Climate Change and Its Impacts on Global Fisheries and Aquaculture

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Introduction

Global fisheries and aquaculture constitute a crucial pillar of food security for billions worldwide. According to the Food and Agriculture Organisation of the United Nations (FAO), over 3.3 billion people rely on fish as a vital source of animal protein, while more than 600 million derive their livelihoods from this sector along the value chain. However, these aquatic systems are increasingly under pressure from anthropogenic climate change. The Intergovernmental Panel on Climate Change (IPCC) reports that the global average temperature has already risen by approximately 1.1°C above pre-industrial levels. More than 90% of the excess heat generated by greenhouse gas emissions is absorbed by the oceans. Consequently, ocean warming, acidification, rising sea levels, and shifting circulation patterns have begun to alter the physical and chemical properties of marine environments at a pace that many species cannot adapt to. The effects are already evident: coral reef bleaching occurs alongside poleward shifts in the distribution of key fish species, the collapse of fisheries in warmer waters, harmful algal blooms, and widespread mortality in aquaculture systems. Existing stressors—such as overfishing, habitat destruction, pollution, and eutrophication—interact with these climate-related impacts, exacerbating the threats to aquatic biodiversity and food production. This article synthesises the current scientific understanding of climate impacts on fisheries and aquaculture, with the aim of informing researchers, policymakers, and practitioners about the imminent challenges and potential pathways toward a resilient future for aquatic food systems.

Ocean and Freshwater Warming

Ocean surface temperatures have risen by an average of 0.11°C per decade since 1971, with the pace of warming accelerating in recent years. Freshwater bodies have experienced similar or even more rapid increases; for instance, some lakes have recorded temperature rises of 0.3°C per decade. These thermal changes are reshaping the vertical stratification of water columns, reducing habitat space for cold-water species and disrupting the timing of food webs. The synchrony between primary production, zooplankton blooms, and fish spawning has developed over millennia, but these established patterns are now under threat. For ectothermic organisms like fish, temperature plays a critical role in regulating physiological processes such as metabolism, growth rate, immune response, reproductive output, and oxygen uptake. Even slight increases in temperature can drive species beyond their thermal limits, ultimately impairing reproduction and survival. Species that are adapted to narrow temperature ranges, such as salmonids and coral reef fish, are particularly vulnerable to these changes.

Ocean Acidification

The oceans have absorbed approximately 30% of the carbon dioxide (CO_2) emissions produced by human activity since the Industrial Revolution. This absorption has led to a measurable decline in seawater pH, a phenomenon known as ocean acidification. Since pre-industrial times, the average ocean pH has decreased from 8.2 to 8.1, indicating a 26% increase in hydrogen ion concentration. As a result, many calcifying organisms—such as corals, oysters, mussels, sea urchins, and pteropods—are facing challenges in building and maintaining their shells and skeletons. The deterioration of coral reefs is particularly concerning, as these ecosystems are vital, supporting an estimated 25% of all marine species. In the context of aquaculture, acidification poses a threat to larval survival and weakens the shells of commercially significant bivalves, which can subsequently increase production costs and threaten entire operations. Additionally, fish larvae exposed to acidified waters exhibit neurological and sensory disturbances, impairing their ability to evade predators and locate suitable habitats.

Changes in Fish Productivity and Abundance

Projections from climate-fisheries models indicate a decline in catch potential under high-emission scenarios (RCP 8.5). By mid-century, global marine fisheries catches could decrease by 3–25%, with tropical regions potentially experiencing even greater losses of up to 40–60%. The factors contributing to these declines are multifaceted. Environmental conditions significantly impact fish reproduction, with temperature serving as a crucial cue for gonadal maturation, migration, and spawning. In response to rising temperatures, many species are spawning earlier, which often leads to mismatches between larval hatching and the peaks of zooplankton availability. Such mismatches resemble those observed in terrestrial ecosystems. In freshwater environments, the disruption of thermal stratification in lakes alters spawning habitats for cold-water species such as trout, whitefish, and salmonids, compelling them into increasingly shallow, cooler refuges. The loss of spawning habitats, increased metabolic stress, and a decrease in available prey all contribute to reduced recruitment rates. Poor recruitment years can have lasting effects on populations and fisheries for decades to come.

Impacts on Aquaculture

Aquaculture operations are highly sensitive to fluctuations in water temperature. Species such as Atlantic salmon, rainbow trout, and tilapia experience reduced immune function when subjected to temperatures outside their optimal range, making them more vulnerable to pathogens and decreasing their feed efficiency. Warmer water accelerates pathogen life cycles, thereby increasing disease pressure in aquaculture facilities. In countries like Norway, Scotland, and Chile, salmon aquaculture is already facing significant challenges from sea lice outbreaks, a situation that worsens with rising water temperatures. Additionally, harmful algal blooms (HABs), which are becoming more frequent in warmer, stratified waters due to increased nutrient runoff, lead to catastrophic losses in both shellfish and finfish aquaculture along the Atlantic and Pacific coasts.

Over half of global aquaculture production by volume comes from freshwater sources, with carp, tilapia, catfish, and other warm-water species dominating in Asia. This sector is also confronting urgent climate challenges. Extreme rainfall can inundate ponds, releasing cultured stock and endangering wild fish gene pools, while droughts diminish freshwater availability for ponds and recirculating systems. In Bangladesh, Vietnam, and other low-lying delta regions, saltwater intrusion—exacerbated by sea-level rise and decreased river flows—turns freshwater areas brackish, necessitating costly species shifts or rendering aquaculture land unusable. These changes in water conditions pose a direct threat to the livelihoods of millions of smallholder aquaculture farmers, the majority of whom are located in developing countries.

The aquaculture industry's dependence on fishmeal and fish oil sourced from wild forage fisheries presents a significant vulnerability. Key species such as anchovies, sardines, and herrings supply the majority of marine ingredients in aquaculture feeds. However, these stocks are highly sensitive to climate-related changes in ocean conditions, including phenomena like El Niño and the Pacific Decadal Oscillation cycles. As a result, forage fish stocks have become increasingly unstable and unpredictable in the face of climate change, leading to greater volatility in both the cost and availability of aquaculture feeds. Additionally, crops like soybean and maize, which serve as alternative feed sources, are also susceptible to climate-related disruptions. These developments introduce vulnerabilities throughout the food system. To address these challenges, there is a need for integrated supply chain management and the advancement of climate-resilient feed alternatives.

Climate-Smart Aquaculture

Developing climate-smart aquaculture necessitates investments across multiple areas. Selective breeding can yield strains with enhanced thermal tolerance, disease resistance, and feed efficiency, thereby decreasing biological vulnerability. Expanding the diversity of cultured species to include more seaweed, bivalves, and low-trophic finfish mitigates environmental impact and climate risk. Relocating facilities to deeper, cooler waters or implementing real-time monitoring systems allows operators to better manage heat stress. Although recirculating aquaculture systems (RAS) require substantial energy, they offer strong environmental control, insulating production from climate variability. Additionally, investing in innovative feed technologies—such as insect meal, single-cell proteins, and algae-based ingredients—can decrease reliance on climate-vulnerable forage fish.

Policy Frameworks and International Cooperation

A comprehensive response to the impacts of climate change on fisheries necessitates coherent policy integration across multiple sectors. This integration encompasses fisheries management, climate adaptation, food security, and rural development. The United Nations Sustainable Development Goals (SDGs)—notably SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 14 (Life Below Water)—provide a strategic framework for this purpose. However, policymakers have not yet succeeded in translating these goals into binding policies and financial commitments. It is essential for nations to collaborate in managing shared and migratory fish stocks that are affected by climate change. Coastal states should specifically establish fisheries adaptation targets and secure adequate climate financing for fisheries in developing countries within their updated UNFCCC commitments (Nationally Determined Contributions, NDCs). The blue economy framework, which harmonizes conservation efforts with sustainable use in national planning, offers a promising approach to align adaptation strategies with economic objectives.

Conclusion

Climate change presents an immediate and escalating crisis for fisheries and aquaculture rather than a distant threat. The combined effects of ocean warming, acidification, deoxygenation, altered hydrology, and extreme weather events are reshaping aquatic ecosystems from the poles to the tropics, leading to significant negative impacts on biodiversity, productivity, food security, and livelihoods. Addressing this challenge requires urgent, transformative action on two concurrent fronts: deep and rapid decarbonization of the global economy to limit warming to 1.5°C, alongside ambitious and well-resourced adaptation of fisheries and aquaculture systems to the changes that are already unavoidable. Neither approach alone is adequate; mitigation without adaptation neglects the damage that is currently occurring, while adaptation without mitigation is akin to combating an ever-receding shoreline. Aquatic food systems hold considerable potential to contribute to feeding a growing global population with a minimal environmental footprint — provided that the species, ecosystems, and communities that support them are safeguarded. Realising this future necessitates the integration of climate science into all levels of fisheries governance, empowering coastal communities to act as stewards of their resources, and acknowledging at the highest levels of international policy that the well-being of the world's oceans and freshwater bodies is intrinsically linked to human prosperity.

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