



EFFECTS OF CLIMATE CHANGE ON FISH FARMING IN LAGOS STATE, NIGERIA

Akinboye, O. A. and Tajudeen, S. O.

Department of Agricultural Extension and Rural Development, Ladoké Akintola University of Technology, Ogbomosho

Corresponding author's e-mail: oaakinboye@lautech.edu.ng

Abstract: This study investigates the multifaceted effect of climate change on fish farming in Lagos State, Nigeria focusing on the interplay between the socioeconomic characteristics of the fish farmers and the adaptation strategies adopted by the farmers to mitigate the effect of climate change. A multistage sampling technique was used in selecting 150 respondents for the study. Primary data was collected with the aid of a well-structured questionnaire. Descriptive statistics such as frequency counts, percentage, mean and weighted mean score (WMS) were used to describe the socioeconomic characteristics of the respondents while Pearson product moment correlation (PPMC) was used to test the study hypothesis. The finding revealed that the most experienced climate change effects on fish farming were reduced dissolved oxygen level and water temperature changes, altered water quality and increased incidence of diseases and parasites while the level of effects of climate change on fish farming in the study area was high and the common adaptation strategies adopted by the farmers to mitigate the effect of climate change were the culturing of heat-tolerant fish breeds, implementation of climate-resilient fish farming practices and the use of advanced technologies for water quality control and environmental monitoring. A significant relationship exists between the fish farmers' age, household size, years spent schooling and fish farming experience, and the level of effect of climate change on fish farming. The study concluded that climate change significantly undermines the sustainability and resilience of fish farming in the study area and it was recommended that investing in research and implementing biosecurity measures is crucial as climate change can exacerbate disease outbreaks.

Keywords: Effects, Climate change, Climate resilient, Fish farming, Adaptation strategies, Sustainable fish farming.

Introduction

Recent global population projections show that about 10 billion people will be living on the Earth by 2050 (United Nations, 2019). More than half of this projected population will come from sub-Saharan countries. Furthermore, recent statistics suggest that the world will not be able to meet the goal of ending all forms of hunger and malnutrition by 2030 (FAO et al. 2022). Hence, food systems must be transformed to ensure the provision of

adequate, nutritious, and healthy foods accessible to different sections of societies, including poor-resource communities, whilst also ensuring the preservation of natural resources (FAO, 2022). Fish, being highly nutritious and widely accessible, especially for those with limited economic resources, play a crucial role in this endeavour (Beveridge et al. 2013; Maulu et al. 2020, 2021c). Aquaculture and fish farming are the largest suppliers of global food fish and have remained the fastest-

Academic Journal of Agricultural and Horticultural Research

An official Publication of Center for International Research Development

Double Blind Peer and Editorial Review International Referred Journal; Globally index

Available <https://cirdjournals.com/index.php/ajahr>; E-mail: journals@cirdjournals.com



growing food production sector globally since the 2000s (Naylor et al. 2021; FAO et al. 2022). The sector's contribution to food and nutrition security is seen as a critical means to achieving the transformation of global food systems. In developing countries, the role of aquaculture is of greater value, particularly in providing accessible animal protein sources, employment opportunities, and gross domestic product (GDP). Fish farming and aquaculture are important livelihood activities in Africa (AUCNEPAD 2014; Roscher et al. 2018). Fish farming, an increasingly important source of protein and livelihood for millions, is vulnerable to a range of climatic changes including rising temperatures, changing precipitation patterns, ocean acidification and extreme weather events. Fish farming has been one of the fastest-growing sectors in the food production industry, contributing to food security, economic development, and rural employment (FAO, 2020). Fisheries and fish farming are confronted with challenges posed by numerous natural and anthropogenic causes such as climate change, natural disasters, unbalanced urbanization and industrialization, overfishing and environmental pollution across the world (Ghose, 2014). However, they have been identified as significant contributors to climate change yielding around seven per cent of global agricultural greenhouse gas emissions (He et al. 2018). On the other hand, fish farming is also significantly affected by climate change. Increased temperature, shift in rainfall regime, changes in weather pattern, the deterioration of water quality and extreme climate events such as flood and drought are all having an impact (Oyebola et al. 2018; Kim et al. 2019). Climate change poses significant threats to global food security, with fish farming being no exception. According to a report by the International Panel on Climate Change (IPCC, 2021), rising temperatures can affect fish metabolism, growth rates and survival, potentially leading to changes in species composition in the fish farming systems. Additionally, altered rainfall patterns can influence water availability and quality, impacting fish welfare and production efficiency (Kumar et al. 2020). Rising temperatures can increase fish metabolic rates, leading to higher oxygen consumption which can threaten the survival of the fish (Portner et al. 2017). Changes in

water precipitation affect water levels in the fish farming system, leading to altered salinity and nutrient levels that can impact the health of the fish (Graham et al. 2016). Natural disasters can physically damage fish farming infrastructure and disrupt fish farming activities (Barange et al. 2018). Studies have shown that the fish farmers utilize various adaptive measures such as adjusting stocking densities, modifying feed formulations and selecting climate-resilient species (Krause et al. 2012). Climate change is expected to disrupt the aquatic ecosystems and fish farming practices leading to reduced fish stocks, increased disease prevalence, and changing species distributions (He et al., 2019). Understanding how climate change affects fish farming is critical to establishing mitigating strategies that can help farmers adapt and sustain their practices for future food security. This research aims to assess the effect of climate change on fish farming practices in Lagos States. Specifically, the study aims to describe the fish farmers' socioeconomic characteristics, identify the effects of climate change on fish farming, assess the level of effects of climate change on fish farming and identify the common adaptation strategies adopted by the farmers to mitigate the effects of climate change. It was hypothesized that there is no significant relationship between selected socioeconomic characteristics of the fish farmers' and level of effects of climate change on fish farming.

Methodology

This study was conducted in Lagos State located in the south-western part of Nigeria; with its capital is Ikeja. Lagos State occupies 3,345 square kilometres. It shares boundaries with Ogun State both in the north and east and is bounded on the west by the Republic of Benin and in the south, it stretches for 180 kilometres along the coast of Atlantic Ocean. Lagos State, with an area of 3,568.6 km² and an estimated population of 17.5 million (NPC, 2006) and with a growth rate of 3.2 percent, the State currently boasts of a population of over 21 Million people. Of this population, Metropolitan Lagos, an area covering 37 percent of the land area of Lagos State is home to over 85 percent of the State population. Lagos state has a coastline that stretches up to 10 percent of its landmass. In addition, over 20 percent of its landmass comprises fresh, brackish



and marine waters. The state also has a fair share of both saline and freshwater mangroves with their associated features which sprawl about 30 percent of the entire landmass. The State is the smallest (in terms of land mass) and most densely populated state in Nigeria, with twenty local government namely Agege, Ajeromi-Ifelodun, Alimosho, Amuwo-Odofin, Apapa, Badagry, Epe, Eti-osa, Ibeju/Lekki, Ifako-Ijaye/Ikeja, Ikorodu, Kosofe, Lagos Island, Lagos Mainland, Mushin, Ojo/Oshodi-Isolo, Shomolu and Surulere. The State is essentially a Yoruba speaking environment, it is nevertheless, a socio-cultural melting pot attracting both Nigerians and Foreigners alike. Lagos State is the nation's economic nerve centre, with over 2,000 industries, and 65% of the country's commercial activities are carried out in the State. Two of the nation's largest seaport; Apapa and Tin-can Ports are located in Lagos State. The State has a tourism policy that recognizes six tourism zones. A multistage sampling procedure was employed to select respondents for this study. In the first stage, two (2) ADP zones (Western and Eastern zones) were randomly chosen from states while the second stage, involved the selection of five (5) extension blocks from each of the selected zones thus making a total of ten (10) extension blocks. Lastly, fifteen (15) fish farmers was randomly selected from each of ten (10) extension blocks thereby making a total of one hundred and fifty (150) fish farmers that constituted the sample size for the study. Primary data was collected using a well-structured questionnaire and interview schedule. Data was analysed using such as frequency counts, percentages, mean and weighted mean score (WMS) while an inferential statistical tool (PPMC) was used for testing the stated hypothesis.

Results and Discussion

Fish Farmers' Socioeconomic Characteristics

Results presented in Table 1 show that 38% of the fish farmers were between the age range of 40-49 years while 34.7% were between the age range of 50-59 years and 23.3% of them were between 30-39 years. Also, 1.3% were below 30 years and 2.7% were 60 years and above with a mean age of 44 years. The majority of the respondents were less than 50 years of age which implies that they were considered physically and economically active, productive

and agile. This implies that younger fish farmers with higher versatility and openness to innovation may better cope with climate effects by integrating new fish farming practices. Table 1 further shows that 70% of the fish farmers were males while 30% were females. This indicates that fish farming in the study area is male dominated which implies that the male-dominated demographic in fish farming may limit the range of adaptation strategies employed as studies indicated that gender influences adaptive capacity with the female farmers often being more resourceful and innovative in using local knowledge to adapt to climate change (Agarwal, 2010) and promoting gender inclusivity can enhance community resilience to climate effects (Quisumbing et al. 2014). The majority of the respondents (90.7%) were married, while 7.3% were single and 2% were divorced. This indicates that married respondents engaged in fish farming in the study area, which implies that the social characteristics of being married and having an established household may foster supportive networks that can be crucial during climate crises. These networks can facilitate information sharing and collective actions for adaptation (Wang et al. 2021). Result presented in Table 1 further shows that 38.7% of the fish farmers had household size of between 5-6 people, while 36% of them had household size of between 3-4 people, 16% had household size of 7 people and above and 9.3% had household size of between 1-2 people with the mean household size of 5 persons. This implies that the respondents in the study area had medium-sized households and a moderate number of dependents may affect labour availability for fish farming activities. A larger household might provide more labour for adaptation activities but could also strain resources during climate-induced stresses (Bene et al. 2016). The composition of the household particularly in terms of gender roles can influence decision-making and resource allocation for adaptive measures (Van Aelst and Holvoet, 2016). Table 1 further shows that 58.7% of the fish farmers spent between 7-12 years in school, 33.3% spent between 1-6 years in school while 6.7% spent between 13 years and above in school and 1.3% had no formal education with 11 years as the mean year spent in school. This implies that the majority of the respondents spent a significant number



of years having formal education and may possess the necessary knowledge to understand climate change threats and engage in adaptive practices, as higher educational attainment is associated with greater awareness and implementation of climate adaptation strategies (Zhou et al. 2021). As shown in Table 1, 48.7% of the fish farmers had between 10 to 14 years of experience in fish farming, 30% had between 15 to 19 years of experience while 11.3% of them had less than 10 years of experience and

10% of the respondents had 20 years of experience and above with 11 years as the mean years of experience in fish farming. This implies that the respondents' years of experience in fish farming is quite encouraging as most of them have been in the business for a long time thus, older fish farmers with substantial experience may have a deeper understanding of traditional practices but could be less adaptable to new methods/technologies in response to climate change (Dey et al. 2019).

Table 1: Distribution of respondents by socioeconomic characteristics (n=150).

Characteristics	Frequency	Percentage	Mean
Age(yrs.)			
<30	2	1.3	44 years
30-39	35	23.3	
40-49	57	38	
50-59	52	34.7	
60>	4	2.7	
Sex			
Male	105	70	
Female	45	30	
Marital status			
Single	11	7.3	
Married	136	90.7	
Divorced	3	2	
Household size			
1-2	14	9.3	5people
3-4	54	36	
5-6	58	38.7	
7>	24	16	
Years spent schooling			
No formal education	2	1.3	11 years
1-6	50	33.3	
7-12	88	58.7	
13>	10	6.7	
Fish farming experience (Yrs.)			
<10	17	11.3	13 years
10-14	73	48.7	
15-19	45	30	
20>	15	10	

Source: Field Survey, 2025

Effects of climate change on fish farming

Result presented in Table 2 shows that the most experienced climate change effects on fish farming in the

study area were reduced dissolved oxygen level and water temperature changes ranked 1st with a weighted mean of 2.04, altered water quality ranked 3rd with a weighted



mean score of 1.99 and increased incidence of diseases and parasites 4th with a weighted mean score of 1.92. This implies that water temperature change has direct effects on the fish physiology, including growth, reproduction, and metabolism. Fish species that have narrow temperature tolerances may struggle to survive or reproduce in warmer waters, leading to decreased stock density and biodiversity in the fish farming sector. This is in line with the report of Portner and Farrell (2008) that the temperature changes could lead to a geographical shift in the fish populations, affecting fish farming viability in some regions while benefiting others. Warmer waters can exacerbate hypoxia (low oxygen conditions), which is critical for the fish's survival. Low oxygen levels can impair the fish's health, leading to stress, increased mortality rates and reduced growth rates, resulting in lower yields for fish farms. This is in tandem with the report of Deepika et al. (2019) that low oxygen conditions can significantly reduce fish growth rates and promotes disease susceptibility as compromised oxygen conditions stress the fish. Changes in water

chemistry due to climate change can lead to increased nutrient runoff, thereby contributing to harmful algae blooms (HABs) as these blooms can deplete the oxygen levels and produce toxins harmful to the fish and potentially making fish products unsafe for consumption thus impacting marketability. This is in support of the report of Paerl and Otten (2013) that nutrient loading and changing climate conditions favour the growth of harmful algae blooms (HABs). Climate change can lead to a rise in the prevalence and virulence of diseases and parasites in fish as warmer temperatures can enhance the reproductive rates of pathogens resulting in more frequent disease outbreaks that may necessitate increased usage of antibiotics and other treatments thus raising the costs and potential risks for human health and the environment. This is in tandem with the report of Kidder and Kaczynski (2020) that climate change affects the dynamics of aquatic diseases and parasites, stressing the likelihood of increased infections in fish farming due to favourable conditions for the pathogens.

Table 2: Distribution of respondents by effects of climate change on fish farming (n=150)

Effects of climate change on fish farming	WMS	Rank
Reduced dissolved oxygen level	2.04	1 st
Altered water quality	1.99	3 rd
Water temperature changes	2.04	1 st
Increased incidence of diseases and parasites	1.92	4 th
High cost of Feed ingredients	1.86	5 th
Economic effects	1.65	8 th
Extreme weather events	1.74	7 th
Changes in species distribution	1.84	6 th
Regulatory and environmental compliance	1.63	9 th
Salinity changes	1.52	10 th

WMS-Weighted Mean Score

Source: Field Survey, 2025

Level of effects of climate change on fish farming

Result presented in Table 3 shows that the majority (72.7%) of the fish farmers in the study area experienced a high level of effects of climate change in their fish farming operations, while 27.3% of them experienced a moderate level of effects of climate change in their fish farming operations. This indicates that the fish farmers experienced high intensity of climate change on their farming operations. This implies that warmer water temperatures

can adversely affect fish growth and reproduction as fish species have a specific temperature range for optimal growth; thus, changes in temperature can lead to stress, which can increase susceptibility to disease. This finding is in tandem with the report of Jones et al. (2023) that hypoxia (low oxygen) is becoming more prevalent in fish farming as temperatures rise can affect fish farming operations. Also, climate change can impact the availability and quality of feed ingredients due to changes



in the marine ecosystems and agriculture. Meyer et al. (2023) reported that fluctuations in climate can lead to

reduced omega-3 fatty acid level in the feed fish which in turn affects fish farming nutrition.

Table 3: Distribution of respondents by level of effects of climate change on fish farming

Level of effects of climate change	Frequency	Percentage
High effect	109	72.7
Moderate effect	41	27.3
Total	150	100.0

Source: Field Survey, 2025

Common adaptation strategies adopted by the farmers to mitigate the effects of climate change

Result presented in Table 4 reveals that culturing of heat-tolerant fish breeds ranked 1st with a weighted mean score of 2.67, implementation of climate-resilient fish farming practices ranked 2nd with a weighted mean score of 2.63 and the use of advanced technologies for water quality control and environmental monitoring ranked 3rd with a weighted mean score of 2.55 and Improved feeding strategies ranked 4th with a weighted mean score of 2.53 were the common adaptation strategies adopted by the fish farmers to mitigate the effect of climate change. This indicates that culturing of heat-tolerant fish breeds, implementation of climate-resilient fish farming practices, the use of advanced technologies for water quality control and environmental monitoring and improved feeding strategies were the common strategies employed by the fish farmers in the study area to counter the effect of climate change on their fish farming operations. This implies that culturing heat-tolerant fish breeds increases growth rates in warmer water conditions. Utilizing heat-tolerant fish species helps to maintain production levels during periods of elevated temperatures, thereby contributing to food security and economic stability of the fish farmers (Tafalla et al. 2020). Climate-resilient practices help to mitigate the physiological stress on the fish caused by temperature fluctuations and low oxygen levels (Bard et al. 2017). By enhancing the resilience of the fish farming systems, these practices contribute to stable

production and income of the fish farmers, allowing them to withstand the economic shocks brought about by climate-related disruptions (FAO, 2020). Implementing such practices usually leads to improved resource efficiency, including better water and feed utilization, which reduces the environmental footprint of fish farming (Pillai et al. 2021). Utilizing advanced technologies enables real-time monitoring of critical water parameters, which are crucial under climate stress, as this allows for immediate adjustments and proactive management decisions (Zhang et al. 2021). The use of advanced data analytics supports informed decision-making, improving management practices and enhancing productivity while minimizing risks associated with water quality degradation (Bai et al. 2022). Effective monitoring can substantially reduce mortality rates by enabling swift responses to adverse changes in water quality conditions, significantly benefiting the fish farmers. Optimizing feed formulations that consider the dietary needs of the fish under varying environmental conditions can lead to cost savings and improved growth rates, as noted by Tacon and Metian (2013) as feed is often the largest operational cost in fish farming. Enhanced feeding strategies can improve the nutritional quality of fish products, which is increasingly important for consumer health and market demands (Naylor et al. 2020). Improved feeding practices can lead to a reduction in feed waste and the associated environmental impacts of fish farming, aligning with sustainable development goals (Sampaio et al. 2021).

Table 4: Distribution of respondents by common adaptation strategies adopted by the farmers to mitigate the effects of climate change (n=150).

Common adaptation strategies adopted	WMS	Rank
Culturing of heat-tolerant fish breeds	2.67	1 st
Implementation of climate resilient fish farming practices	2.63	2 nd



Use of advanced technologies for water quality control and environmental monitoring	2.55	3 rd
Education and training	2.44	7 th
Diversification of fish species	2.51	5 th
Water temperature regulation	2.48	6 th
Disaster preparedness and contingent planning	2.29	9 th
Improved feeding strategies	2.53	4 th
Monitoring and research	2.32	8 th
Insurance programmes	2.25	10 th

WMS-Weighted Mean Score

Source: Field Survey, 2025

Hypothesis testing

There is no significant relationship between selected socioeconomic characteristics of the fish farmers and the level of effects of climate change on fish farming

Relationship between selected socioeconomic characteristics of the fish farmers and the level of effects of climate change on fish farming

The correlation analysis result presented in Table 5 reveals that there was significant relationship between the fish farmers' age ($r = 0.310$; $p = 0.000$), household size ($r = 0.409$; $p = 0.000$), years spent schooling ($r = 0.395$; $p = 0.000$) and fish farming experience ($r = 0.505$; $p = 0.000$) and the level of effects of climate change on fish farming. This indicates that the fish farmers' age, household size, years spent schooling and fish farming experience positively influenced the level of effects of climate change on their fish farming operations. This implies that older fish farmers may have more experience and traditional knowledge about fish farming practices that can help them adapt to changing conditions. However, they might also be less inclined to adopt new technologies or approaches that could improve resilience against climate change impacts. Adger et al. (2006), reported that older farmers may rely on historical practices that may no longer be effective under new climate conditions, thus showcasing the need for tailored interventions that bridge the gap between traditional practices and innovative techniques. Larger households may have more labour resources to allocate to

fish farming, which can aid in the adaptation strategies however, larger households may also face increased pressure on resources, especially in the context of climate-induced environmental changes. According to a study by Islam and Fadillah (2020), larger household size can foster resource sharing and collective action among family members, but they can also exacerbate vulnerabilities if the household's resources become strained due to climate impacts. Higher levels of education are positively associated with the farmers' ability to understand and implement adaptive strategies in response to climate change. Educated farmers may be more adept at acquiring information regarding climate resilience practices, developing risk management strategies and adopting innovative fish farming technologies. A study by Oyinlola et al. (2019) reported that education enhances farmers' knowledge of climate and builds adaptive capacity enabling them to make informed decisions around resource management and fish farming practices. Experienced fish farmers are likely to have a deeper understanding of fish species resilience and farm management practices that are essential for adapting to climate fluctuations however, they may also be limited by entrenched practices that do not accommodate new climate realities. Naylor et al. (2000), reported that experienced in fish farming contributes to successful adaptation strategies although continuous education and knowledge updates are crucial for tackling new climate challenges

Table 5: Summary of Correlation showing relationship between selected socioeconomic characteristics of the fish farmers' and level of effects of climate change on fish farming

Selected socioeconomic characteristics of the fish farmers'	r-value	p-value	Decision
---	---------	---------	----------



Age	0.310	0.000	Significant
Household size	0.409	0.000	Significant
Years spent schooling	0.395	0.000	Significant
Fish farming experience	0.505	0.000	Significant

At 5% level of significance

Conclusion and Recommendations

In conclusion, the effects of climate change on fish farming have become increasingly pronounced, posing significant challenges to the sustainability and productivity of fish farming. Climate parameters have profound implications for the health, growth, and overall viability of the fish farms. The analysis demonstrates a significant relationship between the fish farmers' age, household size, years spent schooling, and years of experience in fish farming and their resilience to the effects of climate change. Younger fish farmers with moderate household size, well-educated, and with substantial experience in fish farming tend to negotiate the challenges of climate change more effectively. However, the high level of effects from climate change necessitates urgent actions to equip the fish farmers with the knowledge, resources and adaptive strategies needed to ensure the sustainability of their fish farming operations in the face of these on-going challenges. Thus it was recommended that;

1. Investing in research and implementing biosecurity measures is crucial as climate change can exacerbate disease outbreaks.
2. Implementation of comprehensive training programmes that focus on climate-smart fish farming practices.
3. Development and dissemination of easily understandable climate information systems that provide the fish farmers with timely data on weather forecasts, as this information can help the fish farmers anticipate the challenges and make informed decisions regarding fish farming practices.
4. Creation of networks among the fish farmers through which they can share knowledge, experience and resources to increase resilience collectively especially among older fish farmers who may bring valuable insight.
5. Setting up of monitoring frameworks to assess the effectiveness of adaptation strategies as continuous feedback can help refine the approaches and ensure that fish

farming practices remain sustainable under evolving climate conditions.

References

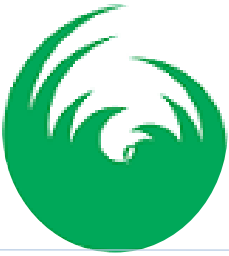
- Agarwal, B.: Gender and land rights revisited: Exploring New Opportunities for improving women's land access. *Journal of World Agribusiness*, 2010
- AUC-NEPAD. The policy framework and reform strategy for Fisheries and Aquaculture in Africa, 2014. https://au.int/web/sites/default/files/documents/30266-doc-au-ibar_fisheries_policy_framework_and_reform_strategy.pdf [accessed 16 April 2019].
- Bai, Y.; Zhang, S.; Wang, J. Smart aquaculture: An emerging research direction for precision aquaculture. *Aquaculture Reports*, 2020, 20, 100782.
- Barange, M.; Bahri, T.; Beveridge, M. C. M.; Cochrane, K. L.; Funge-Smith, S.; Poulain, F. (eds): Impacts of Climate Change on Fisheries and Aquaculture. Synthesis of Current Knowledge, Adaptation, and Mitigation Options. FAO Fisheries and Aquaculture Technical Paper, 2018, No. 627, 628pp, Rome, FAO,
- Bard, S. M.; Faulkner, L. R.; White, H. S. The adaptation of aquaculture to climate change: A special issue of aquatic ecosystem health and management. *Aquatic Ecosystem Health and Management*, 2017, 20(1), 1-6.
- Béné, C.; Arthur, R.; Norbury, H.; Allison, E.H.; Beveridge, M.C.M.; Bush, S.; Campling, L. Contribution of fisheries and aquaculture to food security and poverty reduction: Assessing the current evidence. *World Development* 2016, 79, 177–196.



- Beveridge, M. C.; Thilsted, S. H.; Phillips, M. J.; Metian, M.; Troell, M.; Hall, S. J. Meeting the food and nutrition needs of the poor: the role of fish and the opportunities and challenges emerging from the rise of aquaculture. *Journal of Fish Biology*, 2013, 83, 1067–1084. doi: 10.1111/jfb.12187
- Deepika, S.; Srinivasan, A.; Padmavathy, P.; Jawahar, P. Seasonal variation of phytoplankton diversity in sea grass ecosystem of Mandapam Coast of Gulf of Mannar. *Journal of Experimental Zoology India*, 2019, 21(1), 499–506.
- Dey, M.M.; Srivastava, P.K.; Maji, S.; Das, M.K.; Mukhopadhyaya, M.K.; Saha, P.K. Impact of climate change on the breeding of Indian major carp in West Bengal. *Journal of Inland Fisheries Society India*, 2019, 39, 26–34.
- FAO. FAO Fisheries and Aquaculture Technical Paper. Enhancing climate resilience of aquaculture, 2020, 632.
- FAO. The State of World Fisheries and Aquaculture. Sustainability in Action. Food and Agriculture Organization of the United Nations, 2020, 193.
- FAO. The State of World Fisheries and Aquaculture. Sustainability in Action. Rome: FAO, 2022. Available online at: <https://www.fao.org/3/cc0461en/cc0461en.pdf> (accessed February 20, 2023).
- FAO; IFAD; UNICEF; WFP; WHO. “The state of food security and nutrition in the world 2022,” in Repurposing Food and Agricultural Policies to Make Healthy Diets More Affordable. Rome: FAO, 2022.
- Ghose, B. Fisheries and aquaculture in Bangladesh: Challenges and opportunities. *Annals of Aquaculture and Research*, 2014, 1(1), 1001.
- Graham, N.A.J.; Spalding, M.D.; Sheppard, C.R.C. Reef shark declines in remote atolls highlight the need for multi-faceted conservation action. *Aquatic Conservation*, 2016, 20, 543–548.
- He, J.; Zheng, X.; Rejesus, R.M.; Yorobe, J.M. Climate Change, Aquaculture and the Urgent Need for Climate Adaptation. *Fish Physiology*, 2019, 36, 511-535.
- He, P.; Davy, D.; Sciortino, J.; Beveridge, M.C.M.; Arnason, R.; Gudmundsson, A. Countering climate change: Measures and tools to reduce energy use and greenhouse gas emission in fisheries and aquaculture, in
- Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. and Poulain, F. (eds), 2018. Impacts of Climate Change on Fisheries and Aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options, Fisheries and Aquaculture Technical Paper No. 627. FAO, Rome, pp. 589–609.
- International Panel on Climate Change (IPCC). Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V. et al (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, USA, 2021, 3–32.
- Jones, T.; Verkuijl, C.; Cabré, M. M.; Piggot, G. The effects of climate change on aquatic oxygen levels. *Environmental Management*, 2023, 13(2), 106-112.
- Kidder, G. W.; Kaczynski, Z. Climate Change and the Future of Aquaculture: A Review of Current Knowledge and Future Research Needs. *Aquaculture Reports*, 2020, 20, 100704.
- Kim, B.; Brown, C.L.; Kim, D. Assessment on the vulnerability of Korean aquaculture to climate change, *Marine Policy*, 2019, 99, 111–122.



- Krause, G.; Brugere, C.; Diedrich, A.; Ebeling, M. W.; Ferse, S. C.; Mikkelsen, E. A revolution without people? Closing the people-policy gap in aquaculture development. *Aquaculture*, 2012, 447, 44–55. doi: 10.1016/j.aquaculture.2015.02.009.
- Mastrorillo, M.; Licker, R.; Bohra-Mishra, P.; Fagiolo, G.; Estes, L. D.; Oppenheimer, M. The influence of climate variability on internal migration flows in South Africa. *Global Environmental Change*, 2016, 39, 155-169.
- Maulu, S.; Hasimuna, O. J.; Monde, C.; Mweemba, M. An assessment of post-harvest fish losses and preservation practices in Siavonga district, Southern Zambia. *Fish Aquatic Science*, 2020, 23, 25. doi: 10.1186/s41240-020-00170-x
- Maulu, S.; Nawanzi, K.; Abdel-Tawwab, M.; Khalil, H. S. Fish Nutritional Value as an Approach to Children's Nutrition. *Frontier Nutrition*, 2021c, 8, 780844. doi:10.3389/fnut.2021.780844
- Meyer, R.; Bentley, J.; Odoulami, R. C.; Pigot, A. L.; Trisos, C. H. Risks to biodiversity from temperature overshoot pathways. *Philosophical Transactions of the Royal Society Biological Science*, 2023, 377, 1857, 1–11.
- Naylor, R. L.; Hardy, R. W.; Buschmann, A. H.; Bush, S. R.; Cao, L.; Klingler, D. H. A 20-year retrospective review of global aquaculture. *Nature*, 2021, 591, 551–563. doi: 10.1038/s41586-021-03308-6.
- Naylor, R. L.; Hardy, R. W.; Buschmann, A. H.; Bush, S. R.; Cao, L.; Klingler, D. H.; Little, D. C.; Lubchenco, J.; Shumway, S. E.; Troell, M. A. The future of food from the sea. *Nature*, 2020, 588, 7839, 396-402.
- Oyebola, O.O.; Efitre, J.; Falaye, A.E.; Dada, T.M.; Idowu, F.C. Agriculture in the face of climate-mediated flooding in tropical Africa: technical innovations of fish farmers in South western Nigeria, in Leal, F.W. (ed), Handbook of Climate Change Resilience, 2018, Springer, Cham. 1–19.
- Paerl, H. W.; Otten, T. G. Harmful cyanobacteria blooms: A global and regional perspective. *Harmful Algae*, 2013, 14, 30-66.
- Pillai, J. K.; Vainy, P. S.; Katharina, W.; Gaelle, D.; Inka, S. Advancements in sustainable aquaculture: Practices, technologies and policies. *Aquaculture Reports*, 2021, 19, 100652.
- Pörtner, H. O.; Karl, D. M.; Boyd, P. W.; Cheung, W.; Lluich-Cota, S. E. Ocean Systems in Climate Change: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, (ed.) VR Barros, CB Field, DJ Dokken, MD Mastrandrea, and Mach, K. J. 2017, 41–84. Cambridge, UK: Cambridge University Press.
- Portner, H. O.; Farrell, A. P. Physiological biodiversity in fish: An eco-physiological approach. *Journal of Fish Biology*, 2008, 73(8), 1905-1921.
- Quisumbing, A. R.; Meinzen-Dick, R.; Terri Raney, T.; Croppenstedt, A.; Behrman, J. A.; Peterman, A. Gender in Agriculture: Closing the Knowledge Gap, 2014, Springer, Netherlands.
- Roscher, M.; Eam, D.; Suri, S.; van der Ploeg, J.; Hossain, E.; Nagoli, J.; Cohen, P.J.; Mills, D.J.; Cinner, J. Building Adaptive Capacity to Climate Change: Approaches Applied in Five Diverse Fisheries Settings, Penang, Malaysia: CGIAR Fish Agri-Food Systems Program Brief- FISH-2018-18, *World fish*, 2018, Penang, Malaysia.
- Sampaio, F. G.; Araújo, C. A. S.; Dallago, B. S. L.; Stech, J. L. Sustainable aquaculture: Improving feed efficiency and reducing environmental impacts. *Aquaculture*, 2021, 550, 737501.



Tacon, A. G. J.; Metian, M. Feed Matters: Satisfying the feed demand of aquaculture. *Aquaculture Economics and Management*, 2013, 17(2), 157-174

Tafalla, C.; Bogwald, J.; Dalmo, R.A.; Munang'andu, H.M.; Evensen, O. Fish breeding and reproduction in aquaculture: Advances and challenges. *Aquaculture*, 2020, 518, 734693.

United Nations. World Population Prospects, 2019. New York: Department of Economic and Social Affairs.

Van Aelst, K.; Holvoet, N. The role of social capital in climate change adaptation. *Environmental Science and Policy*, 2016, 79, 40-50.

Wang, J.; Zeng, Y.; Zhong, L. Impact of climate change on tourism on the QinghaiTibetan Plateau: research based on a literature review. *Sustainability*, 2021, 9(9), 1539.

Zhang, L.; Xu, E. G.; Li, Y.; Liu, H.; Vidal-Dorsch, D. E.; Giesy, J. P. IoT-based intelligent aquaculture monitoring system: A review. *Aquaculture and Fisheries*, 2021, 6(4), 257-268.

Zhou, Y.; Negishi, R.; Fukunaga, K.; Udagawa, S.; Shimabukuro, A.; Takemura, A. The impacts of education on climate change adaptation behaviours. *Climate Change*, 2021, 283, 111456.