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Review **Derleme**

Climate Change's Impact on Aquaculture and Consequences for Sustainability

İklim Değişikliğinin Su Ürünleri Yetiştiriciliği Üzerindeki Etkisi ve Sürdürülebilirlik için Sonuçları

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Abstract: Aquaculture is the fastest-growing sector of food production, with catch fisheries currently accounting for more fish biomass. Unfortunately, the sustainability of aquaculture is jeopardized due to the projected repercussions of climate change, which are not only a future but also a present reality. We examine the probable impacts of climate change on aquaculture productivity and the consequences for the sector's long-term viability in this review. Various aspects of a changing climate have been considered, including rising temperatures, sea-level rise, illnesses, toxic algal blooms, changes in rainfall patterns, the unpredictable supply of external inputs, changes in sea surface salinity, and catastrophic climatic events. Climate change's impacts will be long-lasting and almost certainly permanent, wreaking havoc on the economy of people who work in the industry. As a result, the fisheries authorities must put in greater effort to comprehend the scope of climate change's influence on aquaculture and plan for its potential implications, as well as identify the sorts of consequences and design an adequate reaction to manage them.

Keywords

- Climate Change
- Aquaculture
- Sustainability
- Fisheries

Özet: Su ürünleri yetiştiriciliği, mevcutta daha fazla balık biokütlesi oluşturan av balıkçılığı ile gıda üretiminin en hızlı büyüyen sektörüdür. Ne yazık ki, su ürünleri yetiştiriciliğinin sürdürülebilirliği, iklim değişikliğinin sadece gelecek değil, aynı zamanda bugünün bir gerçeği ve öngörülen etkileri nedeniyle tehlikeye atılmaktadır. Bu derlemede iklim değişikliğinin su ürünleri verimliliği üzerindeki olası etkilerini ve sektörün uzun vadeli uygulanabilirliği üzerindeki sonuçları incelenmektedir. Yükselen sıcaklıklar, deniz seviyesinin yükselmesi, hastalıklar ve zehirli alg patlamaları, yağış düzenlerindeki değişiklikler, öngörülemeyen dış girdi arzı, deniz yüzeyi tuzluluğundaki değişiklikler ve zararlı iklim olayları dahil olmak üzere değişen bir iklimin çeşitli yönleri göz önünde bulundurulmuştur. İklim değişikliğinin etkileri uzun süreli ve kalıcı olacağı için sektörde çalışan insanların ekonomisine zarar verecektir. Sonuç olarak, balıkçılık yetkilileri, iklim değişikliğinin su ürünleri yetiştiriciliği üzerindeki etkisinin kapsamını kavramak ve olası etkilerini planlamak, ayrıca sonuçların çeşitlerini belirlemek ve bunları yönetmek için yeterli bir önlem almak için daha fazla çaba sarf etmelidir.

Anahtar kelimeler

- İklim değişikliği
- Su ürünleri
- Sürdürülebilirlik
- Balıkçılık

1. INTRODUCTION

Aquaculture, or fish, shellfish, and aquatic plant cultivation, is the world's fastest-growing food production sector. Between 1990 and 2016, global aquaculture production expanded fold, with an average annual growth rate of 5.8% from 2000 to 2016. (FAO, 2018). Aquaculture's contribution to world fish output has continued to climb, reaching 82.1 million tons (46%) of the predicted 179 million tons of global production, according to FAO (2020). Furthermore, aquaculture's proportion of world fish output is predicted to increase from 46 percent now to 53 percent in 2030. (FAO, 2020). The most pressing question, however, is whether the industry can develop sustainably and quickly enough to satisfy future predicted demand, which is being worsened by a rapidly rising human population and a changing environment. Climate change is now considered a severe threat to the world's food supply, both in terms of quality and quantity ((Beach and Viator, 2008; Hamdan et al., 2015; Myers et al., 2017). Climate change will influence small-scale food producers' lives and revenue, as well as poor net food consumers' livelihoods, limiting access to food through food price rises and instability (Maulu et al., 2021; Elsheikh, 2021a).

Climate change is defined as changes in the statistical distribution of weather over long periods, often decades to millions of years. These changes can occur in the average weather or just in the distribution of weather events around an average, and they can occur in a single place or all over the world (Yazdi and Shakouri, 2010). Also, Climate change is gradual changes in temperature, precipitation, atmospheric moisture, wind intensity, as well as sea level, all of these changes happen at a breakneck speed (Sesana et al., 2021)

The bulk of contemporary research in aquaculture indicates that some climatic changes, such as rising temperatures, altering precipitation patterns, and increased frequency of some extreme events, have already had an impact on water supplies, while others are still emerging. Because of the sector's substantial contribution to global food security, nutrition, and livelihoods, climate change implications on aquaculture sustainability have recently attracted a lot of attention (Fleming et al., 2014; Blanchard et al., 2017; Troell et al., 2017; Zolnikov, 2019; FAO, 2020).

The repercussions also will be long-lasting and certainly irreversible, wreaking havoc on the economy of individuals who work in the industry (Barange et al., 2018; Dabbadie et al., 2018). At both the regional and global levels, the impacts of climate change on aquaculture have been thoroughly researched and evaluated (De Silva and Soto, 2009; Yazdi and Shakouri, 2010; Clements and Chopin, 2016; Bueno and Soto, 2017; Chung et al., 2017; Ellis et al., 2017; Froehlich et al., 2017; Handisyde et al., 2017; Harvey et al., 2017; Klinger et al., 2017; Beveridge et al., 2018; Dabbadie et al., 2018; Elsheikh, 2021b). However, in the bulk of this research, there has been a trend toward focusing on the negative implications of predicted climate change on aquaculture while ignoring the beneficial effects, which are crucial for adaptation measures. This review examines the consequences of climate change on aquaculture output and the implications for sustainability, focusing on how each factor of climate change will influence the sector.

Direct effects of climate change on aquaculture production include affecting the physical and physiology of finfish and shellfish stocks in production systems, while indirect effects include affecting product prices, fishmeal and fish oil costs, and other goods and services required by fishers and aquaculture producers (Handisyde et al., 2006; De Silva and Soto, 2009; Freeman, 2017; Adhikari et al., 2018). Aquaculture has recently seen considerable technical advancements, allowing the industry to extend its present output to fulfill the growing demand for aquatic goods. Climate change, on the other hand, is gradually becoming one of the key concerns challenging the sustainability of food production systems, including aquaculture (Lim-Camacho et al., 2014; IPCC, 2018; FAO, 2020). The following are some of the projected effects of climate change on aquaculture productivity and sustainability: rising temperature, ocean acidification, diseases and harmful algal blooms changes in rainfall/precipitation patterns, sea-level rise, the uncertainty of external input supplies, changes in sea surface salinity, and severe climatic events (Handisyde et al., 2006; Brander, 2007; Ficke et al., 2007; Barange et al., 2018).

The significance of temperature in aquatic animal growth and development is crucial, because fish are poikilothermic, and they may be particularly vulnerable to temperature changes caused by climate change (Ngoan, 2018; Sae-Lim et al., 2017; Adhikari et al., 2018). Most fish, especially cold-water species such as Atlantic halibut, Salmon, and Cod, as well as intertidal shellfish, are expected to die more as a result of the 1.5°C rises in average global temperature forecast for this century. As a result, prolonged temperature stress can have a range of effects on aquaculture productivity, the most common of which is a decrease in output (Hamdan et al., 2012; Gubbins et al., 2013).

Ocean acidification occurs when the pH of ocean water drops over time (typically decades) as a result of CO_2 accumulation from the atmosphere (Richards et al., 2015; Bahri et al., 2018). The seas are thought to store 50 times the amount of CO_2 that the atmosphere does. (Seggel et al., 2016). At 1.5°C or higher global warming, the expected increase in CO_2 absorption by seas would have negative consequences for the growth, development, calcification, survival, and abundance of various aquatic species (IPCC, 2018). Increased CO_2 levels in water might lead to a drop in pH, endangering the environmental sustainability of aquaculture production systems by causing water quality to deteriorate, resulting in low output. Furthermore, when ocean acidity rises, the supply of carbonate essential for the formation of coral skeletons (Calcification) in shell-forming animals including shrimp, mussels, oysters, and corals decreases, posing a danger to marine aquaculture output (Yazdi and Shakouri, 2010; Kroeker et al., 2014; Rodrigues et al., 2015).

Aquaculture diseases are predicted to be affected by a changing temperature regime, such as bacterial, parasitic, viral, and fungal infections, but in an unpredictable way. What is known, however, is that when cultured species are subjected to heat stress, they become more sensitive to illness and that rising temperatures may lead to the spread of exotic diseases (Collins et al., 2020). The sensitivity of finfish and shellfish to pathogens is a primary factor of illness, and both direct and indirect temperature stresses are likely to have an impact. As a result, warm water disease outbreaks are expected to become more common, with the possibility of new ones emerging as a result of climate change (Chiaramonte et al., 2016). The replication rate, pathogenicity, life cycle duration, and transmission of infections among numerous finfish and shellfish species are predicted to increase when the temperature rises (Sae-Lim et al., 2017). Furthermore, rising temperatures may hasten the introduction of epizootic illnesses in aquaculture, posing significant economic concerns. Epizootic disease outbreaks are already one of the most significant challenges limiting the success of aquaculture production systems in many places across the world. (Marcogliese, 2008; Maulu et al., 2019). In Chilean aquaculture, an exceptional loss of fish has been documented owing to the spread of *Pseudochattonella cf. verruculosa* and *Alexandrium catenella* species, whose outbreaks were linked to climate-induced changes in water column stratification. (Trainer et al., 2019). Furthermore, diseases such as inflammation, atrophy, and necrosis have been documented in numerous organs of bivalve mollusks as a result of hazardous algal blooms in several investigations (Haberkorn et al., 2010; Basti et al., 2011; Hégaret et al., 2012).

Changes in rainfall patterns will have two distinct effects on aquaculture productivity and sustainability by increased flooding and periods of low or no rainfall (Drought), Drought risks are anticipated to be greater at 2°C of global warming in a particular location than at 1.5°C, according to the IPCC (2018), whereas flooding occurrence patterns are impossible to predict with certainty. Increased rainfall, especially if it comes in the form of heavier storms, will exacerbate the production risks in lowland regions. (Bell et al., 2010). These dangers include the loss of fish in ponds due to flooding, the invasion of ponds by undesired species, and pond damage caused by infilling and the washing away of walls (Rutkayova et al., 2017). Mixing pond water and fish with wild fish might have a detrimental impact on aquaculture production's environmental sustainability, primarily through the introduction of invasive fish species and worsening of water quality.

Furthermore, pond fish losses endanger the social and economic aspects of aquaculture sustainability by reducing producers' profits and causing poverty in communities. (Maulu et al., 2021). Droughts can cause water stress, such as shortages and degradation in quality, which can have a severe impact on aquaculture productivity (Hambal et al., 1994). Water shortages projected as a result of climate change may exacerbate competition for water among many user groups, including aquaculture, agriculture, residential consumption, and industry (Handisyde et al., 2006; Barange et al., 2018). This will have an impact on all aspects of aquaculture sustainability (Maulu et al., 2021).

According to IPCC (2018) forecasts, sea level rise will be roughly 0.1 meters lower under 1.5°C global warming compared to 2°C by 2100. This trend, however, is predicted to continue after 2100, with the degree and pace of increase likely to be determined by future GHG routes (IPCC, 2018). Coastal habitats such as mangroves and salt marshes, which are critical for maintaining wild fish supplies and producing seeds for aquaculture production, may be destroyed by rising sea levels (Kibria et al., 2017). This will have a detrimental impact on aquaculture breeding initiatives as well as the sector's economic viability. Higher sea levels are expected to have an impact on aquaculture production facilities such as ponds, cages, tanks, and pens, particularly in lowland areas, due to saline water intrusion (Kibria et al., 2017). Aquaculture, freshwater fisheries, and agricultural productivity are all thought to be harmed by groundwater salinization. As a result, salinization makes aquaculture unfit for production, resulting in greater production costs and reduced profits. Changes in species composition, organism abundance and distribution, ecosystem productivity, and phenological shifts are all predicted to occur as sea levels rise, posing a danger to inland and marine aquaculture output (Doney et al., 2012).

Variations in sea salinity are likely to have a detrimental impact on the economic benefits of some aquaculture species, thus jeopardizing the social and economic viability of aquaculture production. The increased salinity effect, on the other hand, has been closely linked to aquaculture production systems in coastal areas downstream (Nguyen et al., 2018). In general, changes in water salinity will result in greater mortalities for a variety of species, posing a threat to the sector's economic and social viability through increasing species losses and higher management costs (Maulu et al., 2021).

The appropriateness of habitat and the geographic dispersion of marine fishes are largely influenced by oxygen availability (Zambonino-Infante et al., 2013). Reduced oxygen concentrations are expected to occur more frequently, and for longer periods in the future as a result of climate change. It is important to recognize the difficulty posed by the ocean's growing low-oxygen zones. One of the biggest imminent risks to future fisheries resources and marine ecosystems, according to the United Nations Environment Program’s 2003 yearbook, is oxygen depletion (Townhill et al., 2017). Regions of the ocean with low oxygen concentrations are expected to develop more frequently and last longer in the future as a result of long-term climate change. When oxygen levels are low, marine species must work harder to fulfill their metabolic needs, which can have an impact on their ability to grow, feed, and reproduce. The analysis carried out has shown that there is already a sizable body of information about the physiological and behavioral reactions of fishes and shellfish to oxygen, particularly hypoxia. However, there is still a significant information vacuum about how these changes may appear as implications for fisheries and ecosystems. The only approach to keep the sector's output going might be to adjust to the anticipated changes in the short term while pursuing mitigating measures in the long run. However, the ability of producers in various parts of the world to adapt will determine if adaptation is effective. By advocating changes in fishing practices, changes in governance, and the deployment of efficient management plans and strategies, aquaculture producers may also adapt to climate change by assuring a steady supply of fish from captured fisheries (Frusher et al., 2014). There is a need to incorporate climate variability and change in the modeling of aquaculture undertakings to reduce the impacts of climate change in fisheries-based livelihoods. According to FAO (2020), global production from capture fisheries has stagnated or declined in some years over the past few decades. Inputs from capture fisheries, such as fishmeal, fish oils, brood stocks, and wild seeds, are significantly reliant on aquaculture output at the moment (Malcorps et al., 2019). Therefore, effective management of resources from fisheries may contribute to a sustainable supply of aquaculture inputs.

At a time when a rising global population needs to be fed and catch fisheries are at their peak and may eventually decrease, the availability of fishmeal and fish oils is already seen as a barrier to the development of aquaculture. The usage of plant-based aquaculture feeds in place of fishmeal currently depends on a few key crops including soy, maize, and wheat, all of which might be consumed directly by humans and are all negatively impacted by climate change. The processing ability, the presence of anti-nutritional components, storage stability, and application to the appropriate fish species in aquaculture are all factors that need to be investigated for aquaculture feed (Hall, 2015). Nevertheless, aside from climate change hazards, the success of the aquaculture insurance industry may rely on how effective and low-risk aquaculture develops. Since aquaculture is a relatively new field, research is needed to explain its advantages and effects on farmers' financial circumstances, particularly in the most disadvantaged regions.

Recirculating Aquaculture Systems (RAS) is one of the possible adaption options when taking environmental sustainability and sensitivity to the impacts of climate change on fish output into consideration. RAS are extremely productive, intensive farming techniques for a wide range of seafood products (Ahmed & Turchini, 2021). They may be used all year long, in a variety of locations, including near to important seafood markets, and are not impacted by seasonality or environmental factors. However, RAS are costly, intricate, and highly constructed systems that need for significant capital expenditure, which is why they mostly function in highly industrialized nations. Moreover, one of the major limitations of RAS is its high energy consumption.

2. CONCLUSION

The possible consequences of climate change on aquaculture productivity were emphasized in this review, which covered significant areas of climate change and aquaculture production. Climate change, which is both a current and future reality, is posing an increasing threat to the aquaculture business. These effects on aquaculture are expected to be both positive and negative, with the negative effects outnumbering the positive ones. Furthermore, while climate change is a global problem for food production, the risks connected with aquaculture are expected to differ by geographical or climatic zones, national economy, water environment, production techniques, production scale, and the farmed species of aquaculture producers. As a result, aquaculture producers must adapt to the options available and minimize the repercussions by making necessary changes to their production operations to develop resilience and maintain output in a changing environment. As the aquaculture industry grows, so does the danger of climate change, necessitating the development of research and field studies to mitigate the risks associated with climate change and its influence on aquaculture.

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Author declares that there is no conflict of interest.

AUTHOR CONTRIBUTION

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Not applicable for review article.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable for the present study as no new data was created or analyzed.

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