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Review Article

Climate Change Challenges on Fisheries and Aquaculture

Abstract

Climate change poses new challenges to the sustainability of fisheries and aquaculture systems, with serious implications for the 520 million people who depend on them for their livelihoods and the nearly 3 billion people for whom fish is an important source of animal protein [1]. Two-thirds of all reefs are in developing countries, and 500 million people in the tropics depend heavily on reefs for food, livelihoods, protection from natural disasters and other basic needs. For many coastal communities in reef areas, fishing activities are the sole source of income. Climate changes may affect fisheries and aquaculture directly by influencing fish stocks and the global supply of fish for consumption, or indirectly by influencing fish prices or the cost of goods and services required by fishers and fish farmers. Potential loss of species or shift in composition for capture fisheries and impacts on seed availability for aquaculture, changes in precipitation and water availability are major impacts of climate change. Climate change lowers water quality causing more disease and increased competition with other water users which altered and reduced freshwater supplies with greater risk of drought. Fishing communities that depend on inland fisheries resources are likely to be particularly vulnerable to climate change. Higher inland water temperatures may reduce the availability of wild fish stocks by harming water quality, worsening dry season mortality, bringing new predators and pathogens, and changing the abundance of food available to fishery species.

Introduction

Climate change is projected to impact broadly across ecosystems, societies and economies, increasing pressure on all livelihoods and food supplies, including those in the fisheries and aquaculture sector. There is an urgent need to better understand where climate change is most likely to reduce livelihood options for fishers and where there is the greatest need to invest in alternative rural and urban enterprises.

The International Food Policy Research Institute [2] examines scenarios, results and policy options to promote sustainable food production in an era of climate change. The report suggests that the negative impacts of climate change on food security could be mitigated by improved agricultural productivity, broad economic growth, and robust international trade to counter regional food shortages [3]. Fish is the main source of animal protein for 3 billion people worldwide. As well as providing a valuable protein complement to the starchy diet common among the global poor, fish is an important source of essential vitamins and fatty acids. Some 520 million people and their dependants worldwide, most of them in developing countries, live by fishing and aquaculture. Fish provides an important source of cash income for many poor households and is a widely traded food commodity. In addition to stimulating local market economies, fish can be an important source of foreign exchange. Fishing is frequently integral to mixed livelihood strategies, in which people take advantage of seasonal stock availability or resort to fishing when other forms of food production and income generation fall short.

Two-thirds of all reefs are in developing countries, and 500 million people in the tropics depend heavily on reefs for food, livelihoods, protection from natural disasters and other basic needs. People living in the coastal zone are often poor and landless, with limited access to services, and hence vulnerable to impacts on natural resources [4]. For many coastal communities in reef areas, fishing activities are the sole source of income. Higher sea temperature is a major cause of coral bleaching and damage to reef ecosystems around the globe [5]. The bleaching event of 1998, driven by El Niño, a global coupled ocean-atmosphere phenomenon that changes the location and timing of regional ocean currents and causes important inter-annual variability in sea surface temperature, killed an estimated 6% of the world's coral. Studies suggest that 60% of coral reefs could be lost by 2030 and that both increasing ocean temperatures and increased acidification of oceans from higher levels of atmospheric carbon dioxide may be a contributing factor.

Changing sea temperature and current flows will bring shifts in the distribution of marine fish stocks, with some areas benefiting while others lose. Fishers need to reduce their reliance on a narrow resource base by learning to exploit a broader range of species and diversify their sources of income.

Climate change related stressors of aquatic ecosystems

Rising sea level: Mean sea level is predicted to rise between 0 and 90 centimeters during this century, with most predictions in the range of 30-50 centimeters [6]. This will damage or destroy many coastal ecosystems such as mangroves and salt marshes, which are essential to maintaining wild fish stocks, as well as supplying seed to aquaculture. Mangroves and other coastal vegetation buffer the shore from storm surges that can damage fish ponds and other coastal infrastructure and may become more frequent and intense under climate change. United Nations environmental protection (UNEP) estimates the annual ecosystem value of mangroves at US$200,000-US$900,000 per square kilometer [6]. A number of studies have identified possible adaptation strategies for mangrove systems and the people that use them.

Inland temperature changes: Higher inland water temperatures may reduce the abundance and distribution of wild fish stocks by reducing water quality, increasing dry season fish mortality, introducing new predators and pathogens, and changing the prey abundance for fishery species. In Lake Tanganyika, which supplies up to 25% of animal protein for the countries that surround it, mixing of surface and deep water layers has become reduced over the last century as a result of higher temperatures. This has limited the nutrients available to plankton and thereby reduced yield in planktivorous fish by an estimated 30%.

Changes in precipitation and water availability

The most significant drivers of change in inland aquaculture and fisheries will be the floods and droughts that result from increasing seasonal and annual variability in precipitation. Bangladesh, one of the world's least developed nations, relies on fisheries for around 80% of its national animal protein intake. Under the scenario of 2-6°C global warming, precipitation is forecast to decline in Bangladesh during the dry season and increase during the wet season, expanding flood-prone areas by 23-39% [7]. While a relationship exists between greater flooding extent and higher production in many floodplain fisheries, potential benefits may be offset by a range of factors, including reduced spawning success of river fishes as a result of higher wet season river flows, reduced fish survival in lower dry season flows, and loss of habitat to new hydraulic engineering projects and other human responses. In shallow African lakes such as Mweru WaNtipa, Chilwa/ Chiuta and Liambezi, water level is the most important factor determining stock size, and catch rates that could decline when the lake levels are low.

Reduced annual and dry season rainfall, and changes in the duration of the growing season are likely to have implications for aquaculture and create greater potential for conflict with other agricultural, industrial and domestic users in water - scarce areas. These impacts are likely to be felt most strongly by the poorest aqua culturists, whose typically smaller ponds retain less water, dry up faster, and are more likely to suffer shortened growing seasons, reduced harvests and a narrower choice of species for culture. However, aquaculture may also provide opportunities for improving water productivity in areas of worsening water scarcity.

Impact of climate change stressors on fisheries and aquaculture

Climate changes may affect fisheries and aquaculture directly by influencing the abundance and distribution of fish stocks and the global supply of fish for consumption, or indirectly by influencing fish prices or the cost of goods and services required by fishers and fish farmers. Changes in sea surface temperature can produce more frequent harmful algal blooms, less dissolved oxygen, increased incidence of disease and parasites, altered local ecosystems with changes in competitors, predators and invasive species, and changes in plankton composition. For aquaculture, changes in infrastructure and operating costs from increased infestations of fouling organisms, pests, nuisance species and/or predators. For capture fisheries, impacts on the abundance and species composition of fish stocks. In most African Lakes, which supplies more of animal protein for the countries that surround it, mixing of surface and deep-water layers has become reduced over the last century as a result of higher temperatures. This limits the nutrients available to plankton and reduces yield in planktivorous fish [8].

Enhanced primary productivity may lead to potential benefits for aquaculture and fisheries may be offset by changing species composition, influencing the timing and success of migrations, reducing spawning success, and changing sex ratios. Coral reefs that serve as breeding habitats and help protect the shore from wave action will be impacted. Its exposure to which may rise along with sea levels, reduced recruitment of fishery species. Worsened wave damage to infrastructure or flooding from storm surges. El Niño-Southern Oscillation Changed location and timing of ocean currents and upwelling alters nutrient supply in surface waters and, consequently, primary productivity [9].

Climate change changes in the distribution and productivity of open sea fisheries. Changed ocean temperature and bleached coral reduced productivity of reef fisheries. Altered rainfall patterns bring flood and drought. Rising sea level loss of land reduced area available for aquaculture. Loss of freshwater fisheries, changes to estuary systems impacted on shifts in species abundance, distribution and composition of fish stocks and aquaculture seed. Salt water infusion into groundwater, damage to freshwater capture fisheries and reduced freshwater availability for aquaculture could have a shift to brackish water species. Loss of coastal ecosystems such as mangrove forests reduced recruitment and stocks for capture fisheries and seed for aquaculture. Worsened exposure to waves and storm surges and risk that inland aquaculture and fisheries become inundated. Higher inland water temperatures increased stratification and reduced mixing of water in lakes, reducing primary productivity and ultimately food supplies for fish species. Raised metabolic rates increase feeding rates and growth if water quality, dissolved oxygen levels, and food supply are adequate, otherwise possibly reducing feeding and growth.

Shift in the location and size of the potential range for a given species will result in potential loss of species and alteration of species composition for capture fisheries. Reduced water quality, especially in terms of dissolved oxygen; changes in the range and abundance of pathogens, predators and competitors; Invasive species introduced, altered stocks and species composition in capture fisheries. Changes in precipitation and water availability, changes in fish migration and recruitment patterns can again impacts on altered abundance and composition of wild stock as a result impacts on water and seed availability for aquaculture. Lower water quality causing more disease and increased competition with other water users this altered and reduced freshwater supplies with greater risk of drought which ends up with higher costs of maintaining pond water levels and stock loss consequently reduced production capacity. Conflict with other water users and change of culture species occurred. Changes in lake and river levels and the overall extent and movement patterns of surface water altered distribution, composition and abundance of fish stocks as a result fishers forced to migrate more and expend more effort.

Many fishers and aqua culturists are poor and ill-prepared to adapt to change, making them vulnerable to impacts on fish resources. Fisheries and aquaculture are threatened by changes in temperature and, in freshwater ecosystems, precipitation. Storms may become more frequent and extreme, imperiling habitats, stocks, infrastructure and livelihoods.

Wider implications of the impacts of climate variation on fisheries

Many artisanal fishers are extremely poor. Even in cases where they earn more than other rural people, fishers are often socially and politically marginalized and can afford only limited access to healthcare, education and other public services. Social and political marginalization leaves many small-scale and migrant fishers with little capacity to adapt, and makes them highly vulnerable to climate impacts affecting the natural capital they heavily depend on for their livelihoods. Heightened migration to cope with and exploit climate-driven fluctuations in production may worsen a range of cultural, social and health problems [4]. HIV/AIDS is prevalent in many fishing communities and this problem will worsen as climate change forces increased migration and social dislocation. As declining catches worsen poverty and food shortages, desperate people become less risk averse. Transactional sex, in which women fish traders around Lake Victoria, for example, trade sex for fish will become an increasingly important vector for the transmission of HIV/AIDS [1].

Recent stern review on the Economics of Climate Change states, "For fisheries, information on the likely impacts of climate change is very limited." Efforts to increase understanding of how and why climate change may affect aquaculture and fisheries should emphasize developing strategies by which fisheries, and perhaps more significantly aquaculture, can play a part in our wider adaptation to the challenges of climate change. However, the inherent unpredictability of climate change and the links that entwine fishery and aquaculture livelihoods with other livelihood strategies and economic sectors make unraveling the exact mechanisms of climate impacts hugely complex. This argues for placing a very strong focus on building general adaptive capa city that can help the world's poor fishing and aquaculture communities cope with new challenges, both foreseen and not.

Extreme events and worsening risk

Extreme events such as cyclones and their associated storm surges and inland flooding can have serious impacts on fisheries, and particularly aquaculture, through damage or loss of stock, facilities and infrastructure. Institutional responses such as constructing artificial flood defenses and maintaining natural ones can provide protection that is significant but incomplete. Poor communities in exposed areas are unlikely to be able to build substantial defenses, so the most realistic and economic strategy will be to increase resilience. In Bangladesh and other countries where floods are common, short culture periods and minimal capital investment in aquaculture help reduce stock loss and associated cost. Building greater adaptive capacity will entail approaches, such as mixed livelihood strategies and access to credit, by which aqua culturists can cope financially with sudden losses of investment and income. Other considerations for coping strategies in high-risk areas include monitoring and assessing risk and promoting aquaculture species, fish strains, and techniques that maximize production and profit during successful cycles.

Diagnosing vulnerability to climate change

The vulnerability of fishery- and aquaculture-dependent communities and regions to climate change is complex, reflecting a combination of three key factors: the exposure of a particular system to climate change, the degree of sensitivity to climate impacts, and the adaptive capacity of the group or society experiencing those impacts. Vulnerability varies greatly across production systems, households, communities, nations and regions. It is influenced by changing demographics, the degree of market globalization and emerging agricultural development policy. Poor and marginalized groups, including women, are likely to be the most vulnerable because climate change will likely exacerbate the unequal access to natural resources, productive assets, information and technology that already exists [10]. Developing policies and strategies to address climate change impacts on fisheries and aquaculture depends on identifying vulnerable places and people and understanding what drives their vulnerability. This requires vulnerability assessment at multiple scales and taking into account multiple interacting drivers. Key questions that need to be addressed include the following [1].

What is the nature and extent of vulnerability among fishery- and aquaculture-dependent communities and regions to specific climate-related threats?

How do other drivers of change influence vulnerability to climate change?

Out puts of research to answer these questions will be vulnerability maps that identify 'hotspots' and most affected people. These maps can be used to guide investments in adaptation. Understanding climate vulnerability in the context of other drivers helps to prioritize climate-related actions and inform programs to mainstream climate change responses in other development policy and planning activities. Two thirds of the nations most vulnerable to climate change are in Africa, where fish provides more than half of the animal protein consumed in some countries [6]. Inland and coastal waters are highly sensitive to climatic variation, and adaptive capacity is low.

Understanding current coping mechanisms and adaptive responses

The identification and promotion of aquaculture species and techniques that are suitable to changing environments and resources may offer new uses for land that has become unsuitable for existing livelihoods strategies and will enable aqua culturists to adapt to change. In cooler zones aquaculture may benefit from faster growth rates and longer growing seasons as a result of rising ambient temperatures. Schemes that integrate pond aquaculture with traditional crops in Malawi have successfully reduced farmers' vulnerability to drought, provided a source of high-quality protein to supplement crops, and boosted overall production and profit. In terms of water use efficiency, systems that reuse water from aquaculture compare very favorably with terrestrial crop and livestock production.

Policies enabling adaptation to climate change can be guided by an understanding of the complex ways in which fisheries and aquaculture have responded to past climate variability as well as other 'shocks'. Examining the responses of fishing communities to natural disasters, in particular the responses of women and the poor, can aid understanding of which measures may reduce vulnerability and enhance resilience in the face of future climate impacts. Key research questions that need to be addressed include the following [11].

To what extent do current successful responses to climate variability confer resilience to future climate change?

What are the known limits to adaptation based on analysis of adaptation failures following natural disasters or multiple stresses?

Under what conditions do short-term coping mechanisms undermine long-term adaptive capacity?

Research addressing these questions will provide governments, communities and their development partners with a summary of the lessons that fishers and fish-farmers have learnt from past responses to climate variability and other disasters and 'shocks'.

Contributing to mitigation

Agriculture contributes 10-12% of global greenhouse gas emissions, with aquaculture contributing a small but unknown fraction of that. Fishing burns 1.2% of the fossil fuel used globally each year (Tyedmers et al. 2005). While the potential benefit of investing in fishing energy efficiency and emission reduction is minor, the sector does provide opportunities to improve livelihoods and environmental and resource management in ways that mitigate climate change. Market instruments for financing mitigation, such as the Clean Development Mechanism and voluntary carbon markets, may be used to fund work that contributes to the development of sustainable fisheries and aquaculture.

Mitigation strategies for fisheries include promoting the use of fuel-efficient fishing vessels and methods, removing such disincentives to energy efficiency as fuel subsidies, and reducing overcapacity in global fishing fleets, as there are too many boats burning too much fuel to chase too few fish. Aquaculture technologies that reduce energy consumption and optimize the potential for carbon sequestration provide opportunities for mitigation. Similarly, conserving and restoring mangroves sequesters carbon, protects coastlines, and enhances fisheries and livelihoods. Opportunities for funding adaptation through novel schemes that also contribute to mitigation, such as the Reduced Emissions from Deforestation and Degradation scheme for mangroves, should be promoted. In pursuing these mitigation opportunities, key research questions include the following:

3.1 How can fisheries and aquaculture contribute to reducing greenhouse gas sources and emissions?

3.2 What are the opportunities for using aquatic production systems as carbon sinks?

3.3 To what extent can mitigation strategies enhance the sustainability of fisheries and aquaculture?

3.4 What effects, good and bad, will mitigation strategies adopted in other sectors likely have on fisheries and aquaculture?

Research on the potential for fisheries and aquaculture to contribute to mitigation will provide governments, communities and their partners with a range of options for funding adaptation activities, as most mitigation initiatives are linked to markets or global funds. Reducing the carbon footprint of fisheries and aquaculture, as well as making a small contribution to halting climate change, can set an example to other food sectors in commitment to environmentally sustainable production.

Strategies for coping with climate change

Fish can provide opportunities to adapt to climate change by, for example, integrating aquaculture and agriculture, which can help farmers cope with drought while boosting profits and household nutrition. Fisheries management must move from seeking to maximize yield to increasing adaptive capacity. Fish can alleviate poverty and may serve as a vital safety net for people with limited livelihood alternatives and extreme vulnerability to changes in their environment. Fishing communities that depend on inland fisheries resources are likely to be particularly vulnerable to climate change. Globally, aquaculture has expanded at an average annual rate of 8.9% since 1970, making it the fastest growing food production sector. Today, aquaculture provides around half of the fish for human consumption, and must continue to grow because limited — and in many cases declining — capture fisheries will be unable to meet demands from a g rowing population. Integrating aquaculture with agriculture by, for example, raising fish in rice fields or using agricultural waste to fertilize ponds, can provide significant nutritional and economic benefits from available land and resources.

Draft targets for 2020: The so-called "strategic plan" with 20 targets for 2020 is also still under negotiation. To the frustration of for instance the European Union, draft texts that were approved at the last convention on biological diversities (CBD) meetings in Nairobi are again opened up again for changes. Main issues were as follows [12].

Species loss: A target has been formulated to prevent the loss of endangered species and to improve the conservation status of threatened species. This clear goal now needs to be translated into clear accountable actions for individual countries to truly stop the loss in biological diversity.

Ecosystem loss: The level of ambition to reduce the loss of ecosystems is still under negotiation. It is though clear that this target will mainly aim to address the conversion of ecosystems not their degradation. This is a sad outcome as many areas suffer from heavy degradation due, for example to over-harvesting of harvesting wood, overgrazing or drainage. Many areas, although still classified as for example wetland, or forest have lost most of their natural values. In many cases restoration is feasible and worthwhile. The incentive to reduce these stresses is minimal as long as the target just focuses on absolute loss only.

Protected areas: The discussion on how much of terrestrial, inland or marine areas should be protected is still ongoing. The agreed formulation is not to only count protected areas, but also all 'area based conservation measures'. The risk with this formulation is that any area with a minimal level of conservation could count for this target – and yet still progressively degrade.

Climate change: A clear and potentially ambitious target has been agreed on restoring 15% of all degraded areas to enhance their role in terms of climate resillience and carbon strorage. Dependent on the definition of the word ‘degraded’, this target could help the efforts to restore for instance degraded mangrove forests or the deforested peatswamps in Southeast Asia.

Water and biodiversity

Still negotiations are taking place on the role of biodiversity and ecosystems for water provision and regulation; and on water for biodiversity. Wetlands International “Water and biodiversity is a sensitive issue as many countries see water as a national matter. Many do not want to touch the sensitive international dimension of trans boundary water such as the impact of the loss of upland marshes and lakes for countries downstream”.

A draft text on ecosystem services mentions the role of ecosystems for water. It is a small step to get water on the agenda of the Convention. The complete picture on the final and approved targets will remain unclear till the end of the convention meeting. Even then, important rounds of negotiations will follow to make the abstract targets measurable, with clear commitments for individual countries [12]. Wetlands International: “*Ambitious, approved targets on biodiversity are crucial to commit countries to actions for saving biodiversity. Biodiversity loss at this moment is now posing risks to society through reduced services such as food and water security*”. According to the Intergovernmental Panel on Climate Change (IPCC), science now allows to estimate greenhouse gas emissions from wetlands. This breakthrough was presented there by the IPCC at the UN climate conference (UNFCCC) in Cancun (Mexico). This conclusion is crucial for allowing countries to reduce their emissions through rewetting drained wetlands [13]. During the UNFCCC COP 15 in Copenhagen, the Global Partnership on Climate, Fisheries and Aquaculture (PaCFA) hosted a side event at the European Environment Agency on “Fisheries, aquaculture and aquatic systems in a changing climate”. The event, organized by the European Bureau for Conservation and Development, a member of PaCFAA, made a deeper look at the implications of climate change on the sustainability of fisheries and aquaculture and its impacts on food and livelihood security.

Building the capacity to respond and adapt

Reducing vulnerability in fisheries and aquaculture urgently requires the application of adaptation and mitigation options at appropriate scales. Their effectiveness depends on building community and national capacity to respond to changes and on mainstreaming climate change adaptation in policies regarding natural resource management and development. A broad range of activities are required, ranging from building climate monitoring and forecasting capacity, to applying forecasts to aid disaster prevention, and to develop capacity for policy implementation and technological innovation to address adaption in aquaculture systems. By directly managing fish production, aquaculture has the potential to improve adaptive capacity and enhance resilience to climate change in vulnerable communities, compensating for variability and decline in capture fisheries exacerbated by climate change [14]. However, aquaculture depends heavily on fishmeal feeds derived from small, wild-caught pelagic fish and on wild-caught larvae for seed. The stocks of both are sensitive to climate change. Adaptation strategies must include a search for fishmeal substitutes and ways to culture species in hatcheries that previously depended on wild seed. Developing the capacity of national innovation systems in aquaculture will both aid the sectors’ adaptation to climate change and keep it competitive in the context of changing markets.

Building adaptive capacity to respond to climate change also involves strengthening the ability of the fishers and fish farmers to respond to current climate threats. Indeed, some areas where aquaculture and fisheries are the most productive and contribute the most to poverty reduction and food security are also the areas most prone to natural disasters caused by extreme weather events and sea level rise. Because these events are forecast to increase in frequency and severity in many parts of the world, and sea level rise is projected to accelerate, it is vital to work with disaster relief agencies and affected communities to develop processes for disaster preparedness and post-disaster rehabilitation of fisheries and aquaculture. Finally, institutions need support to improve their capacity to facilitate the mainstreaming of climate change adaptation into broader fishery and rural development policy. Understanding and addressing the disproportionate effect of climate change on vulnerable groups will be especially important. Towards these goals, fisheries and aquaculture management and research institutions need to engage in global, regional and national policy for that shape thinking and investment in climate change adaptation. In considering these issues, key research questions that need to be addressed include the following:

4.1 How can lessons from individual, household, enterprise and community adaptive responses around the world be effectively shared and applied to build resilience to climate change from the bottom up?

4.2 What policy processes nationally, regionally and globally do fishery and aquaculture agencies need to engage with to finance and implement adaptation?

4.3 How can climate change adaptation and disaster risk management be effectively incorporated into fishery and aquaculture development and management planning?

Research outputs will provide strategies for building adaptive capacity that can be used by governments, communities, or firms to inform their responses to climate change and other drivers. By identifying key policy processes, stakeholders in the fishery and aquaculture sector will have a clearer picture of how to go about getting both technical and financial support for adaptation. By learning from other experiences with mainstreaming, sectoral policies will be more effectively ‘climate-proofed’ and governments will be better able to work with their aquatic resource-dependent citizens to secure the development benefits of fisheries and aquaculture into the future.

Conclusion

Climate change is inevitably a challenge for fisheries and aquaculture. Through rigorous research on impacts, mitigation and adaptation, combined with practical actions locally, nationally, regionally and globally, World Fish aims to provide new knowledge to inform solutions. High-quality research that involves resource users, builds strong partnerships and harnesses political will is crucial for making fisheries and aquaculture systems more resilient to the challenge of global climate change and securing a bright future for the people that depend upon them. Greater climate variability and uncertainty complicate the task of identifying impact pathways and areas of vulnerability, requiring research to devise and pursue coping strategies and improve the adaptability of fishers and aqua culturists.

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