The 2nd International Conference on Biological Engineering and Medical Science
DOI: 10.54254/2753-8818/3/20220413

Impact, Responses and Future Prediction of Climate Change on the Phenology of Jellyfish

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Abstract. Climate variation can be devastating to marine life. This essay mainly focuses on how jellyfish cope with changes in ocean temperature and whether they benefit or are also affected by the population's decline. In terms of whether jellyfish benefit from climate change, this paper focuses on two case studies: the mass propagation of jellyfish in the coastal areas of China and the abundance change of jellyfish in the Bering Sea area. The results conclude that jellyfish are increasing because of climate change. However, for the case study on the decrease of the race caused by the influence of jellyfish, this paper only found that it occurred in Humboldt Current, West Greenland Shelf, and Oyashio Current. Through comparative study, this paper demonstrates that jellyfish mainly benefited from climate variation because overfishing significantly reduced their predators. Critical species of the Marine food chain were transformed into flagellates. Flagellates reduce the oxygen content in the ocean. In addition, the paper found that the mortality of individual jellyfish in the study was increased by ocean acidification due to climate change. The increase in mortality rate is because the jellyfish's reproductive and body functions are greatly affected, leading to higher mortality. This discovery proves that there are still a few jellyfish that could be negatively affected by climate change. As a result, jellyfish, with their simple but adaptable bodies, gradually replaced fish as the dominant creatures in the water. Since studies of jellyfish and their corresponding measures are still scarce, researchers will need more attention to these small and unremarkable creatures in the future. Even in the face of human overfishing, their numbers are still more significant than the correct number. To restore the marine ecosystem balance, scientists must do something to reduce the number of jellyfish in the ocean.

Keywords: climate variation, consequences, jellyfish population abundance, marine ecosystem, future prediction.

1. Introduction

Oceans cover 70 percent of the Earth's surface and are home and food sources for many marine mammals, plants, and plankton. The oceans absorb the sun's energy and transmit it to land. Specifically, the oceans absorb warm water transported throughout the Earth by ocean currents and solar heat. However, with the Earth's temperature rising at an alarming rate, global warming and ocean acidification are two serious concerns. As the Earth's climate warms, the oceans become less frigid and more prone to sinking. Water expands as the temperature rises. As a result, warmer water takes up more space in our oceans, which causes sea levels to rise. Global warming is also causing glaciers on land to melt, which drains the ocean. The more water in the ocean, the higher the sea level. Rising sea levels will cause illness and even death for animals and plants. Another critical issue is ocean acidification, which means there is too much carbon dioxide in the water. The production of carbon dioxide by humans is significant. For instance, more carbon dioxide enters our atmosphere due to vehicles, aircraft, and industrial exhaust. The Earth absorbs more heat, primarily produced by the seas when there is too much carbon dioxide in the atmosphere.

Jellyfish are fascinating and essential creatures. Firstly, jellyfish are very diverse. Jellyfish is the general name for the Cnidarian phylum, which includes more than 10,000 species of different colors and sizes. Some species can be as small as 1 cm (Malo SPP.), while the largest grows to 36.5 m (Cyanea capillata), as described in the results section. Moreover, jellyfish are very simple. As invertebrates, they do not have any bones, gills, or fins. They do not even have a heart or a brain. Despite their simple structure, they are among the oldest living things on Earth. Evidence suggests they may have been around for more than 700 million years, three times more senior than the first dinosaurs discovered. Green fluorescent protein, a marker protein very commonly used in cell studies, is extracted from jellyfish, further illustrating the importance of jellyfish. This paper will focus on the phenology of jellyfish. Given that jellyfish niches are becoming increasingly crucial in marine ecology and that studies are scarce, it is necessary to understand the underlying causes of these changes. This paper will present climate change's positive and negative impacts on jellyfish phenology and future projections based on current findings.

2. Positive impact

A considerable amount of Velella velella, a species of jellyfish, appeared massively in the spring. They are on the beaches in Washington, Oregon, and California [1]. The average ocean temperature has increased by around 0.9 degrees over the last century [2]. While most marine species suffer from this climate variation, jellyfish can travel to some regions that were extremely cold before [3]. In recent years, jellyfish have begun to appear in large numbers and have been reported more and more, which has gradually attracted the attention of scientists. Examples are the swarms of V. velella

Table 1. Occurrence of the Four Species of Jellyfish [4].

Species	Year	Location	Direct consequences
Aurelia aurita	2004;2008	Qinhuangdao,Hebei province	Over 4000 tons of A.anrita were cleaned up in July 2008
A.aurita	2007	Yantai,Shandong province	Interference with aquaculture
A.aurita	2008	Weihai, Shandong province	20-50 tons of A.anrita were cleaned up each day
A.aurita	2009	Qindao, Shandong province	Over 10 tons of A.anrita were cleaned up for two days
Cyanea sp.;Nemopilema nomurai	1999	Middle South Zhejiang province	Interference with fisheries
Cyanea nozakii	2004	Liaodong Bay	Sharp decline of edible jellyfish Rhopilema esculentum
Cyanea sp.	2003;2004	Yangtze Estuary	Comprised 85.47% of the totla catch of fisheries in November 2003 and 98.44% in May 2004
Nemopilema nomurai	2003-2005	East China sea	Mean biomass in monitoring sites 608-7144 kg/h
N. nomurai	2005;2007	Huludao,Liaoning province	Interference with fisheries

DOI: 10.54254/2753-8818/3/20220413

Table 2. Hospital Reports of Jellyfish Stings [4].

Location	Period	Number of cases	Number of severe cases	Number of Deaths
Qinhuangdao,Hebei province	1983-1987;1995-2000	583	7	2
Huludao,Liaoning province	2006	2	1	0
Dalian,Liaoning province	2001-2004;2007	241	11	1
Weihai,Shandong province	1994-2000;2007	1274	58	10
Yantai,Shandong province	2002	1	1	0
Qindao, Shandong province	2001-2003;2005-2006	93	3	0
Zhejiang province	1998-2004	32	2	0
Fujian province	2001;2006	106	No data	0
Guangdong province	2004	35	No data	0
Sanya,Hainan province	1984-1993;2001-2005	133	6	0

jellyfish in the US and the constant presence of jellyfish in China. Scientists studying jellyfish blooms in China have focused on three dominant jellyfish species: A. Aurora, C. Nozakii, and N. Nomurai [4]. They examined the species' occurrence records in the past 40 years (Table 1) and hospital reports of jellyfish stings (Table 2).

3. Jellyfish blooms in China water region

According to the existing data survey, there has been an apparent upsurge in jellyfish populations in recent years. In the 17 years between 1983 and 2000, there were 583 jellyfish injuries, which translates to about 35 jellyfish-related hospitalizations each year. Nearly 1.5 million people worldwide are injured by jellyfish each year, a high number of cases in the area the researchers focused on [5]. The removal of nearly 20 tons of jellyfish a day suggests to researchers that something is wrong with the local marine ecosystem, and jellyfish are growing phenomenally. They then conducted case studies on the three most frequent jellyfish species to speculate on possible causes of the explosive growth. The researchers concluded that some anthropogenic factors contributed to the increase of these jellyfish, including the possibility of climate change. Although there is evidence of a general rise in temperature in Chinese oceans, the researchers believe that this is not the most direct cause of the jellyfish bloom, at least in Chinese oceans; this hypothesis remains to be tested.

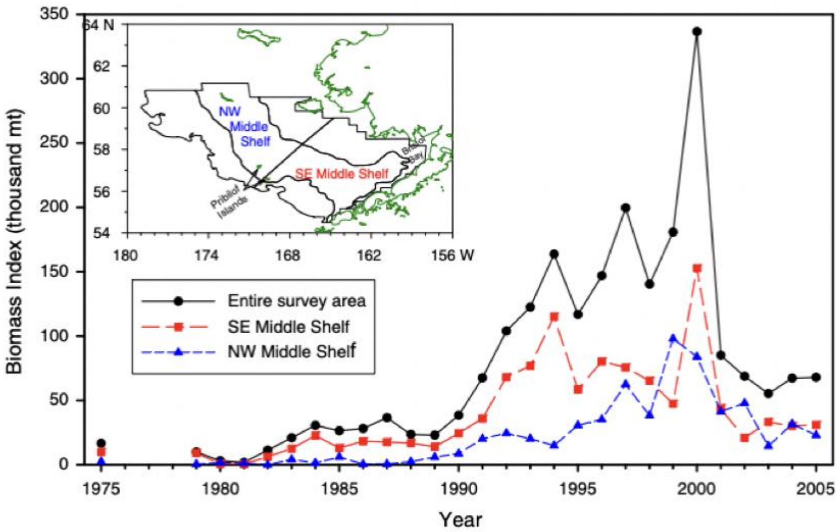

Figure 1. Jellyfish abundance in Bering sea [6].

4. Bering sea Jellyfish abundance

The Bering Sea survey shows that jellyfish are increasing due to climate change. The researchers collected samples from 1975 to 2005. Local jellyfish biomass was low in the 19th century, but as the climate warmed, jellyfish biomass peaked in the summer of 2000 (Figure 1). Since then, it has fallen sharply but remains at a moderate level. The 20th century marked a significant turning point in jellyfish adaptation to rising temperatures and climates. The increase in biomass is further evidenced, which shows the annual distribution of jellyfish biomass (Figure 2). [6]. Evidence shows that if the current marine ecosystem changes from a fish-based structure to a gel-based form, the ecological environment, economy, and society will be seriously affected [7]. Researchers have concluded that climate is the fundamental reason for the mass reproduction of jellyfish after a large amount of data. The first reason is that as the climate warms, the bottom of the marine food web will be replaced by flagellates, and this new ecological food web will favor jellyfish more than fish. At the same time, temperature rise accelerates the reproduction period of jellyfish, which can be concluded from the study of the abundance and quantity of jellyfish by Purcell, Gibbons, and Richardson [7-9]. Purcell and his colleagues' study focused on 15 types of tropical jellyfish species, nearly 11 of which increased in abundance because of ocean warming [7]. In their analysis of trends in the total number of jellyfish in the North Atlantic during the previous 50 years, Gibbons and Richardson concluded that jellyfish populations tend to increase during warmer years [8, 9]. In addition to climate change, overfishing is another decisive factor that has led to massive jellyfish blooms. Overfishing has indirectly affected jellyfish abundance. The past has shown the magnitude of human impact on marine ecology. Historically, overfishing has decimated the number of top predators in the ocean, giving some species a chance to repopulate, including jellyfish. Jellyfish are becoming more critical as the number of predators declines. This, in turn, affects the amount of food available to the jellyfish [10].

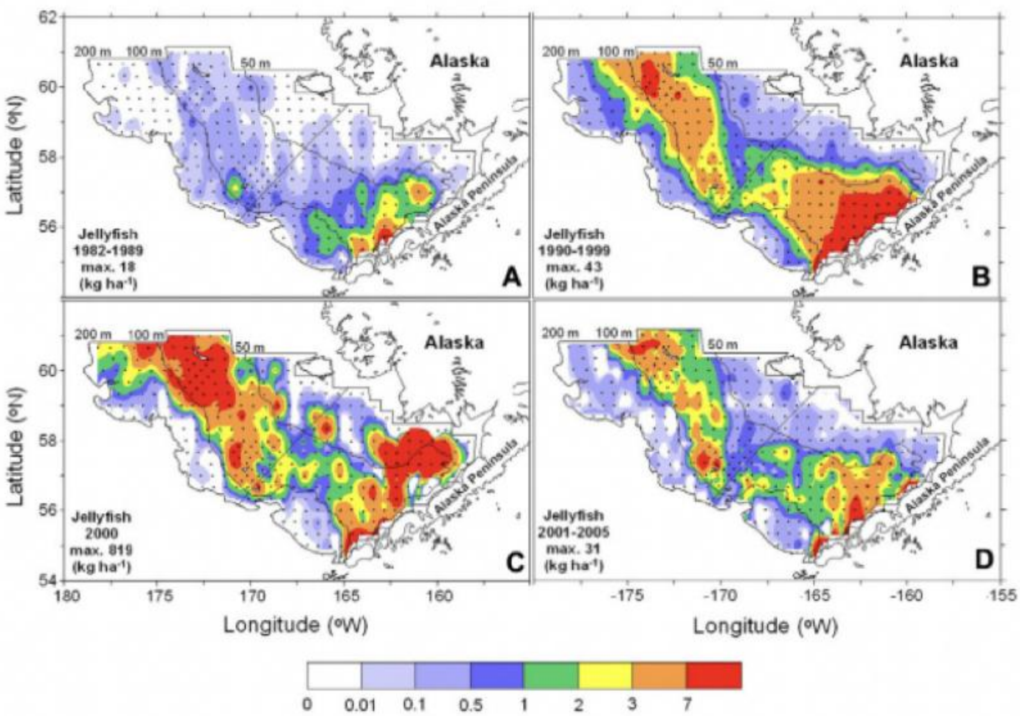

Figure 2. Jellyfish distribution in the ocean [6].

Overall, this suggests that jellyfish thrive under conditions of climate change. Specifically, global warming and ocean acidification boost jellyfish reproduction by creating conditions that are good for jellyfish but bad for other jellyfish, especially their competitors and predators. The burning of fossil

DOI: 10.54254/2753-8818/3/20220413

fuels, deforestation, industrial production, and other human activities have contributed to increased atmospheric carbon dioxide. This extra carbon dioxide is absorbed by the seas, which react with water to create carbonic acid, a weak acid in which hydrogen ions can dissolve. Carbonate ions in the ocean react with dissolved hydrogen ions and are consumed, which means that organisms need fewer carbonate ions for calcification [11]. Rokita's research shows that the concentration of carbonate ions decreases as carbon dioxide surges. Calcification is significant for corals, shelled organisms, and some calcified plankton and algae. If corals and these invertebrates are less abundant, so will the diversity and abundance of fish since reefs are typical habitats for young fish, and marine invertebrates are food sources for fish. As fish populations decline, there is less competition for jellyfish and more space to feed and live, leading to jellyfish blooms. One study reported that jellyfish frequencies in the North Sea were significantly correlated with decreased surface water pH from 1971 to 1995 [12]. Although the mechanism behind this incident is not precise, the correlation does occur. In addition, global warming promotes seawater stratification, which occurs when the density of water varies [13]. Temperature and salinity affect seawater density. As global warming accelerates, more freshwater from melting icebergs flows into the ocean, making the surface water less salty and the sea less dense. Surface waters are also warmer and less dense. As a result, light penetrates the ocean more efficiently and further promotes the growth of some phytoplankton by boosting photosynthesis. This is good for jellyfish because some phytoplankton, such as flagellates, are their food source [13]. In addition, warmer water absorbs less oxygen because the kinetic energy of the water molecules is too high for the oxygen molecules to dissolve. With less oxygen in the water, it is hard for creatures like fish to thrive. Jellyfish, however, can outdo other animals by being able to tolerate a lack of oxygen. In addition, jellyfish have strong hunger tolerance, fast growth, and reproduction ability. As a result, they can adapt to climate change more quickly than other species, such as fish. Fish are endangered by climate change. Ocean warming has slowed the growth of coral reefs, which are their typical habitat, and researchers predicted that coral could stop growing altogether by 2070. As reported in the case study of the Middle Red Sea, some algae that jellyfish prey on, such as benthic dinoflagellates, may become more successful, while others may decrease [14, 15]. With potential habitat loss and limited food sources, jellyfish could replace fish with more food and less competition.

5. Negative impact

However, there are also a few cases where jellyfish are negatively impacted by ocean climate change. The first example is a study of jellyfish in the North Sea [16]. In this investigation, Sabine Holst created an experiment to examine the effects of rising wintertime ocean temperatures on four North Sea jellyfish species. Surprisingly, the result shows that one of the four jellyfish species, C. capillata, exhibited a negative correlation between its strobilation and ocean winter temperatures. Therefore, C. capillata suffers in warmer ocean temperatures through significantly decreasing ephyrae per polyp and shorter strobilation duration. Other than warmer temperatures, ocean acidification also plays a role. In the second case study, researchers looked at how both variables affected the dynamics of the polyp population of the jellyfish Cotylorhiza tuberculate, one of the most prevalent bloom-forming scyphozoans in the Mediterranean [17].

The result is that, at 18 oC, strobilation was reduced. At 24 and 30 oC, the percentage of strobilation was meager. Meanwhile, more considerable stability was formed at trail two. The result shows that the recruitment of Medusas and C. tuberculata population dynamics is due to climate change. Finally, the increasing temperature and acidic sea conditions may impact the polyp's phase transition to ephyra and the development of C. tuberculate well-developed ephyra. Ocean acidification caused by human activity can be a factor leading to jellyfish population decreases. Pierre J. C. Chuard and his colleagues found that ocean acidification caused the mortality rate of a specific jellyfish named Carybdea xaymacana to increase during its medusa stage [18]. Research has found that jellyfish become more sensitive and challenging to handle when the pH level of the ocean decreases. Even when they are entirely developed, jellyfish's ability to swim is reduced by ocean acidification. Their ability to bounce back from crises is significantly diminished when they are at ocean acidification.

DOI: 10.54254/2753-8818/3/20220413

Because of the increased likelihood of being hunted by their predators, their death rate is rising. It turns out that jellyfish will become extinct if they begin to die off in large numbers while still reproducing. Given how crucial jellyfish are to the environment and how their numbers would fluctuate if they are harmed, that is not very optimistic for the entire ecosystem.

6. Future prediction

In general, jellyfish populations are benefiting from climate change [19]. Forecasting the future breeding numbers of jellyfish is difficult. The number of jellyfish has been rising globally in recent decades, with most changes occurring in coastal areas or semi-closed oceans, even though their unusual life cycle can lead to excessively high temporal and spatial variability in abundance [20]. For analysis, whether the population of jellyfish is increasing or decreasing is very hard to define, and some evidence of indirection does not have a reference value. The increase in jellyfish numbers may also be related to human activity. It can be speculated that due to many external factors, the number of jellyfish may continue to rise in the next decade. First, humans are overfishing their natural enemies, like turtles and sharks. Over the past two decades, human overfishing has averaged 100 to 120 million tons of marine life removed from the oceans each year.

Many of these marine species eat some of the same food as jellyfish: mostly zooplankton. Jellyfish have less food competition since other plankton predators are caught in the sea, which allows them to grow and reproduce more freely [21]. Moreover, increasing ocean temperatures due to global warming is another reason for the increase in jellyfish populations. Warmer water can help jellyfish embryos, and larvae develop faster, allowing their offspring to grow faster. Jellyfish that favor warm water will have more accessible regions to live and grow. However, this could also harm some species as the habitat of cold-water-favored jellyfish species shrinks [20].

Additionally, "dead zones" are created when the ocean receives large volumes of fertilizer runoff, which causes an explosion in plankton and algae populations. While many marine organisms cannot survive in these areas, certain jellyfish can consume plankton without being impeded by rivals or predators. A decrease in jellyfish populations could result from overfishing. However, even human overfishing in some regions cannot stop people from growing. It is yet unknown how to forecast jellyfish populations and reproduction. According to the theory, most oceanic locations would experience an increase in jellyfish, albeit this tendency wouldn't be universal. Since jellyfish can harm humans, jellyfish blooms are a serious issue that needs to be resolved in the future. Eutrophication

In coastal areas, eutrophication enables phytoplankton blooms. The plankton is the main food for jellyfish, which means that the plankton massive growth the jellyfish had more food, which may also be responsible for the growth of jellyfish. Both sewage and fertilizer runoff contain large amounts of nutrients, and when these nutrients went into ocean that lead to rapid growth of phytoplankton [5]. Because jellyfish can live in low oxygen environment [4], These phytoplankton was sink to the seafloor and cause local hypoxia, so this results in fish not being able to survive in a low oxygen environment like jellyfish, which such a living environment reduces jellyfish competitors and predators [5]. This situation can provide a good habitat for jellyfish reproduction.

7. Conclusion

This paper finds that global warming is harming most Marine life, but for jellyfish, the changes provide a favorable environment for them to thrive. Thus, global warming and climate change have indirectly contributed to the increase in jellyfish populations due to their highly adaptive and catastrophic impact on predators. Human activity has also affected jellyfish populations. For example, predictors of overfishing jellyfish and competing factors provide a better environment for jellyfish to reproduce. In addition, warmer waters and lower pH levels can negatively affect the survival of certain jellyfish species. Overall, jellyfish populations are growing exponentially and are affecting the balance of marine ecosystems and the economics of human fisheries. However, the quality of existing research is insufficient to evaluate the complex impacts of climate change on the ocean. Many factors contribute to jellyfish blooms, and they all interact. This article aims to raise researchers' awareness of

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the importance of jellyfish in the marine biosphere and to remind readers not to overlook the presence of these humble creatures. Future research should focus on controlling jellyfish blooms and preventing continued jellyfish blooms' impact on marine ecosystems and the human economy. The current study only looked at the relationship between jellyfish and climate change.

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