes through periodic climate changes that last for more than a decade, and this cycle is measured using atmospheric and oceanic data which are indicated by the Pacific Decadal Oscillation (PDO). A study conducted by Kaeriyama in 2014 revealed that when the PDO is in a positive phase, the number of salmon caught in the North Pacific tends to increase over time. Conversely, when the PDO is negative, the number of salmon caught tends to decrease over time. Low-frequency signals, like the PDO, have crucial impacts on fish and thus further have negative effects on human productivity; one example is that 20% of human food nutrition comes from the ocean. Therefore, global warming also has a significant impact on the ocean. The phenomenon of ocean acidification is a consequence of the rise in global temperatures, resulting from increased levels of carbon dioxide (CO_2) emissions in the atmosphere. This process involves the gradual absorption and release of excess CO_2 by the ocean, leading to the progressive acidification of seawater. Since the industrial revolution, the pH of seawater has fallen by 0.1.

The increase in acidity of seawater can alter the chemical balance of seawater in a number of ways, putting at risk a wide range of marine life and even ecosystems that depend on a chemically stable environment. Changes in some typical marine ecosystems indicate some preliminary evidence of the impact of global warming on marine ecosystems. Research shows that colorful corals are losing their luster and are facing threats to their survival. Rising sea temperatures are one of the factors leading to coral bleaching, and scientists have found that in some areas, coral bleaching is strongly linked to the warming of seawater [4]. For example, rising water temperatures in Australian waters have led to massive coral mortality [5]. The study of marine ecosystems allows for a comprehensive understanding of how the ocean is changing and how the marine ecosystem will respond in the future, so that future changes in the marine ecosystem can be predicted. In turn, laws, regulations, and

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policies can be better formulated for sustainable development, rational fishing, and protection of the productive nature of the ocean.

2. Marine Ecosystems

2.1. Ocean Acidification

Due to global warming, which is caused by a sustained increase in atmospheric CO_2 concentration, the concentration of CO_2 gas absorbed by the oceans is increasing, making surface seawater less alkaline and thus causing ocean acidification. Ocean acidification has been widely recognized as another major environmental problem caused by the rise in CO_2 [6] and is one of the most serious pollution problems in the oceans. Changes in ocean chemistry caused by ocean acidification are altering the chemical environment on which marine life depends, affecting the metabolic processes of marine organisms, and changing the stability of marine ecology [7].

When carbon dioxide dissolves in the ocean, some of it forms carbonic acid with water and ionizes hydrogen ions, resulting in a lower pH and higher acidity of seawater.

$$H_2O + CO_2 \rightarrow H_2CO_3 \tag{1}$$

$$H_2CO_3 \rightarrow H^+ + HCO^{3-} \tag{2}$$

Ocean acidification is changing the ratio of total inorganic carbon concentration to the concentration of different forms of inorganic carbon (CO_2, HCO_3^- , and CO_3^{2-}) in seawater and affecting the $CaCO_3$ saturation of seawater, i.e.

$$\Omega = [Ca^{2+}] \times [CO_3^{2-}]/Kc,$$

$$H^+ + CO \rightarrow HCO^{3-} \tag{3}$$

Where Kc is the solubility product of Ca^{2+} and CO_3^{2-} when the $CaCO_3$ solution is saturated and is related to the type of $CaCO_3$ crystal (e.g., calcite, aragonite). Currently, HCO_3^- accounts for more than 90% of the total dissolved inorganic carbon (DIC) in open ocean waters, with CO_3^{2-} concentrations around 9% and CO_2 less than 1%. Increasing atmospheric CO_2 concentrations increases dissolved CO_2, HCO_3^-, and H^+ concentrations, while CO_3^{2-} concentrations and $CaCO_3$ saturation decrease. According to Tang’s work in 2013, a doubling of the atmospheric CO_2 concentration would increase pCO_2 in surface seawater by nearly 100%, HCO_3^- by 11%, DIC by 9%, and CO_3^{2-} by about 45%, with a corresponding decrease in calcium carbonate saturation [7].

The correlation between pCO_2, dissolved inorganic carbon, pH, $CaCO_3$ saturation, and their interactions in seawater may affect the calcification of calcareous organisms [7]. Although the organisms can still take up calcium even when the calcium carbonate concentration decreases, more biological energy is required. Because it takes more effort to absorb calcium, it has less energy to use for reproduction. As a result, individual organisms need to expend more energy to mature, which leads to a reduction in reproductive capacity and therefore a reduction in the reproductive capacity of the organism's population, leading to a reduction in species [8].

2.2. *Fish Catch and Habitat*

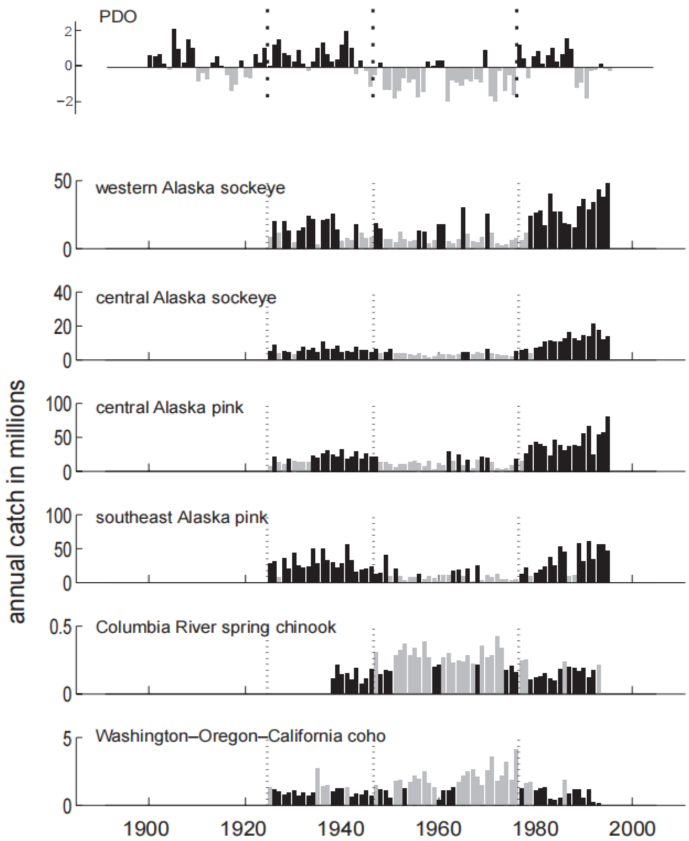

Figure 2. Selected Pacific salmon catch records with PDO signatures [9].

In the figure provided, the three dotted lines correspond to the years 1923, 1945, and 1977. The bars in black represent the annual fish production in millions when the Pacific Decadal Oscillation (PDO) is positive, while the grey bars correspond to the annual fish production in millions when the PDO is negative. The first sub-figure displays the overall relationship between the PDO and the total fish catch, while the remaining sub-figures exhibit the relationship between the PDO and the catch of individual fish species, such as western Alaska sockeye, central Alaska sockeye, central Alaska pink, southeast Alaska pink, Columbia River spring chinook, and Washington-Oregon-California coho, respectively.

The results depicted in Figure 2 demonstrate that from around 1923 to 1945, the fishing of Pacific salmon increased over time during positive PDO phases and decreased over time during negative PDO phases. This can be attributed to the Pacific Ocean being warmer during this period, which led to an increase in the number of various salmon species. However, in subsequent decades, the Pacific Ocean's temperature decreased significantly, resulting in a substantial reduction in salmon populations. Nonetheless, in 1977, the temperature of the Pacific Ocean increased again, accompanied by an increase in salmon populations. Therefore, it is evident that the abundance of salmon populations exhibits a decadal oscillation, which corresponds to changes in the sea surface temperature (SST) in the Pacific Ocean.

Meanwhile, in addition to the PDO, the salmon biomass is also closely associated with the strength of the Aleutian Low in winter. This is because when winter storms occur, coastal currents intensify, resulting in increased eddies, which, by stirring up coastal waters through synergy with tides, can carry large amounts of nutrients (e.g., nitrogen and phosphorus) from the bottom to the surface. These nutrients are then distributed to the Gulf of Alaska via ocean currents and circulation. At the same time, active winter storms cause the vertical mixing of seawater to become greater, and bottom nutrients are spread to the surface layer by the strengthening Aleutian Low in the eastern Bering Sea. In addition, a counterclockwise low pressure eddy brings wet, warm air and warm water from the south, which warms surface waters in the Gulf of Alaska and Eastern Bering Sea, thereby attracting more salmon [10].

Li's work in 2019 shows that the predicted lead time and associated amplitudes of the PDO decrease sharply under global warming conditions, and this decrease is mainly attributed to the strengthening of ocean stratification caused by warming. Accordingly, the interdecadal cycle of salmon and other fish species will be affected, and thus, global warming will affect the production in fish catches. And furthermore, the global warming will make the prediction of the PDO more challenging with far-reaching implications.

In addition, global warming can have significant impacts on fish catches in a number of ways. As the Earth's temperature rises, so do the temperatures of rivers, lakes, and oceans. This can have a major impact on fish populations, as many species are adapted to specific temperature ranges. For example, some cold-water species, such as trout and burbot, require cold water with adequate levels of dissolved oxygen, so they are particularly vulnerable to the change in temperature [11]. If water temperatures rise beyond their tolerance range, this can lead to reduced survival and smaller fish. Moreover, changes in precipitation patterns due to global warming will affect the amount and timing of freshwater flow into rivers and lakes. This may affect fish populations that depend on specific water levels and flows for reproduction and foraging. Further, global warming is causing changes in ocean chemistry, particularly an increase in carbon dioxide levels. While making the water more acidic, it may also harm fish populations that depend on specific pH ranges for survival.

Overall, the effects of global warming on fish catches are complex and will vary by species, location, and other factors. However, it is clear that global warming poses a significant threat to many fish populations, and efforts to address climate change are critical to protecting these important resources.

3. Conclusion and Discussion

The Earth's temperature has been rising since the industrial revolution, and the period from 2015 to 2021 is the warmest seven years on record. The effects of global warming are irreversible, and these effects have led and will continue to lead to an even greater increase in the frequency and intensity of extreme events. In this paper, the response of the ocean to global warming from different aspects is studied and analyzed. In the current climate of global warming, the oceans play a huge mitigating role as heat containers. Due to the high specific heat capacity of water, a large amount of heat content is stored in the oceans. It is estimated that more than 90% of the global warming in the last few decades has accumulated in the deep ocean, where the heat is stored. At the same time, the increasing concentration of carbon dioxide gas absorbed by the ocean makes the surface seawater less alkaline, thus causing ocean acidification, which is one of the most serious pollution problems in the ocean. The changes in ocean chemistry caused by this phenomenon are altering the chemical environment on which marine life depends and changing the stability of ocean ecology. In addition to these, changes in ocean currents and changes in precipitation due to global warming are also affecting fish populations, thus leading to a decrease in marine primary productivity. This shows that the marine ecosystem is suffering from unprecedented challenges, which in turn is having a negative impact on the planet and on the productive lives of human beings.

The amount of marine life harvested through natural reproduction has declined since 2000 and is now estimated at 90 million tons, and fisheries are no longer considered sustainable resource management [10]. The decline in catches due to climate change is a global issue and therefore requires political action on a global scale. For example, governments could strengthen international cooperation to address climate change and protect marine ecosystems; or they could support scientific research to improve understanding of fish ecosystems, including fish stock distribution, abundance, and fisheries management. However, the data show that while there is a wealth of local and regional knowledge, tools, and methods to promote adaptation, there are surprisingly few examples of specific adaptation actions and measures [12]. This emphasizes the need to raise general awareness of climate change impacts in

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addition to setting laws and regulations, which is most important in order to maximize the effectiveness of actions.

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