CLIMATE SMART ACTIONS (CSA) AQUACULTURE, AGROFORESTRY AND RESOURCES MANAGEMENT

GLOBAL ISSUES & LOCAL PERSPECTIVES

Edited by

Eteyen E. Nyong

Samuel O. Asagba

Michael K. Watti

Idris Ndagi

G. A. Kalio

Monica Ogochukwu

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Global Issues & Local Perspectives

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Preface

This book adopts an exegetical approach as well as a pedagogic model, making it attractive agriculture and environmental economics teachers, professional practitioners and scholars. It is eschews pedantry and lays bars the issues in such clarity that conduces to learning. The book elaborates on contemporaneous **Climate smart actions (CSA) aquaculture, agroforestry and resources management** issues of global significance and at the same time, is mindful of local or national perspectives making it appealing both to international and national interests. The book explores the ways in which **Climate smart actions (CSA) aquaculture, agroforestry and resources management** issues are and should be presented to increase the public's stock of knowledge, increase awareness about burning issues and empower the scholars and public to engage in the participatory dialogue **Climate smart actions (CSA) aquaculture, agroforestry and resources management** necessary in policy making process that will stimulate increase in food production and environmental sustainability. **Climate smart actions (CSA) aquaculture, agroforestry and resources management :** *Global Issues & Local Perspectives* is organized in three parts. Part One deals with The Concept of **Climate smart actions (CSA)**, Part Two is concerned with The Concept of **aquaculture,** and Part Three deals with the Concept of **agroforestry and resources management**

Eteyen Nyong; March 2026

Chapter 10:

Aquatic Food Systems at the Climate Frontier: Vulnerability, Adaptation, and Resilience in Fisheries and Aquaculture

***Afia, O. Edet and Ekanem, I. Emmanuel**

Department of Fisheries and Aquatic Environmental Management, University of Uyo, Uyo,Nigeria*ofonimeafia@uniuyo.edu.ng* id.ekanem@yahoo.com

ORCID ID: 0009-000-6390-2383; 0009-0005-3580-808X

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1.0 Introduction

Global food systems are experiencing growing pressure from rising demand, environmental degradation, and climate change. Projections indicate that food production must increase substantially in the coming decades to meet population growth, while climate related stressors increasingly threaten the stability of both terrestrial and aquatic food systems. These interacting pressures have intensified interest in production systems that can support food security, nutrition, and livelihoods under changing environmental conditions (FAO, 2022).

Fisheries and aquaculture play an increasingly important role in global food supply, providing a significant proportion of animal protein and supporting millions of livelihoods worldwide. The rapid expansion of aquaculture, in particular, has positioned the sector as one of the fastest growing food production systems. At the same time, fisheries and aquaculture production systems are particularly vulnerable to environmental variability and long term climatic shifts.

Rising water temperatures, ocean acidification, altered hydrological regimes, sea level rise, and the increasing frequency of extreme events are already affecting aquatic ecosystems, with implications for species distribution, productivity, health, and infrastructure.

While climate variability has occurred throughout Earth's history, contemporary climate change is largely driven by anthropogenic greenhouse gas emissions. Recent assessments confirm that warming of the climate system is unequivocal, with oceans absorbing the majority of excess heat, thereby increasing the exposure of aquatic systems to thermal stress and related impacts (IPCC, 2021; IPCC, 2022). These changes have direct and indirect consequences for fisheries and aquaculture, including shifts in suitable production zones, increased disease risk, and greater uncertainty in production outcomes.

In Sub - Saharan Africa, and particularly in Nigeria, climate change has intensified existing vulnerabilities in fisheries and aquaculture systems. Recurrent flooding, drought, coastal erosion, and salinity intrusion have been widely reported, with consequences for inland and coastal production systems, value chains, and livelihoods. Although a growing body of literature has examined climate change impacts on fisheries and aquaculture at global and regional scales, evidence remains fragmented across production systems, species, and geographic contexts.

Despite the growing body of research on climate related stressors affecting aquatic food systems, important gaps remain in understanding how fisheries and aquaculture systems can effectively adapt to rapidly changing environmental conditions. Many existing studies examine climate impacts in isolation without adequately integrating ecological, technological and governance perspectives. This fragmentation limits the development of comprehensive strategies capable of strengthening resilience across fisheries value chains. In regions such as sub-Saharan Africa where fisheries contribute significantly to food security, employment and rural livelihoods, climate related disruptions pose substantial socio-economic risks. Addressing these challenges requires a synthesis of current knowledge on vulnerability, adaptation strategies and emerging technological innovations that can support climate resilient fisheries and aquaculture systems.

Recent global assessments indicate that climate change is already altering fisheries productivity, species distribution and aquatic ecosystem functioning across many regions of the world. Warming waters, ocean acidification, and increasing climatic variability are influencing fish growth, migration patterns and reproductive cycles, particularly in tropical and subtropical waters where fisheries support millions of livelihoods. Studies have also shown that small scale fisheries in developing countries are among the most vulnerable due to limited adaptive capacity, weak governance systems and high dependence on natural resources. Strengthening resilience in aquatic food systems therefore requires integrated strategies that combine ecological management, technological innovation and supportive policy frameworks.

The main objective of this study is to synthesize existing scientific knowledge on climate change impacts on fisheries and aquaculture while identifying strategies that enhance system resilience. Specifically, the study aims to:

1. Examine the major climate change stressors affecting aquatic ecosystems and fisheries production systems.

2. Assess the vulnerability of fisheries and aquaculture to climate variability and environmental change.

3. Review adaptation and mitigation strategies that support climate resilient fisheries management.

4. Highlight emerging technologies, governance approaches and policy frameworks that can strengthen resilience in fisheries and aquaculture systems.

1.1 Methodological Approach

This study adopts a narrative review methodology to synthesize existing literature on climate change impacts and resilience strategies in fisheries and aquaculture systems. Relevant peer-reviewed articles, international reports and policy documents published between 2015 and 2025 were retrieved from academic databases including Web of Science, Scopus, Google Scholar and FAO knowledge repositories. Keywords used in the search included “climate change”, “fisheries resilience”, “aquaculture adaptation”, “ecosystem-based management”, and “climate-smart fisheries”. Sources were screened based on relevance, scientific credibility and contribution to understanding climate impacts, adaptation strategies and governance approaches in aquatic food systems. The selected literature was critically analyzed to identify key trends, emerging technologies, policy frameworks and research gaps.

2.0 Understanding the Impact of Climate Change on Aquatic Ecosystems

Aquatic ecosystems play a fundamental role in regulating the Earth’s climate, sustaining biodiversity, and supporting global food systems. However, these systems are increasingly disrupted by climate change, which is now recognized as one of the most significant drivers of ecological change in marine and freshwater environments. While natural climate variability has occurred throughout Earth’s history, recent warming trends are predominantly driven by anthropogenic greenhouse gas emissions associated with fossil fuel combustion, land-use change, agriculture, and industrial activities (IPCC, 2021).

Oceans absorb more than 90 percent of the excess heat generated by global warming and approximately one quarter of anthropogenic carbon dioxide emissions, making aquatic systems particularly vulnerable to climate stressors (IPCC, 2021; FAO, 2022). Rising water temperatures, ocean acidification, altered circulation patterns, sea-level rise, and increasing frequency of extreme weather events are collectively reshaping aquatic ecosystems. These stressors interact across spatial and temporal scales, producing cumulative and often nonlinear effects on ecosystem structure, function, and productivity.

Thermal stress is among the most pervasive impacts of climate change on aquatic ecosystems. Increasing water temperatures reduce dissolved oxygen availability, alter metabolic rates, and disrupt growth, reproduction, and survival of aquatic organisms. Such changes influence species distribution and recruitment dynamics, with implications for fisheries productivity and ecosystem stability (Pörtner et al., 2021; IPCC, 2022). Cold-water and stenothermal species are particularly vulnerable, while thermal stress can also exacerbate energy trade-offs, reducing investment in growth, immunity, and reproduction.

Ocean acidification represents an additional and closely linked stressor. As atmospheric carbon dioxide concentrations rise, increased absorption by the oceans lowers pH and alters carbonate chemistry, impairing calcification processes in corals, molluscs, and crustaceans. Beyond calcifying organisms, acidification affects behaviour, sensory function, and trophic interactions, with cascading consequences for food webs and carbon sequestration processes (Doney et al., 2020; Bindoff et al., 2022).

Climate-driven changes in precipitation and hydrological regimes further modify aquatic habitats, particularly in rivers, estuaries, and coastal zones. Altered runoff patterns influence water quality, nutrient loading, and habitat availability, indirectly shaping ecosystem productivity and biodiversity. Extreme weather events such as floods, storms, and cyclones increasingly disrupt aquatic ecosystems and fisheries infrastructure, leading to stock losses, habitat degradation, and livelihood insecurity. Although episodic mixing events may enhance nutrient availability, the net effects of climate extremes are largely negative, especially for small-scale and coastal fisheries (IPCC, 2022).

Climate change also affects aquatic ecosystem health through altered disease dynamics. Elevated temperatures and environmental stress weaken host immune responses while enhancing pathogen growth, transmission, and persistence. Evidence indicates increasing frequency and duration of disease outbreaks in both wild and cultured populations, posing major challenges for fisheries sustainability and management (Groner et al., 2021; FAO, 2023).

Sea-level rise presents additional risks to coastal and low-lying ecosystems through habitat loss, salinity intrusion, and infrastructure damage. At the same time, expanding brackish water zones may create new opportunities for certain aquaculture systems, underscoring the spatially uneven distribution of climate impacts (Rowley et al., 2024; IPCC, 2022). However, without appropriate planning, such changes are more likely to exacerbate existing vulnerabilities than generate benefits.

Water quality degradation is another critical pathway linking climate change to aquatic ecosystem decline. Higher temperatures, altered precipitation, and increased carbon dioxide concentrations intensify eutrophication, hypoxia, and acidification, reducing ecosystem resilience and fisheries productivity (Clements et al., 2020; Rodrigues et al., 2023). In contrast, healthy aquatic ecosystems such as mangroves, seagrasses, and wetlands provide essential climate regulation services by sequestering carbon, buffering against extreme events, and improving water quality (UNEP, 2022; FAO, 2024).

Given the scale and complexity of these impacts, climate vulnerability assessments and ecosystem-based management approaches are increasingly recognized as essential tools for identifying at-risk species, systems, and regions. Recent international frameworks, including the Paris Agreement and the Kunming–Montreal Global Biodiversity Framework, emphasize the integration of climate adaptation, mitigation, and biodiversity conservation within fisheries and aquatic resource governance (IPBES, 2022; FAO, 2024).

2.1 Adaptation and Mitigation Strategies in Fisheries

Adaptation and mitigation strategies are central to sustaining fisheries under climate change. Oceans contribute to climate adaptation primarily through coastal ecosystems such as mangroves, coral reefs, and seagrass meadows, which provide natural protection against wave energy, storm surges, and coastal erosion. These ecosystems function as nature-based solutions that complement or, in some cases, replace grey infrastructure such as seawalls and jetties. Mangroves, in particular, enhance coastal resilience by stabilizing shorelines, supporting fisheries productivity, conserving biodiversity, and sequestering significant amounts of carbon. Their protection and restoration are increasingly recognized as cost-effective strategies for climate adaptation and mitigation in coastal fisheries systems (IPCC, 2022; FAO, 2024; UNEP, 2022).

2.2 Climate-Resilient Species Selection and Management

Climate resilience is fundamental to sustaining fisheries production and the livelihoods that depend on it. In fisheries, resilience strategies refer to management and production approaches that enable systems to absorb, adapt to, or recover from climate-induced disturbances. Species and system diversification, including the use of climate-tolerant species and polyculture approaches, has been widely identified as a key adaptation pathway that reduces vulnerability and enhances long-term sustainability (Atroch et al., 2026; FAO, 2022).

Climate change affects fisheries through multiple, interacting stressors, including warming waters, ocean acidification, altered precipitation patterns, sea-level rise, and increased frequency of extreme events. These stressors influence species physiology, habitat suitability, productivity, and disease dynamics. Building climate-resilient fisheries therefore requires approaches that explicitly account for cumulative impacts rather than addressing stressors in isolation (Pörtner et al., 2021).

3.0 Addressing Cumulative Climate Impacts

The cumulative effects of climate change on fisheries include habitat loss and fragmentation, altered hydrological regimes, declining water quality, and increased sediment and contaminant loading. Mitigation strategies aimed at reducing greenhouse gas emissions remain critical, including energy efficiency, transition to renewable energy sources, reduced reliance on fossil fuels, and protection of carbon-rich ecosystems. In fisheries and aquaculture, mitigation also includes improving feed efficiency, reducing waste, and lowering the carbon intensity of production systems (FAO, 2022; Troell et al., 2023).

At the local level, capacity building and access to climate-resilient technologies are essential. Training fisheries stakeholders in adaptive management, early warning systems, and ecosystem-based approaches enhances their ability to respond proactively to climate risks.

3.1 Sustainable Fisheries Practices under Climate Change

Sustainable fisheries management remains a cornerstone of climate adaptation. However, climate change necessitates dynamic and flexible approaches, including adaptive catch limits, spatially *responsive management as species distributions shift, and ecosystem-based fisheries management. Tools such as harvest control rules, fishing quotas, and gear regulations that allow juvenile escape contribute to stock resilience by maintaining reproductive capacity and genetic diversity (Hilborn et al., 2020; FAO, 2023).

Failure to address overexploitation and habitat degradation can erode stock resilience, reduce ecosystem stability, and increase vulnerability to climate variability. Sustainable management therefore plays a dual role by supporting both climate adaptation and long-term productivity.

3.2 Integrating Resilience into Fisheries Governance

Resilience-based fisheries management emphasizes the capacity of socio-ecological systems to absorb shocks while maintaining essential functions. Effective fisheries governance increasingly requires integration of ecological resilience with social and economic dimensions, recognizing that fish stocks, ecosystems, and fishing communities are interdependent (Folke et al., 2021; IPBES, 2022).

Resilient fisheries systems are characterized by healthy fish stocks, diversified livelihoods, adaptive institutions, and sustained ecosystem services. Management actions that enhance resilience include protecting habitat diversity, maintaining stock structure, and strengthening community adaptive capacity. Such approaches align closely with global policy frameworks promoting climate-resilient food systems and sustainable ocean use.

4.0 Innovative Technologies for Climate-Resilient Fisheries

Emerging technologies are becoming central tools for strengthening adaptive capacity in fisheries and aquaculture systems. Systems such as recirculating aquaculture systems, integrated multi-trophic aquaculture, and aquaponics improve resource efficiency, reduce environmental impacts, and enhance resilience to climate variability. These systems allow greater control over production conditions, reduce water use, and lower nutrient emissions, making them increasingly attractive under changing climatic conditions (Troell et al., 2023; FAO, 2024).

Digital technologies are also transforming fisheries management and operations. Precision, smart, and digital fisheries approaches leverage sensors, satellite data, artificial intelligence, and automated monitoring to optimize feeding, water quality management, and disease detection. These technologies support data-driven decision-making and reduce uncertainty associated with climate variability.

Remotely operated vehicles have emerged as valuable tools for monitoring submerged infrastructure and aquatic environments. By enabling real-time inspection of cages, nets, and underwater habitats, ROVs reduce labor costs, improve safety, and enhance early detection of damage or biofouling. Such technologies contribute to operational efficiency and resilience, particularly in offshore and deep-water systems where climate risks are increasing.

4.1 Technological and Ecosystem-Based Approaches for Climate-Resilient Fisheries

Climate change has intensified stressors in fisheries, including disease outbreaks, parasite load, and reduced productivity under high stocking densities. Addressing these challenges requires a combination of technological innovation, improved feeding strategies, ecosystem-based management, and enabling policy frameworks.

4.2 Autonomous and Robotic Systems in Fish Farming

Dense fish culture environments often accelerate disease transmission and operational costs. Emerging autonomous cage systems, such as mobile offshore aquaculture platforms or “aqua-pods,” offer a promising alternative by facilitating better water exchange, reduced parasite load, and improved welfare conditions (Troell et al., 2023). Although initial capital costs are high, long-term gains include enhanced biosecurity, reduced maintenance, and increased production efficiency (FAO, 2023). Robotic technologies enable continuous monitoring of nets and moorings, reducing reliance on human divers and improving workplace safety (Haut & Côté, 2021). The integration of autonomous monitoring aligns with broader trends in marine robotics for sustainable aquaculture (Breen et al., 2021).

4.3 Drones, Sensors, and Digital Monitoring

Unmanned underwater vehicles and drones are increasingly used to support real-time monitoring and data acquisition in fish farms. Equipped with cameras, sonar, and environmental sensors, these systems reduce the need for risky human inspections while enhancing the precision of farm surveillance (Føre et al., 2018; Nguyen et al., 2022). Continuous sensor data on temperature, dissolved oxygen, pH, salinity, and turbidity enables early detection of stressors and supports proactive management (Bostock et al., 2020). Biosensors that track physiological indicators such as metabolic rate and heart rate further support optimized growing conditions and improved survival (Martins et al., 2021). Acoustic technologies, including echo sounders and fish finders, also contribute to biomass estimation and habitat mapping, enhancing stock assessment and operational planning (Fernandes et al., 2024).

4.4 Artificial Intelligence and Data-Driven Decision Making

Artificial intelligence (AI) enhances predictive analytics and decision-making in fisheries by transforming large datasets into actionable insights. Machine learning models can forecast disease outbreaks, environmental stress events, and production outcomes, allowing managers to implement targeted interventions (Zhou et al., 2021). Beyond production optimization, AI supports traceability, species identification, and compliance monitoring, improving transparency and governance across value chains (FAO, 2024). Emerging applications of blockchain, augmented reality (AR), and virtual reality (VR) are also being explored to support training, traceability, and stakeholder engagement in fisheries systems (Santos et al., 2022).

4.5 Sustainable Aquafeeds and Precision Feeding

Aquafeeds represent one of the most resource-intensive inputs in fisheries and aquaculture systems. Given the carbon intensity associated with traditional fishmeal and fish oil, alternatives such as microalgae, insect meal, and plant-based proteins are being developed and evaluated for growth performance and environmental impact (Henry et al., 2021; Ahmed et al., 2022). These alternative ingredients can reduce dependence on finite marine resources while maintaining nutritional adequacy. Precision feeding technologies, supported by sensors and AI, align feeding rates with behavioral and environmental cues, improving feed conversion efficiency, reducing waste output, and lowering production costs (Kousoulaki et al., 2021).

5.0 Ecosystem-Based Fisheries Management

Ecosystem-based fisheries management (EBFM) provides an integrative framework that accounts for ecological interactions, environmental variability, and socio-economic dimensions (Pikitch et al., 2020; UNEP, 2022). Unlike single-species approaches, EBFM emphasizes the interconnectedness of habitats, species, and human uses, facilitating adaptive responses to multiple stressors. Integrated ecosystem assessments combine biological, physical, and human data to evaluate ecosystem status and project future conditions under different management scenarios (Levin et al., 2020). By considering trade-offs across stakeholder priorities, EBFM supports resilient decision making in the face of climate variability (FAO, 2023).

5.1 Climate-Smart Fisheries Policies

Climate-smart fisheries policies aim to increase sustainable production while enhancing resilience to climate change. Building on the principles of climate-smart agriculture, this approach integrates productivity, adaptation, and mitigation goals across the fisheries value chain (FAO, 2022). Key elements include environmentally selective gears, bycatch reduction, harvest strategies consistent with maximum sustainable yield, and support for low-carbon technologies. Policy instruments such as market incentives, certification schemes, and climate finance mechanisms encourage adoption of resilient practices, especially among small-scale fishers (Allison et al., 2021). Aligning national fisheries management with international climate commitments enhances coherence between food security, biodiversity, and climate adaptation goals (IPCC, 2022).

5.2 Capacity Building and Knowledge Transfer

Capacity building is essential to translate scientific advances into practice. Effective knowledge transfer begins with baseline assessments of fishers' climate knowledge and adaptive capacity, guiding targeted education programs (Bennett et al., 2020). Participatory training that blends scientific and local knowledge enhances relevance and acceptance. Mobile platforms, community radio, and extension services help disseminate timely climate and fisheries information. Demonstration projects and participatory field trials allow fishers to evaluate adaptive practices in situ, fostering experiential learning and peer exchange

(Cinner et al., 2022). Continuous monitoring and feedback loops ensure that capacity-building efforts remain responsive to evolving needs.

6.0 Case Studies and Best Practices in Climate-Resilient Fisheries

6.1 Fisheries Resilience in Vulnerable Regions

Resilience in fisheries refers to the capacity of social–ecological systems to absorb disturbances while maintaining core functions, structures, and feedbacks (Swetz, 2025). Contemporary fisheries management increasingly recognizes that resilience depends not only on ecological integrity but also on social, economic, and institutional factors. Healthy ecosystems with high biodiversity and intact habitats are better able to withstand climate-related stressors, including warming, extreme events, and ocean acidification (IPCC, 2022).

Fisheries resilience is undermined by cumulative pressures such as overexploitation, pollution, habitat degradation, and climate change, particularly in regions where governance capacity is limited. However, resilience can be strengthened through targeted management interventions, including habitat protection, adaptive harvest strategies, and reduction of non-climatic stressors (Folke et al., 2021). Empirical studies show that resilient fisheries systems are more likely to sustain fish stocks, preserve cultural identities, and support long-term livelihoods in fishing-dependent communities (Maltby et al., 2023; FAO, 2023).

6.2 Integrated Fisheries–Farming Systems

Integrated fisheries–farming systems represent a widely documented best practice for enhancing climate resilience, particularly in small-scale and resource-constrained settings. These systems combine fisheries with crop production, livestock rearing, or horticulture, allowing waste from one subsystem to serve as inputs for another, thereby improving resource-use efficiency and reducing environmental impacts (Singh et al., 2021).

Recent case studies demonstrate that integration enhances income diversification, reduces vulnerability to climate shocks, and improves household food security (FAO, 2022). By recycling nutrients and optimizing land and water use, integrated systems contribute to ecological sustainability while providing stable and diversified revenue streams (Ahmed et al., 2022). Such systems have proven particularly effective in regions facing increasing climate variability and limited access to external inputs.

6.3 Community-Based Fisheries Initiatives

Community-based fisheries management has emerged as a critical approach for building climate resilience by empowering local users to participate in decision-making and stewardship. Participatory governance systems that integrate traditional knowledge with scientific management have been shown to enhance compliance, improve ecological outcomes, and strengthen adaptive capacity (Cinner et al., 2022).

Despite these benefits, poorly planned fisheries development has, in some cases, resulted in environmental degradation and social inequities, including exclusion of local users and “ocean grabbing”. Successful community-based initiatives address these challenges by balancing economic development with environmental protection and social equity.

Well-documented benefits of community-based fisheries include improved local employment, enhanced food security, transparent governance, strengthened social cohesion, and increased environmental stewardship (FAO, 2023; Allison et al., 2021). These models offer scalable lessons for climate-resilient fisheries governance.

6.4 Climate-Resilient Fisheries in Urban Environments

Urban fisheries face distinct climate risks linked to space constraints, water pollution, and competing resource demands. Urban areas contribute approximately 70 percent of global greenhouse gas emissions and are increasingly exposed to climate hazards such as flooding, heatwaves, and sea-level rise (IPCC, 2022). These pressures directly affect urban aquatic ecosystems and fisheries-dependent populations.

Nature-based solutions, including wetlands, green infrastructure, and restored riparian zones, are increasingly adopted to enhance urban climate resilience while improving water quality and aquatic habitat (UNEP, 2022). However, pollution remains a major concern for urban fisheries, particularly where fish are harvested for consumption. Recent studies have documented persistent contaminants such as mercury, polychlorinated biphenyls, and pesticides in urban fish populations, posing risks to human health (Joosse et al., 2021).

Improving regulatory enforcement, reducing plastic and chemical runoff, and promoting integrated urban water management are essential for sustaining fisheries in urban settings under climate change.

6.4 Indigenous Knowledge and Traditional Fisheries Practices

Indigenous and local knowledge systems play a vital role in climate-resilient fisheries by supporting sustainable resource use and conservation of fish genetic diversity. Indigenous knowledge, developed through long-term interaction with local environments, informs practices such as seasonal fishing closures, gear selectivity, species protection, and habitat conservation (Rocliffe et al., 2020).

Recent studies highlight the importance of integrating indigenous knowledge into formal fisheries management to improve ecological outcomes and adaptive capacity (Jabali et al., 2020). In many regions, indigenous practices have supported natural stock regeneration and maintained genetic integrity by avoiding intensive technological interventions.

Evidence from empirical studies across Asia, Africa and Latin America demonstrates that fisheries systems adopting diversified production strategies and ecosystem based management approaches show higher resilience to climate variability. Integrated aquaculture systems, habitat restoration initiatives and community based fisheries management have been shown to improve productivity while reducing ecological risks. For example, integrated fish farming systems in parts of Asia and Africa have enhanced household income and food security while promoting efficient resource utilization. These findings highlight the importance of combining ecological conservation with adaptive management strategies to strengthen long term sustainability in fisheries systems under climate change (FAO, 2024).

6.5 Scaling Up Climate-Resilient Fisheries Practices

Scaling up climate-resilient fisheries practices requires enabling policy environments, strong research–practice linkages, and sustained community engagement. Successful case studies consistently highlight the importance of institutional support, access to finance, capacity building, and participatory governance (FAO, 2023; IPBES, 2022).

When effectively scaled, climate-resilient fisheries initiatives contribute to improved food security, livelihood stability, and ecosystem conservation. These experiences provide transferable lessons for policymakers and practitioners seeking to mainstream climate adaptation in fisheries across diverse socio-ecological contexts (Troell et al., 2023; FAO, 2024).

7.0 Future Prospects and Challenges in Climate-Resilient Fisheries

7.1 Emerging Technologies and Innovations

Advances in technology are reshaping the future of climate-resilient fisheries, offering new opportunities to enhance productivity, sustainability, and adaptive capacity. Genetic improvement remains a cornerstone of aquaculture development, with selective breeding programs producing strains with improved growth rates, feed efficiency, and disease resistance. However, genetic gains through conventional breeding are constrained by heritability limits and long generation intervals. Recent progress in genome editing and genomic selection has therefore generated significant interest as a means of accelerating genetic improvement while supporting sustainability goals (Houston et al., 2020; FAO, 2024).

Genome editing technologies have expanded understanding of fish development, immunity, and stress tolerance, and hold potential for developing climate-tolerant strains. At the same time, concerns persist regarding ecological risks associated with escapees, gene flow into wild populations, and public acceptance of genetically modified organisms. While products derived from selective breeding are widely accepted, societal and regulatory uncertainty continues to shape the future role of genome editing in fisheries and aquaculture (Pew Initiative, 2021; Troell et al., 2023). In parallel, the introduction of non-native species for aquaculture, such as tilapia, remains a challenge due to their potential to alter ecosystem structure and compete with native species.

7.2 Artificial Intelligence in Fisheries Management

Artificial intelligence is increasingly applied to fisheries management to improve selectivity, compliance, and decision-making. AI-based image recognition systems can automatically identify fish species and size during capture and processing, reducing bycatch, minimizing discards, and lowering administrative burdens associated with catch documentation (Li et al., 2023; FAO, 2024). These systems enable real-time monitoring of catches by species and weight, generating high-resolution data that support stock assessments, research, and adaptive fisheries policies.

Beyond compliance, AI improves operational efficiency by optimizing onboard processing, reducing crew workload, and enhancing safety. As digital monitoring becomes more widespread, AI is expected to play a growing role in predictive analytics, supporting climate-responsive harvest strategies and improved fisheries governance (Zhou et al., 2021; Hilborn et al., 2023).

7.3 Blockchain Technology and Supply-Chain Transparency

Blockchain technology has emerged as a promising tool for improving transparency, traceability, and trust across fisheries and aquaculture value chains. By enabling decentralized, tamper-resistant ledgers, blockchain systems allow stakeholders to track products from harvest to consumer, reducing seafood fraud and mislabeling, which remains a significant challenge globally (FAO, 2023).

Recent applications demonstrate how blockchain can record production data such as feed inputs, growth conditions, harvest details, and transport history, thereby improving supply-chain visibility and market confidence (Shrestha et al., 2021; Sengupta et al., 2021). Pilot projects tracing tuna and other seafood products have shown that integrating blockchain with digital tools such as QR codes and mobile reporting can enhance regulatory oversight, reduce illegal fishing, and support sustainability certification. However, high implementation costs, limited digital infrastructure, and capacity gaps remain barriers, particularly in developing regions.

7.4 Anticipating Climate Change Impacts

Anticipating future climate impacts is essential for proactive fisheries management. Climate models, informed by historical observations and satellite data, project continued warming, ocean acidification, sea-level rise, and increasing variability in precipitation patterns (IPCC, 2021; IPCC, 2022). These changes are already evident in shifting species distributions, altered phenology, glacier retreat, and increased frequency of extreme events.

The magnitude of future impacts depends strongly on current mitigation efforts. Incorporating anticipation and adaptive behavior into climate assessments improves estimates of local and regional impacts, as individuals and communities that anticipate change are more likely to relocate, diversify livelihoods, or adopt adaptive strategies (Weder di Mauro, 2021). Despite widespread awareness of climate risks, uncertainty remains regarding how anticipation shapes long-term socio-ecological outcomes, highlighting the need for integrated modeling approaches that combine climate, ecological, and human dimensions.

Recent global assessments highlight that climate change is already altering fisheries productivity and distribution patterns, particularly in tropical and subtropical regions where warming rates are accelerating (Free et al., 2022; FAO, 2024).

8.0 Policy Frameworks and International Collaboration

Effective policy frameworks are critical for scaling climate-resilient fisheries, particularly in regions such as Africa where fisheries support food security, employment, and economic development. The complexity of multispecies fisheries and diverse value chains has often led to fragmented management approaches. In response, continental initiatives such as the African Union’s Policy Framework and Reform Strategy for Fisheries and Aquaculture emphasize governance reform, regional cooperation, and ecosystem-based approaches (AU-IBAR, 2021; FAO, 2023).

These frameworks prioritize sustainable resource use, development of small-scale fisheries, expansion of market-led aquaculture, responsible trade, and strengthened regional collaboration. Successful implementation depends on political commitment, institutional capacity, and alignment with broader development agendas such as climate adaptation, food security, and poverty reduction. When effectively operationalized, coordinated policy frameworks can enhance productivity, sustainability, and equity across fisheries value chains.

8.1 Socio-Economic Implications and Equity

Climate change poses significant socio-economic challenges for fisheries-dependent communities, particularly in freshwater and riverine systems. Enhancing resilience requires integrated management strategies that protect habitats while enabling adaptive use of shifting resources (FAO, 2022). Restoration of connectivity, maintenance of environmental flows, and protection of thermal refugia are increasingly important as droughts intensify and water temperatures rise (Kovach et al., 2019).

Equity considerations are central to climate-resilient fisheries. Unequal access to resources, information, and adaptive capacity can exacerbate vulnerability, particularly among small-scale fishers. Maintaining a diversity of fishing opportunities and livelihood options across landscapes can stabilize ecosystem services and reduce socio-economic risk under climate variability (IPBES, 2022).

9.0 Ethical Considerations and Environmental Justice

Ethical considerations increasingly shape climate-resilient fisheries governance. Environmental ethics emphasize ecosystem integrity, biodiversity conservation, and intergenerational equity, while environmental justice frameworks prioritize human wellbeing, fairness, and access to resources. The recognition of water as a human right underscores its fundamental role in food production, cultural identity, and dignity (Rida, 2025).

Climate-resilient fisheries policies must therefore balance ecological sustainability with social justice, ensuring that adaptation measures do not disproportionately burden vulnerable communities. Ethical decision-making requires that current resource use does not compromise future ecosystem functions or the rights of future generations (Knox-Hayes et al., 2025; Lima Weston, 2024).

9.1 Building Climate-Resilient Fisheries Communities

Building resilience in fisheries communities requires the capacity to anticipate climate risks, absorb shocks, and transform development pathways over time. Biodiversity-rich ecosystems, such as coral reefs and mangroves, provide natural protection against climate extremes, while diversified livelihoods and strong social networks enhance adaptive capacity (IPCC, 2022; Cinner et al., 2022).

Technological innovation further supports resilience through climate-tolerant species, storm-resistant infrastructure, improved vessel design, and digital information systems that disseminate weather and market data. Effective governance, access to capital, and inclusive decision-making are critical enablers of these adaptations. Together, ecological integrity, social cohesion, and technological innovation form the foundation of climate-resilient fisheries systems capable of withstanding future uncertainty.

Empirical studies from Asia and Africa show that fisheries systems adopting integrated management approaches and diversified production systems demonstrate greater resilience to climate variability compared to monoculture or single-species management systems (Ahmed et al., 2022; Troell et al., 2023).

10.0 Conclusion

The accelerating pace of climate change now represents one of the most significant challenges confronting fisheries and aquaculture systems worldwide.

These changes pose substantial risks to fisheries productivity, ecosystem stability, and the livelihoods of millions who depend on aquatic resources. At the same time, the evidence reviewed in this study demonstrates that fisheries systems possess considerable adaptive potential when supported by sound governance, innovation, and inclusive management approaches.

This synthesis highlights that climate-resilient fisheries are fundamentally social–ecological systems in which ecological integrity, technological innovation, and human capacity are tightly interconnected. Adaptive management, ecosystem-based approaches, and emerging technologies such as digital monitoring, artificial intelligence, and improved breeding strategies offer pathways to reduce vulnerability and enhance resilience. Equally important are ethical considerations, environmental justice, and the integration of indigenous and local knowledge, which contribute to equitable and context-specific solutions.

A central finding of this review is that collaboration is critical to successful climate adaptation. Effective responses require coordinated action among scientists, policymakers, industry actors, and fishing communities, supported by international cooperation to address transboundary climate and fisheries challenges. Continued investment in research, infrastructure, and education is essential to advance climate-resilient practices and ensure their adoption across diverse production systems and regions.

Ultimately, strengthening climate resilience in fisheries is not solely a technical challenge but a governance and societal imperative. By aligning innovation with sustainability, respecting traditional knowledge systems, and embedding equity into policy frameworks, fisheries can adapt to a changing climate while continuing to support food security, livelihoods, and aquatic biodiversity. Such integrated efforts are essential to safeguard fisheries systems for present and future generations (FAO, 2023; IPCC, 2022; Troell et al., 2023).

For countries such as Nigeria, where fisheries and aquaculture contribute significantly to national nutrition and employment, integrating climate resilient strategies into fisheries development policies will be essential for long term sustainability and economic stability.

11.0 Recommendations

Based on the evidence reviewed, the following recommendations are proposed to support the development and scaling of climate-resilient fisheries:

a. Strengthen Research and Innovation

Increased investment in research and development is needed to advance climate-resilient fisheries, including selective breeding and genomic tools, ecosystem modeling, digital technologies, and low-carbon production systems. Research should prioritize region-specific vulnerabilities and applied solutions.

b. Promote Sustainable and Adaptive Practices

The adoption of sustainable production systems such as integrated multi-trophic aquaculture, recirculating systems, polyculture, and ecosystem-based fisheries management should be encouraged to reduce environmental impacts and enhance resilience to climate variability.

c. Invest in Climate-Resilient Infrastructure

Fisheries infrastructure should be designed or retrofitted to withstand sea-level rise, extreme weather events, and water quality changes. This includes resilient cages, improved landing sites, cold-chain systems, and nature-based coastal protection measures.

d. Enhance Education, Capacity Building, and Awareness

Targeted education and training programs are essential to improve understanding of climate risks and adaptive practices among fishers, aquaculturists, policymakers, and value-chain actors. Integrating scientific knowledge with local experience enhances uptake and long-term effectiveness.

e. Facilitate Knowledge Exchange and Co-Production

Platforms that support knowledge sharing among researchers, fishing communities, indigenous groups, and industry stakeholders should be strengthened. Co-production of knowledge improves relevance, legitimacy, and adaptive capacity in climate-resilient fisheries governance.

f. Conserve Biodiversity and Critical Ecosystems

Protecting and restoring aquatic habitats such as mangroves, wetlands, seagrasses, and coral reefs is essential for sustaining ecosystem services, buffering climate impacts, and maintaining fisheries productivity.

g. Strengthen Policy and Governance Frameworks

Policymakers should develop and enforce coherent policy frameworks that incentivize climate-resilient practices, support small-scale fisheries, promote ethical standards, and align fisheries management with national and international climate commitments.

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