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Aquaculture's Climate Crisis: Navigating Risks and Rewards

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SUMMARY

Aquaculture is poised to meet the increasing global food demand and combat undernourishment, particularly in developing nations, as traditional capture fisheries face declines due to unsustainable practices and climate change. This paper examines the critical climate-related challenges to aquaculture, including greenhouse gas emissions, rising sea temperatures, ocean acidification, sea level rise, changes in sea surface salinity, shifting rainfall patterns, uncertainty of external input supplies, severe climatic events, diseases and harmful algal blooms. Each challenge is accompanied by potential opportunities for aquaculture, such as the cultivation of new species, reliance on hatcheries, and development of saline-tolerant species. Adaptation strategies include better feeds, selective breeding, integrated systems like recirculating aquaculture systems (RAS), biofloc technology, and aquaponics. The article emphasises the need for innovative approaches and effective mitigation measures to ensure sustainable aquaculture expansion and its vital role in feeding the growing global population amidst climate change.

INTRODUCTION

According to FAO (2024), 600 million people are undernourished worldwide. With the global population expected to reach 8.5 billion by 2030, aquaculture offers a sustainable solution to growing food demand and undernourishment, particularly in developing nations. Aquaculture's importance is rising as capture fisheries decline due to unsustainable practices and climate change. In 2022, aquaculture surpassed capture fisheries for the first time, producing 94.4 million tons (51%) of the global 185 million tons of fish. The critical challenge is whether aquaculture can sustainably and rapidly expand to meet future needs amid a fast-growing population and climate change. Climate change, driven by human activities like burning fossil fuels and deforestation, leads to the accumulation of greenhouse gases (CO2, CH4, N2O, and fluorinated gases), altering temperature, precipitation, humidity, and sea levels. This article highlights climate concerns related to aquaculture and its mitigation measures.

Major climate concerns in Aquaculture

a) Green House Emission Gases (GHGs): Greenhouse gases trap more solar energy, causing oceans to absorb excess heat, leading to higher ocean temperatures, melting ice caps, and rising sea levels. Stronger tropical storms and altered global climate patterns are caused by warmer waters, which also cause fish populations to migrate in search of warmer temperatures. This ultimately disturbs the availability of fish seeds for brackish water aquaculture.

b) Sea surface temperature: Hamdan *et al.* predicted that a 1.5℃ rise in global temperatures this century may increase mortalities, especially in cold-water species like Atlantic halibut, salmon, cod, and intertidal shellfish due to thermal stress. Rising ocean temperatures and acidification weaken the ocean's carbon sink, alter water hydrology, and increase red tides. These changes raise management costs and reduce productivity, threatening aquaculture's economic and social sustainability. Thermal stratification in deep waters may disrupt nutrient distribution, and upwelling events could cause severe economic losses for open-water aquaculture producers.

Opportunities: However, warmer periods (within the limits of species tolerance) can encourage the growth of warmer-water species like tilapia, mussels, oysters, and giant tiger prawns. This can also enable the cultivation of new species and genetic improvements, enhancing sustainability.

c) Ocean acidification: Ocean pH will decrease from 8.2 to 7.8 by 2100, which might cause acidification to increase twofold or threefold and impact seafood supply in the future. Around 50 times as much CO_2 is stored in the oceans as there is in the atmosphere, and when global warming rises to 1.5°C or more, increased CO_2 uptake would negatively impact the growth, development, calcification, survival, and abundance of many aquatic species (IPCC, 2019).

Opportunities:

One benefit of ocean acidification is that large-scale aquaculture producers may become entirely or partially dependent on hatcheries to produce spats, which might result in enormous financial advantages for the hatchery owners when wild spat collections are impacted by coral reef bleaching.

d) Sea Level Rise: T

he sea level has been rising at an alarming rate of 3.7 mm/year and is expected to reach 11 mm/year between 2081 and 2100 due to global warming and glacier melting. Sea level rise threatens several coastal ecosystems, including salt marshes and mangroves, which are essential for preserving wild fish populations and providing seed for aquaculture. Inland and marine aquaculture output may be threatened by changes in species composition, organism abundance and distribution, ecosystem productivity, and phenological shifts brought on by rising sea levels.

Opportunities:

Rising sea levels might expand regions suited for high-value brackish water species cultures, such as mud crabs and shrimp. This could help ensure the sustainability of aquaculture output by creating new options, especially for coastal communities.

f) Changes in Rainfall Pattern:

Rainfall patterns that shift will have two directly opposing effects on aquaculture productivity and sustainability: periods of high or no rainfall (called flooding) and periods of low or no rainfall (called drought). The hazards to production in lowland areas will rise with increased rainfall, especially if it falls in the form of heavier events. These hazards consist of fish loss from ponds during floods, invasion of undesired species, and wall erosion and water intrusion into the pond.

Opportunities:

However, flooding may expand the land used for aquaculture production in underproductive areas, especially for pond-based systems. When it comes to droughts, it might encourage advancements in wastewater treatment. For instance, inland saline aquaculture is carried out in Australia, Israel, and India in saline-affected inland state lands primarily formed by drought.

g) Uncertainty of External Input Supplies:

The main external input sources for aquaculture production are agriculture and capture fisheries. The quantity and distribution of fish species in capture fisheries will change due to climate change, which will substantially influence fishmeal and fish oil supplies. Agriculture is currently the primary source of components for aquatic animal diets that meet energy requirements, and it is expected to become the primary source of protein sources in the future due to the decline in fish harvests from capture fisheries. Even now, there has been a growing shift in the production of cereals and soybeans toward aquaculture to produce feed. But now the Agricultural output is also vulnerable to the effects of climate change, which means that the availability of inputs needed to maintain aquaculture production is also in danger.

Opportunities:

However, the growing costs of fishmeal and fish oil will probably accelerate the advancement of research projects that look for different sources of protein and oil to replace traditional aquafeed constituents. Plant proteins, mostly oilseeds from agriculture, have recently gained much interest as potential aquaculture protein sources. To maintain the aquaculture industry, it is now necessary to substitute alternative ingredients for fishmeal and fish oils in feed formulations.

h) Severe Climatic Events:

According to reports, extreme weather events, including storms, waves, and cyclones, are predicted to impact aquaculture development, particularly for marine ornamental goods and those produced near coasts.

Opportunities:

However, because thermal stratification confines nutrients and water to specific columns, extreme weather events like storms are expected to promote aquaculture production's environmental sustainability. Furthermore, storms might be critical in lowering water temperatures and hazards that may harm cultivated and wild creatures.

i) Diseases and Harmful algal blooms

Shifting temperature regimes can potentially impact aquaculture diseases, including bacterial, parasitic, viral, and fungal infections, but they will probably do so unpredictably. It is always possible that rising temperatures could lead to the emergence of exotic diseases and that species that have been cultivated could become more prone to illness when exposed to heat-stress conditions.

Opportunities:

The steady increase in water temperature each day may eventually eliminate cold-water pathogens. Research on breeding to produce disease-tolerant organisms for culture may rise.

Table 1- Impact of Climate Change in Aquaculture

Culture system	Climate risk	Water risk due to climate change	Mechanism of impact
Earthern ponds	Tropical storms that provide 3 to 5 days of rain to the surrounding watercourse catchment	Floods overflow into the pond.	Pond Fishes escape; invasion of exotic species; damage to ponds and equipment.
	large storm systems with heavy, continuous clouds	Low water DO concentrations.	Low photosynthesis during the day causes low DO levels at night, which can stress or kill fish.
River-based cage aquaculture	Bringing 3–5 days of rain in upstream catchment due to tropical storms	High river discharge and bank overflow floods	Fish swim until tired; cages get damaged, displaced, and distorted.
	Intense rainfall during the first rain after a dry period	Heavily sedimented or polluted runoff	Due to low water quality, fish are stressed, become more susceptible to disease and eventually die.
	Late start to the wet season, which causes drought	Water exchange is limited due to shallow, slow-moving rivers.	Effective fish densities increase, and low flows lead to poor water quality, fish stress and death.
Reservoirs	Seasonal transition into excellent/dry season; windy conditions	Thermal stratification causes low DO levels in deeper waters	Fish are exposed to low-DO stress because of thermal destratification after mixing.
	Low rainfall at the end of the wet season or late start to monsoon	Drought	Cages are Forced to relocate into less ideal, denser areas with a chance of poor water quality.
Hatcheries	Overall, warmer conditions will present in already high average temperature periods.	High water temperatures in tanks	Overly rapid egg or young development
	Cold spells	Cause sudden thermal destratification, which causes low DO to move to the surface	reduces fish growth and nutrition in all culture systems and makes hatchery breeding more difficult.

Adaptations to climate change in aquaculture

The adaption to the issues caused by climate change in aquaculture is displayed in the following table 2.

Table 2- Solutions to the Climate change problems in Aquaculture

Climate change problems	Solutions
Rise in temperature above the optimal range of tolerance	Better feeds; selective breeding for higher temperature tolerance
Limitations on fishmeal & fish oil supplies; increase in fishmeal feed price	Fishmeal & fish oil replacement; new forms of feed management; shift to non-carnivorous commodities
The availability of wild seed stocks is reduced, or the availability period is changed.	Shift to artificially propagated seed; extra cost.
Saltwater intrusion	Shift upstream stenohaline species- costly; new euryhaline species in old facilities.
Droughts and heavy rainfall	Shift from earthen pond culture to RAS, Bio floc system, IMTA, Aquaponics.
Thermal stratification	Increase aeration system
Oceanic acidification	Integrated mangrove shrimp culture (silvo aquaculture)

CONCLUSION

Aquaculture offers a sustainable solution to global food demand and undernourishment, especially as capture fisheries decline due to unsustainable practices and climate change. However, its expansion threatens climate-related challenges such as greenhouse gas emissions, rising sea temperatures, ocean acidification, and severe weather events. Despite these risks, there are opportunities for cultivating new species, improving hatchery reliance, and innovating aquaculture practices. Effective adaptation strategies, including better feeds, selective breeding, and integrated systems, ensure the industry's sustainable growth and role in feeding the growing global population.

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