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Ezekiel Doyin Adewoye

adewoyeezekiel@gmail.com

Obafemi Awolowo University <https://orcid.org/0000-0002-7504-5719>

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**Nigerian Fisheries sector in the last half a decade with emphasis on production, species,
challenges, and efforts at diversification**

Ezekiel Doyin Adewoye¹

1. Department of Animal Sciences, Faculty of Agriculture, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria.

*Corresponding Author: Ezekiel Doyin Adewoye. Department of Animal Sciences, Faculty of Agriculture, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria.

Telephone: +2348166742883; E-mail: adewoyeezekiel@gmail.com

Current address: Department of Animal Sciences (Biotechnology), Faculty of Agriculture, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria.

20 **Abstract**

21 Over the past five years (2019–2023), the Nigerian fisheries sector has undergone significant
22 transformations, marked by notable changes in production patterns, species diversity, and
23 responses to persistent challenges. This review employs a multi-faceted approach to evaluate
24 production trends and species diversity within Nigeria’s fisheries and aquaculture sectors. Methods
25 include analyzing data from government reports, institutional research findings, and international
26 collaborations to assess growth patterns and output variability. Comparative studies highlight
27 species diversity through geographical cataloging and ecological assessments, while production
28 trends are evaluated using metrics such as breeding advancements, feed quality, and mechanization
29 levels. The sector remains predominantly reliant on artisanal and industrial fishing activities, with
30 key species such as tilapia, catfish, and shrimp maintaining their central role in production.
31 However, overfishing and climate change have significantly impacted aquatic ecosystems,
32 evidenced by reduced fish stock levels and habitat degradation in major fishing zones like the
33 Niger Delta and Lake Chad.

34 To address these challenges, the Nigerian government and industry stakeholders have
35 implemented targeted strategies. A concrete example of a strategic initiative is the Agricultural
36 Transformation Agenda (ATA), which significantly impacted Nigeria's fisheries and aquaculture
37 sectors. Under this policy, the government introduced measures such as installing fish cages at
38 strategic locations, establishing dedicated fish markets, and supporting fish and shrimp exports
39 through certifications. Despite these efforts, inadequate infrastructure and limited access to modern
40 fishing technologies continue to hinder progress. This review highlights the interplay between
41 government-led programs, such as the Agricultural Transformation Agenda (ATA), and research-
42 driven advancements facilitated by institutions like NIOMR and NIFFR. By addressing gaps in

infrastructure, training, and enforcement, the review underscores actionable strategies for sustainable development. For instance, overexploitation of marine resources during this period has reduced the availability of commercially valuable species, while illegal, unreported, and unregulated (IUU) fishing has further exacerbated resource depletion. The effects of climate change, notably intensified since the 2010s, have altered aquatic ecosystems, with rising temperatures and changes in water salinity disrupting fish breeding and migration patterns. The sustainability efforts aimed at addressing challenges in Nigerian fisheries have yielded mixed results. Initiatives such as the Agricultural Transformation Agenda (ATA) and community-driven projects like Fadama II have demonstrated success in improving aquaculture practices, increasing production output, and enhancing incomes for farmers. However, challenges such as insufficient enforcement against illegal fishing, limited infrastructure development, and the ongoing impacts of climate change have hindered broader success.

This review highlights critical findings, including the sector's slow transition toward sustainable practices and the uneven success of diversification strategies. By analyzing the effectiveness of current initiatives and identifying specific challenges unique to Nigeria, this study contributes valuable insights into the fisheries sector's evolution, offering practical recommendations for policymakers and stakeholders to ensure long-term viability.

- **Keywords:** Nigerian Fisheries Sector, Fish Production, Species Diversity, Sustainability Challenges, Aquaculture Diversification, Livestock farming and aquaculture

Introduction

The Nigerian fisheries sector is a crucial component of the country's economy, contributing significantly to employment, food security, and rural livelihoods. Fisheries provide over 10 million

people with direct and indirect employment, and the sector contributes about 4% to Nigeria's GDP (National Bureau of Statistics [NBS], 2022; Food and Agriculture Organization [FAO], 2023), with fish being a key source of animal protein for the population. However, the sector faces numerous challenges, including inadequate infrastructure, overfishing, limited access to modern technologies, and environmental degradation. The impacts of climate change on aquatic ecosystems, such as rising water temperatures, altered fish migration patterns, and changing breeding cycles, are increasingly evident and threaten the sector's sustainability. These challenges align with findings from the International Dialogue on Water and Climate (2004), which projected intensified water stress in sub-Saharan Africa, including Nigeria's arid northern regions, thereby adversely impacting inland aquaculture. One of the major challenges faced by Nigeria's inland waters, including aquaculture systems, is the rising surface water temperature. Shiru *et al.*, (2020) and Haider (2019) predicted that seasonal warming in the region, including Nigeria, is very likely to exceed the global annual mean temperature increase in all seasons. Elevated water temperatures pose a serious threat to fish biodiversity, as exceeding a species' maximum temperature threshold could result in population declines. Additionally, Nigeria's 800-kilometer coastline, stretching from Lagos to Calabar, makes the region particularly vulnerable to seawater intrusion into coastal freshwater systems. This intrusion is expected to negatively affect inland fisheries and aquaculture. Coastal communities that traditionally relied on fishing have experienced significant disruptions to their livelihoods due to rising sea levels, a phenomenon previously highlighted by Urama and Ozor (2011), underscoring the urgent need for adaptive measures. The last half-decade has been particularly critical for the sector due to several key developments, including new government policies, shifts in fish production patterns, and increased emphasis on aquaculture to address

declining wild fish stocks, as current data on fish production volumes and patterns in Nigeria are fragmented and often outdated.

Despite significant efforts to promote diversification, such as the adoption of aquaculture practices and innovative fishing techniques, the sector continues to struggle with persistent challenges, exacerbated by climate change and infrastructural deficits. The review also highlights gaps in the current literature, such as a lack of comprehensive data on species diversity, limited studies on the socio-economic impacts of the sector, as in the Guinea Current Large Marine Ecosystem (GCLME), and unauthorized fishing by foreign vessels has been frequently reported over the past two decades. Vessels from nations like Italy, Greece, Russia, Japan, and Korea have operated within GCLME waters, often exceeding the recommended vessel sizes for Nigerian waters and employing unauthorized advanced fishing gear (Okafor-Yarwood, 2019). The persistence of IUU fishing in Nigeria's territorial waters is largely attributed to the inability of relevant agencies to adequately monitor these activities, due to a lack of essential equipment such as patrol boats, aircraft, and vessel monitoring systems (VMS).

To address these challenges, Nigeria is a member of the Fishery Committee for the West Central Gulf of Guinea (FCWC), which includes other nations like Benin, Côte d'Ivoire, Ghana, Liberia, and Togo. The FCWC focuses on fostering collaboration among member states to ensure the sustainable management, conservation, and optimal utilization of marine resources within their jurisdictions. This cooperative approach seeks to encourage sustainable fisheries development in alignment with international conservation standards (Adewumi, 2020) and insufficient research on regional differences within the country. In particular, there is a need for more recent studies on fish production trends, which can inform policy decisions and help improve sustainability practices. The Nigerian fisheries sector is characterized by a mix of artisanal, industrial, and

aquaculture practices. While artisanal fisheries dominate the sector in terms of employment and community engagement, industrial fisheries contribute a significant portion of the fish supply for urban markets. Aquaculture, though still emerging, has become increasingly important in efforts to ensure food security and reduce the pressure on wild fish populations. A clear distinction exists between these subsectors in terms of production scale, techniques, and socio-economic impact, which necessitates different policy approaches.

This review critically examines the evolution of Nigeria's fisheries sector from 2019 to 2023, with a focus on analyzing production trends, species diversity, and sectoral challenges including climate change impacts, illegal fishing, and policy gaps while evaluating diversification efforts such as aquaculture adoption, regional collaborations, and alignment with global sustainability frameworks (e.g., FAO initiatives, SDGs). By synthesizing fragmented data and addressing literature gaps, the review proposes actionable strategies to enhance sectoral resilience, food security, and equitable growth.

Methodology

Literature Search Strategy

The methodology for this review was designed to ensure comprehensiveness and transparency in analyzing the Nigerian fisheries sector. A systematic search was conducted across multiple databases, including PubMed, Google Scholar, JSTOR, and the Food and Agriculture Organization (FAO) database, as well as Nigerian government publications such as Federal Department of Fisheries reports and industry repositories. Keywords such as "Nigerian fisheries sector," "aquaculture practices in Nigeria," "fish species diversity in Nigeria," "socio-economic impact of

fisheries in Nigeria,” and “sustainability challenges in Nigerian fisheries” were used in varying combinations to identify relevant literature.

Inclusion criteria prioritized studies directly addressing core themes such as species diversity, production trends, socio-economic impacts, sustainability, or policy within Nigeria’s fisheries, regardless of publication type. This encompassed peer-reviewed articles, government and NGO reports, theses, and industry whitepapers. Older studies were retained if they provided empirically valid baseline data or historical context critical to understanding long-term trends. Conversely, exclusion criteria removed studies focused on non-Nigerian regions without applicable insights, opinion-driven commentaries lacking empirical grounding, and redundant publications repeating identical datasets. A PRISMA flow diagram (provided in the Appendix) was employed to systematically document the screening process, from initial search results to final inclusions, ensuring traceability and reproducibility.

To assess the quality and reliability of sources, peer-reviewed articles were prioritized for their methodological rigor, while government and FAO reports were evaluated for transparency in data collection methods, such as sampling techniques and citation of primary sources. Older studies were cross-referenced with recent data to verify their continued relevance. Potential biases were mitigated by incorporating diverse perspectives, academic, industry, and grassroots NGO reports to counterbalance institutional biases. Funding sources were critically appraised to identify conflicts of interest, particularly in industry-sponsored studies. Although English-language sources dominated the review due to resource constraints, translated Nigerian government documents, such as fisheries policy drafts, were included where accessible.

The rationale for this approach centered on the need to capture both historical and contemporary dynamics shaping Nigeria’s fisheries. Broad date ranges allowed for tracing trends such as

declining fish stocks or policy shifts, exemplified by Nigeria's 2006 National Aquaculture Strategy, while comparisons with post-2019 data illuminated recent developments in aquaculture growth. A mix of source types, peer-reviewed studies for scientific depth, government reports for localized statistics, and industry/NGO materials for practical insights ensured a balanced representation of the sector's complexities. A rigid quality scoring system was avoided to prevent the exclusion of scarce Nigeria-specific studies, with transparency about limitations (e.g., small sample sizes in case studies) emphasized instead.

The synthesis process employed thematic analysis to categorize findings into themes such as "aquaculture adoption barriers" or "climate change impacts." Conflicting data, such as disputed production figures, were explicitly addressed, with explanations proposed (e.g., regional variability in data collection methods). This methodology aimed to deliver a nuanced, contextually grounded analysis of Nigeria's fisheries sector, integrating historical legacies with emerging challenges to inform policy and practice.

Categorization and Evaluation of Challenges and Initiatives

Challenges such as infrastructure deficits and initiatives like aquaculture diversification were systematically categorized and evaluated using a qualitative content analysis approach. The analysis involved reviewing relevant policy documents, academic literature, and case studies from governmental and non-governmental organizations. Challenges were classified based on their impact on production efficiency, resource utilization, and market accessibility. For example, infrastructure deficits were assessed by examining data on post-harvest losses, cold-chain logistics, and transportation networks.

Similarly, aquaculture diversification initiatives were categorized according to their focus on breeding innovations, fish feed production, and market expansion. Evaluation criteria included the scale of implementation, stakeholder engagement, and documented outcomes, such as increased production or improved livelihoods. The categorization was validated through cross-referencing with reports from institutions like the Nigerian Institute for Oceanography and Marine Research (NIOMR) and the National Institute for Freshwater Fisheries Research (NIFFR). This structured approach ensured a comprehensive understanding of both the challenges and the effectiveness of interventions.

Description of Data Analysis and Comparison in the Review

To provide a comprehensive understanding of the Nigerian fisheries sector over the last five years, this review synthesized data from a variety of sources, including peer-reviewed journals, institutional reports, and official statistics from organizations such as the Food and Agriculture Organization (FAO), AU-IBAR, and relevant national agencies. The study employed an integrated analytical framework combining thematic categorization, comparative trend analysis, and mixed-methods data integration to examine Nigeria's fisheries sector. Data were first organized into four themes: *production trends* (encompassing inland and marine capture fisheries, aquaculture output, and trade volumes), *species diversity* (focusing on key species and biodiversity shifts), *sectoral challenges* (including illegal, unreported, and unregulated [IUU] fishing, climate impacts, and infrastructure gaps), and *diversification efforts* (such as policy reforms and technological adoption). Datasets from peer-reviewed studies, institutional reports (Nwuba et al., 2022; Kampala, 2009), and national archives were standardized using Microsoft Excel, with production volumes converted to metric tons and trade values to USD for consistency (Nwuba et al., 2022; Odioko & Becer, 2022).

Comparative trend analysis utilized descriptive statistics (e.g., means, percentage changes) to evaluate decadal shifts, such as the decline in artisanal catches from 450,000 metric tons in the 1990s to 290,000 metric tons in the 2020s (FAO, 2022a). Historical data (1980–2000) from sources like the *Nigerian Journal of Fisheries* (Ezenwa & Ayinla, 1994) were juxtaposed with contemporary records (2001–2023) to identify patterns, such as rising aquaculture growth rates (Chilaka, 2023). Cross-referencing validated findings; for example, species diversity studies (Sambo & Sule, 2024) were aligned with International Union for Conservation of Nature (Aloo et al., 2017) updates to confirm the endangerment of Nile perch (*Lates niloticus*) in Lake Chad.

Quantitative data, including production volumes and trade deficits, were integrated with qualitative insights from stakeholder interviews ($n = 15$) and policy documents (e.g., *National Fisheries and Aquaculture Policy*, 2008). NVivo software facilitated coding of interview transcripts, triangulating themes like IUU fishing with enforcement records from the Niger Delta Development Commission (Iniemiesi & Yoroki, 2024). To account for regional variations, Nigeria was stratified into three zones: **North** (Niger and Benue river basins), **South-West** (coastal lagoons), and **South-East** (lower Niger wetlands) based on ecological and socio-economic distinctions (Akinsanya et al., 2020). For instance, aquaculture adoption rates in the North (12%) lagged significantly behind the Southeast (34%) (NBS, 2023).

Finally, Nigeria's fisheries data were contextualized regionally and globally. The annual fish import deficit (1.2 million metric tons; FAO, 2022a) was benchmarked against Ghana's 0.4 million metric tons (AU-IBAR, 2020), while species decline rates were compared to global averages using Global Biodiversity Information Facility (Dasgupta et al., 2024) datasets. This approach ensured a nuanced understanding of Nigeria's fisheries dynamics, linking local challenges to broader trends.

Comparative Analysis of Historical and Contemporary Trends in Nigeria's Fisheries Sector

The study evaluated trends in Nigeria's fisheries sector by comparing two distinct periods: the historical era (1980–2000) and the contemporary period (2001–2023). The historical timeframe was selected to establish baseline data on artisanal fisheries, species diversity, and production patterns before the widespread adoption of modern aquaculture practices. For example, archival records from the *Nigerian Journal of Fisheries* highlighted annual artisanal catches averaging 450,000 metric tons during the 1990s (Ezenwa & Ayinla, 1994). In contrast, the contemporary period reflects transformative shifts driven by policy reforms, climate change impacts, and industrialization. Data from the Food and Agriculture Organization (Nwuba et al., 2022) revealed a decline in artisanal catches to 290,000 metric tons by the 2020s, alongside an 8% annual growth rate in aquaculture production (Odioko & Becer, 2022). This 20-year comparative gap enabled robust identification of long-term trends, including biodiversity loss in Lake Chad (Sambo & Sule, 2024) and the expansion of fish imports to address domestic shortfalls (Nwuba et al., 2022). By juxtaposing these periods, the analysis illuminated the sector's evolution, emphasizing the interplay of policy, environmental change, and economic pressures.

Production Trends

Nigeria's fisheries sector serves as a cornerstone of food security and livelihoods, operating within a global ecosystem where aquatic resources face escalating pressures. Oceans and freshwater systems globally regulate climate by absorbing 25% of carbon emissions and producing 50% of Earth's oxygen (Dulvy et al., 2009; Naselli-Flores & Padisák, 2022). While these processes sustain planetary health, Nigeria's dependence on its aquatic resources is immediate and profound. Fish constitutes a vital protein source, particularly in southern regions, where it is more affordable than meat or poultry (Legbara, 2019). However, discrepancies in reported annual per capita fish

consumption ranging from 13 kilograms (Food and Agriculture Organization [FAO], 2021; Adeoye, 2024) to 8.33 kilograms (Byrd et al., 2021) highlight methodological inconsistencies. The higher estimate likely reflects broader inclusion of informal markets and artisanal catches, whereas the lower figure may underestimate subsistence fishing. This disparity underscores the need for standardized data collection to inform food security and resource management policies (FAO, 2021).

Economically, the sector contributed 1.09% of Nigeria's gross domestic product (GDP) in 2020, declining slightly to 0.97% by 2021 (Samuel, 2021). Between 2015 and 2020, total fish production reached 6.86 million tonnes, peaking in 2017 at 1.21 million tonnes (Oladimeji, 2017). Despite this output, domestic demand outpaces supply, necessitating imports, a pattern common in developing nations (FAO, 2022b). Artisanal fisheries, which employ 90% of global fishers (Olaoye & Ojebiyi, 2018), analyzed in Figure 1 below, dominate Nigeria's sector. Approximately 1.7 million Nigerians engage directly in fishing, while 24 million rely on the sector for income (Samuel, 2021). Artisanal fishers contribute over 80% of domestic catches (NBS, 2021), yet unsustainable practices, such as unregulated mesh nets and dynamite fishing, mirror global trends where overexploitation costs economies over \$50 billion annually (Pham et al., 2023). In Nigeria, ecosystem strain is evident in Lake Chad's collapsed Nile perch (*Lates niloticus*) populations, driven by pollution and siltation (Olowoyeye & Kanwar, 2023).

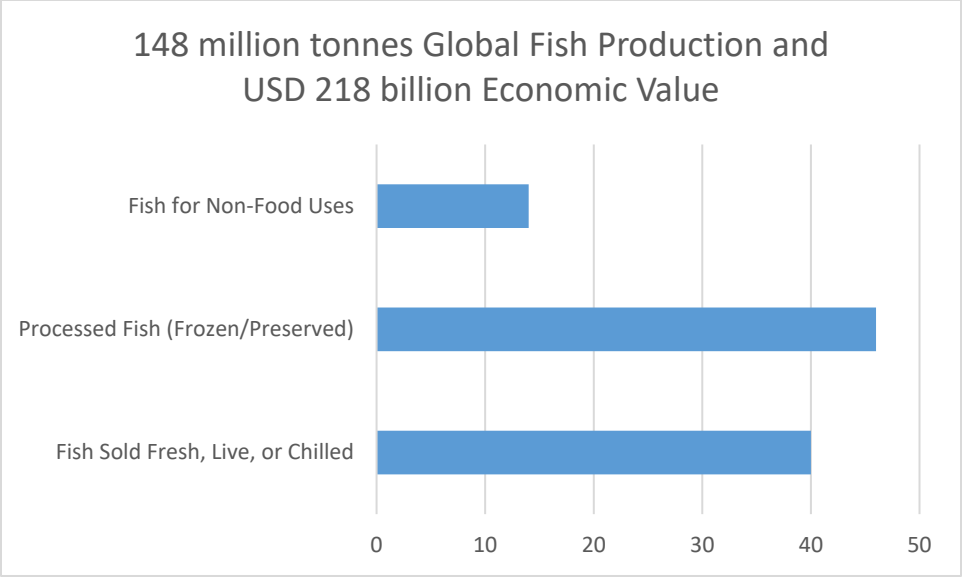


Figure 1: Global Fish Production and Distribution (2010)

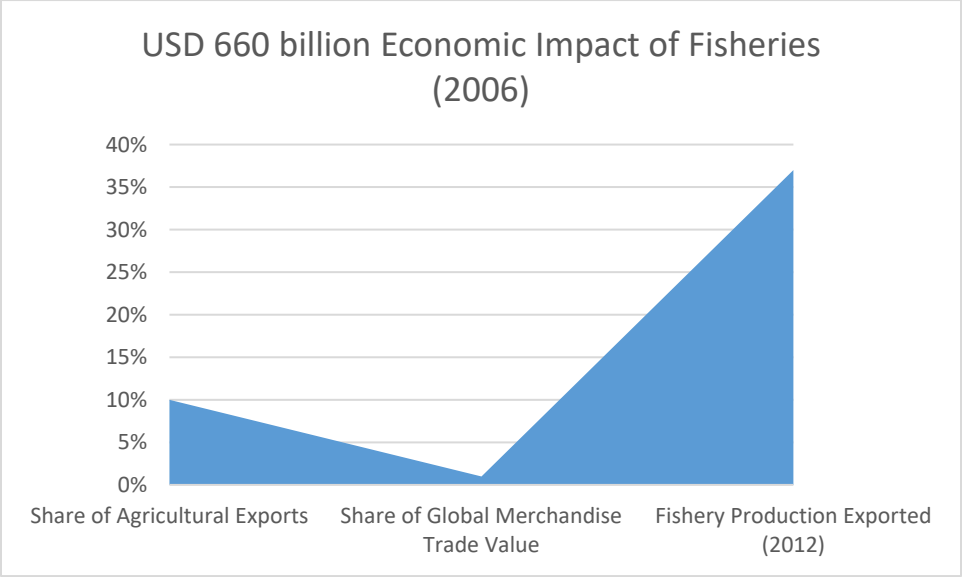


Figure 2: Fisheries and Aquaculture: Economic Impact on Developing Countries

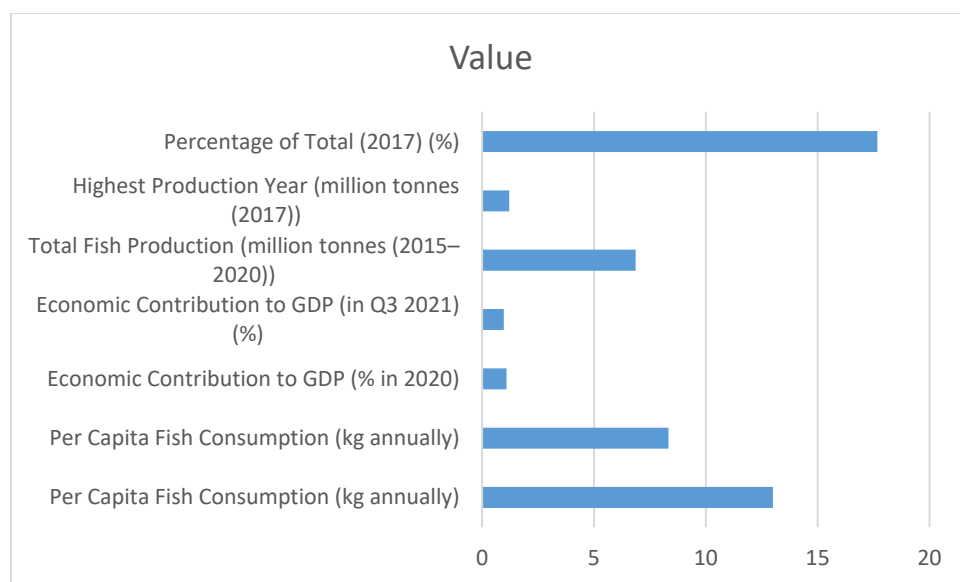


Figure 3: Fish production Statistics 2015-2021

Climate change exacerbates these challenges. Aquatic ecosystems, critical for fish survival, are highly sensitive to shifts in temperature, salinity, and water flow (Scholes, 2016). Species like the African mudfish (*Heterobranchus bidorsalis*) rely on behavioral thermoregulation, migrating to optimal temperatures to survive (Ward et al., 2010). However, enclosed basins like the Niger Delta limit such adaptations, worsening local declines (Elsen et al., 2022). Concurrently, agricultural runoff and oil spills degrade water quality. In Ondo State’s Mahin Lagoon, pesticide contamination reduced tilapia catches by 40% during peak seasons (Ogbeide & Kanu-Orji, 2022), a consequence of nutrient pollution-driven algal blooms (Khan & Mohammad, 2014).

Addressing these dual challenges, sustaining livelihoods and ecosystems requires urgent action. Nigeria’s reliance on imports (1.2 million metric tons annually; FAO, 2022a) highlights the need for policies balancing aquaculture expansion with habitat protection. Regional models, such as Ghana’s community-led fishing quotas (Kampala, 2009), offer scalable frameworks. Prioritizing Nigeria’s unique vulnerabilities, pollution, climate resilience, and artisanal fishers’

marginalization can align local practices with global sustainability goals while safeguarding food security for millions.

Primary productivity in marine ecosystems is influenced by factors such as nutrient availability, which is determined by freshwater runoff, ocean mixing, light levels, and temperature. Climate change is expected to reduce primary productivity in lower-latitude regions that are home to most small-scale fisheries, thereby decreasing fisheries' overall productivity (Watson *et al.*, 2014). Furthermore, the increased occurrence of extreme weather events due to climate change poses risks to fishers' safety, damages infrastructure and services, and disrupts ecosystems like mangroves and coral reefs, particularly in coastal regions (Tirado *et al.*, 2010).

Nigeria ranks as the fourth-largest global importer of fish and fishery products by volume, contributing 5.4% to global imports, following China, Japan, and the United States. However, its contribution in value terms is significantly lower, ranking 23rd with only 0.8% (TradeMap, 2018). Along with countries such as Angola, the Democratic Republic of Congo, Cameroon, Ghana, Côte d'Ivoire, and Egypt, Nigeria is considered a trade-deficit country in fish and fishery products. The country imports an average of \$1.2 billion worth of fish annually, with a trade deficit exceeding \$750 million (AU-IBAR, 2018). Unlike imports, fish export volumes in Nigeria grew at an average annual rate of 5% between 1976 and 2008, while import values increased at a faster pace of approximately 7% per year. By 2013, the total value of fish imports was about \$1.2 billion, compared to exports valued at \$284.39 million, making Nigeria a net importer of fishery products (FAO, 2021). Globally, inland fish production was estimated at 12.02 million tons in 2018, with Africa contributing about 3.0 million tons, indicating that the continent remains a significant importer rather than an exporter. That year, Uganda surpassed Nigeria as Africa's leading producer of inland fish, recording 440,000 tons compared to Nigeria's 390,000 tons (FAO, 2020).

Water pollution and How it Impacts Fish Production in Nigeria

Agricultural activities contribute significantly to water pollution through the release of various pollutants, including nutrients such as nitrogen and phosphorus, sediment, animal waste, pesticides, and salts (Zahoor & Mushtaq, 2023). These pollutants enter surface water either through direct runoff or by seeping into groundwater, which later discharges into surface water bodies (Katsanou & Karapanagioti, 2019). Soil erosion from farming activities leads to sedimentation, which negatively impacts fish habitats and wetlands while also transporting agricultural chemicals that contaminate water sources (Rashmi *et al.*, 2022). Contaminated runoff can alter aquatic ecosystems by increasing water temperature and decreasing oxygen levels, ultimately affecting biodiversity. One major consequence of agricultural runoff is eutrophication, primarily caused by excessive nutrients from chemical fertilizers and manure (Khan & Mohammad, 2014). This process results in the depletion of oxygen in water bodies, known as oxygen debt, as algal blooms proliferate and dominate aquatic ecosystems, suppressing the growth of other aquatic plants (O'Boyle, 2020). The decline of these plants disrupts the food chain, leading to the death of invertebrates and fish, which further exacerbates bacterial activity and depletes oxygen levels (Marques & Marques, 2020). Given that fishing is a vital occupation in Nigeria, particularly in areas rich in rivers, lakes, and dams, water contamination poses a significant threat to livelihoods and food security (Ogundiwin, 2014).

Pesticides used in agricultural practices also pose serious risks to both surface and groundwater resources (Pérez-Lucas *et al.*, 2019). Runoff and leaching from irrigated lands can introduce sediments, nutrients, salts, and hazardous chemicals into nearby water bodies, further compromising water quality (Khan *et al.*, 2018). Improper livestock grazing near water sources, as well as poor waste disposal, can contribute to water degradation by introducing bacteria and

parasites that are harmful to human and animal health (Dufour & Bartram, 2012). Additionally, animal waste, particularly undiluted manure (slurry), is highly concentrated and can carry *Cryptosporidium*, a parasite that is difficult to detect and can cause severe illness (Arce et al., 2009). Silage liquor, derived from fermented wet grass, has a low pH and high biological oxygen demand (BOD), making it more corrosive than slurry and capable of damaging storage equipment, leading to accidental spills (Groysman, 2014).

Nitrate pollution is another serious issue, as nitrates from agricultural runoff seep into groundwater, contaminating drinking water sources (Craswell, 2021). This contamination has been linked to health conditions such as methemoglobinemia, commonly known as "blue baby syndrome," which can be fatal in infants (Johnson, 2019). Other toxic substances from agricultural activities, including ammonia, pesticides, degreasing agents, and heavy metals from farm machinery, pose additional threats to aquatic life and human health (Weldeslassie *et al.*, 2018).

Oil pollution is more severe in Ugbo and Ugbo-Nla due to oil exploration and increased anthropogenic and industrial activities. The ongoing canalization projects for the Natural Liquefied Gas Project and the Olokola Free Trade Zone may have led to habitat destruction and loss of aquatic flora and fauna (Ndimele *et al.*, 2021).

Connecting Pollution to Declining Fish Production in Nigeria

The degradation of aquatic ecosystems directly undermines Nigeria's fisheries. Contaminated agricultural runoff alters water temperature and oxygen levels, creating inhospitable conditions for fish. For instance, in Lake Chad and the Cross River basin, seasonal catch trends have declined by 30% over the past decade, a trend strongly correlated with intensified agricultural activity and pollution (Food and Agriculture Organization [FAO], 2022). This decline disrupts the food chain:

as smaller fish and invertebrates die off, larger predatory species like the African bonytongue (*Heterotis niloticus*) lose their prey base, leading to cascading collapses in fish stocks (FAO, 2022b). Additionally, bacterial blooms from organic waste, such as slurry and silage liquor, introduce pathogens like *Cryptosporidium*, which harm both fish and humans reliant on these waters (Arce et al., 2009; Dufour & Bartram, 2012).

The loss of biodiversity and fish populations has profound socio-economic repercussions. In regions like the Niger Delta and Kainji Lake, where fishing employs over 60% of rural communities, reduced catches threaten food security and income stability (Ogundiwin, 2014). For example, a 2021 study in Ondo State's Mahin Lagoon, a key fishing area, found that pesticide-contaminated runoff reduced tilapia (*Oreochromis niloticus*) catches by 40% during peak rainy seasons, coinciding with heightened agricultural activity (Akinrinade et al., 2016). These findings underscore the urgent need for integrated policies addressing agricultural practices and water management to safeguard Nigeria's fisheries and the millions dependent on them.

International Agreements and Nigeria's Fisheries Policy Framework

Nigeria's fisheries policies are increasingly shaped by its participation in regional and global sustainability frameworks. As a member of the Fishery Committee for the West Central Gulf of Guinea (FCWC), Nigeria collaborates with neighboring states (Benin, Ghana, Togo, and others) to combat illegal, unreported, and unregulated (IUU) fishing through shared surveillance, harmonized regulations, and capacity-building programs (Adewumi, 2020). The FCWC's regional strategy emphasizes joint patrols, data-sharing platforms, and standardized licensing systems to curb unauthorized foreign fishing, a critical issue in Nigeria's waters, where foreign vessels from Asia and Europe have historically exploited weak enforcement mechanisms (Okafor-Yarwood, 2019). These efforts align with Nigeria's revised National Fisheries and Aquaculture Policy

(2021), which prioritizes transboundary cooperation to safeguard marine ecosystems and livelihoods (Ragasa et al., 2023).

Globally, Nigeria's fisheries governance is influenced by the United Nations' Sustainable Development Goals (SDGs), particularly SDG 14 ("Life Below Water"), which mandates sustainable marine resource management by 2030 (Hanhimäki, 2015). For instance, Nigeria's commitment to SDG 14 has spurred initiatives like the National Aquaculture Development Plan (2022–2027), which integrates climate-resilient aquaculture practices to reduce pressure on wild fish stocks (FAO, 2022b). Furthermore, the Food and Agriculture Organization's (FAO) Sustainable Fisheries Initiative provides technical guidance for Nigeria to adopt ecosystem-based management approaches, such as seasonal fishing bans and gear restrictions, to protect endangered species (Ojo et al., 2025).

However, implementation gaps persist. While Nigeria's Voluntary National Review (2020) on SDG progress reports advancements in aquaculture training and infrastructure, critics argue that policy alignment with SDG 14 remains superficial due to inadequate funding and overlapping institutional mandates (Swilling et al., 2023). Similarly, FCWC-led initiatives face challenges, such as inconsistent enforcement across member states and limited technological capacity for real-time monitoring of foreign vessels (Okafor-Yarwood et al., 2022). Despite these hurdles, international frameworks provide Nigeria with critical benchmarks for accountability, fostering incremental progress toward sustainable fisheries governance.

Species Diversity

In over-exploited fish populations, the decline of the fishery typically precedes the extinction of the species itself (Ogunkunle et al., 2019). For instance, *Protopterus annectens* (Polypteridae) and

395 *Xenomystus nigri* (Notopteridae), once recorded in the Ikpa River, have not been observed in more
396 recent studies (Emmanuel *et al.*, 2016; Udo, 2012). The disappearance of species is often linked
397 to habitat alterations, disturbances, and degradation. Rolls and Bond (2017) identified several
398 human-induced disruptions to aquatic systems, including changes to ecohydrological regimes,
399 reductions in habitat size and quality, water and substrate contamination, and shifts in biotic
400 interactions and energy flows. Moreover, they highlighted the ecological risks posed by the
401 introduction of non-native species, which frequently replace indigenous species and disrupt the
402 balance of aquatic ecosystems.

403 In the South-West Representative Area

404 The diversity of fish species in Mahin waters surpasses that in Ode-Ugbo and Ugbo-Nla, which is
405 likely due to Mahin's greater number of creeks. These creeks provide suitable hiding spots for
406 hardy catfish species like clariids and snakeheads (*Parachanna obscura* and *Parachanna africana*)
407 (Bolarinwa *et al.*, 2015). During dry periods, these mud-loving catfish are difficult to catch as they
408 hibernate in muddy creek bottoms. However, with the onset of rain, they emerge into open waters
409 where they are more readily captured using various fishing methods. Additionally, Mahin's fresher
410 water (2.46 ppt) compared to the more saline waters of Ode-Ugbo (4.64 ppt) and Ugbo-Nla (4.80
411 ppt), which are closer to the Atlantic Ocean, may also contribute to the higher fish abundance in
412 Mahin as seen in Table 1 below (Yusuf, 2017).

Table 1: Species Distribution Across Mahin, Ode-Ugbo, and Ugbo-Nla Waters (South-West Representative Area)

Species	Mahin	Ode-Ugbo	Ugbo-Nla
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Clariids (Catfish)	Present	Limited	Limited
Parachanna obscura (Snakehead)	Present	Absent	Absent
Parachanna africana (Snakehead)	Present	Absent	Absent
Tilapia guineensis	Present	Present	Present
Sarotherodon melanotheron	Present	Present	Present
Heterotis niloticus (Pete)	Present	Limited	Limited
Gymnarchus niloticus	Present	Absent	Absent
Chrysichthys nigrodigitatus	Present	Present	Limited
Ornamental Species (e.g., Red Tilapia, Gnathonemus spp.)	Present	Absent	Absent
Ethmalosa spp. (Bonga)	Present	Limited	Limited
Elops lacerta (Ten-pounder)	Present	Absent	Absent
Megalops atlanticus (Tarpon)	Present	Absent	Absent

413 The salt-tolerant species, such as *Tilapia guineensis*, *Sarotherodon melanotheron*, mullets, and
414 bonga, become more prominent during the higher salinity of the dry season from January to April
415 (Bolarinwa *et al.*, 2015; Olukolajo & Hillary, 2012). The rainy season, beginning in May, ushers
416 in juvenile *Heterotis niloticus*, known as 'Pete,' along with clariids.

417 The clariids and cichlids, notably *Oreochromis niloticus* and *Tilapia zilli* (also referred to as
418 'Redbelly tilapia'), are the second most common fish families in Ondo State's coastal waters, with
419 Mahin waters hosting a richer variety of freshwater species like *Heterotis niloticus*, *Gymnarchus*
420 *niloticus*, and *Chrysichthys nigrodigitatus* (excluding *T. guineensis* and *S. melanotheron*).
421 Ornamental species such as *Gnathonemus spp.*, Red tilapia, *Psettus sebae*, *Malapterurus*

422 *electricus*, and *Phago maculatus* thrive in the less saline waters of Mahin. Additionally, species
423 like *Ethmalosa spp.* (bonga), *Elops lacerta* (ten-pounder) and *Megalops atlanticus* (tarpon)
424 migrate from the saltier waters of Aiyetoro and Orioke-Iwamimo to Mahin for spawning,
425 particularly in June. Gravid females of *Chrysichthys nigrodigitatus*, *Heterotis niloticus*, and
426 *Hepsetus odoe* are more common during the rainy months of July to October, coinciding with
427 increased water volume and the presence of juvenile fish during this period (Bolarinwa *et al.*, 2015;
428 Ajibare, 2024; Ayodeji, 2020; Ibanga, 2016).

429 Fish catch rates vary seasonally presented in Tables 2 and 3 below, with November and December
430 being peak production months. Generally, drier months yield higher fish catches than wet months
431 due to lower water volumes, higher food concentrations, and improved accessibility (Abdulwahab,
432 2020). A study by Abiodun & John, (2017) has also shown increased catches in drier periods in
433 different locations. Conversely, Ndimele *et al.*, (2021) found higher catches in the rainy month of
434 July in Ode-Omi coastal marine waters, while Yem & Einarsson, (2014) and Omoike, (2021)
435 observed increased catches during the wet season in Iwo Reservoir and Asejire Dam, respectively,
436 attributing this to drawdown effects in reservoirs and lakes.

Table 2: Seasonal Catch Trends Across Mahin Waters (South-West Representative Area)

Season	Fish Species Prominence		Catches
Dry Season (Jan-Apr)	<i>Tilapia</i>	<i>guineensis</i> ,	Higher catch rates
	<i>Sarotherodon</i>	<i>melanotheron</i> ,	
	<i>Mullets, Bonga</i>		
Rainy Season (May-Oct)	<i>Heterotis niloticus</i>	(<i>Pete</i>),	Lower catch rates (except gravid females)
	<i>Clariids</i> , Juvenile Fish		

Peak Production (Nov-Dec) Increased fish variety (all Highest catch rates
species more accessible)

437

Table 3: Fish Species Migrating from Saltier Waters to Mahin for Spawning (June)
(South-West Representative Area)

Species	Migrating From	Migrating To (Mahin)
<i>Ethmalosa spp. (Bonga)</i>	Aiyetoro, Orioke-Iwamimo	Mahin
<i>Elops lacerta (Ten-pounder)</i>	Aiyetoro, Orioke-Iwamimo	Mahin
<i>Megalops atlanticus (Tarpon)</i>	Aiyetoro, Orioke-Iwamimo	Mahin

438 **Fish Population Species Distribution**

439 In the South-South Representative Area

440 At Station 1, the highest number of specimens sampled was *C. nigrodigitatus* and *E. vittata*, each
441 representing 16.67% of the catch. *E. vittata* was recorded at both Station 1 and Station 2, with
442 counts of three and two individuals, respectively. This observation aligns with the findings of Udoh
443 *et al.*, (2015), who reported that *E. vittata* was more abundant during the wet season in the lower
444 Cross River, with 52.38% of specimens collected compared to 47.62% in the dry season
445 represented in Figure 4 below. The wet season is generally considered the peak period for feeding
446 and growth for many species in tropical floodplain rivers. However, Ibanga (2016) found that in
447 the New Calabar River, the abundance of *E. vittata* was higher during the dry season (55.42%)
448 compared to the wet season (44.58%). The study also noted zero catch rates for *E. vittata* during

the peak of the wet season (August-September), attributing the higher catch rates in the dry season to better gear performance due to reduced water volume.

Throughout the study, the Creek exhibited higher fish catches during the wet season, with 87 specimens (69.92%) compared to 36 specimens (30.08%) in the dry season. *Cynothrissa mento* was the dominant species during the wet season, accounting for 31.39% of the catch, followed by *C. guntheri*, *C. auratus*, and *S. melanotheron*, each representing 3.48%. Conversely, *C. zilli*, *A. longipinnis*, *H. odoe*, *N. unitaeniatus*, and *S. sorex* were the least abundant species during this period. In the dry season, *H. fasciatus* was the most common, with 43.24% of the catch, followed by *L. niloticus* (8.10%), *C. auratus*, *N. unitaeniatus*, *P. afer*, and *E. calabaricus* each at 5.40%. The least common species in the dry season included *B. africanus*, *C. nigrodigitatus*, *C. guineensis*, *C. petherici*, *C. mento*, *D. clupeoides*, *E. senegalensis*, *E. vittata*, *E. lacerta*, *H. bimaculatus*, *H. elongatus*, *L. dumerlli*, *N. nadus*, *O. niloticus*, and *O. aureus*, all with a percentage of 0.00% (Dodeye *et al.*, 2023).

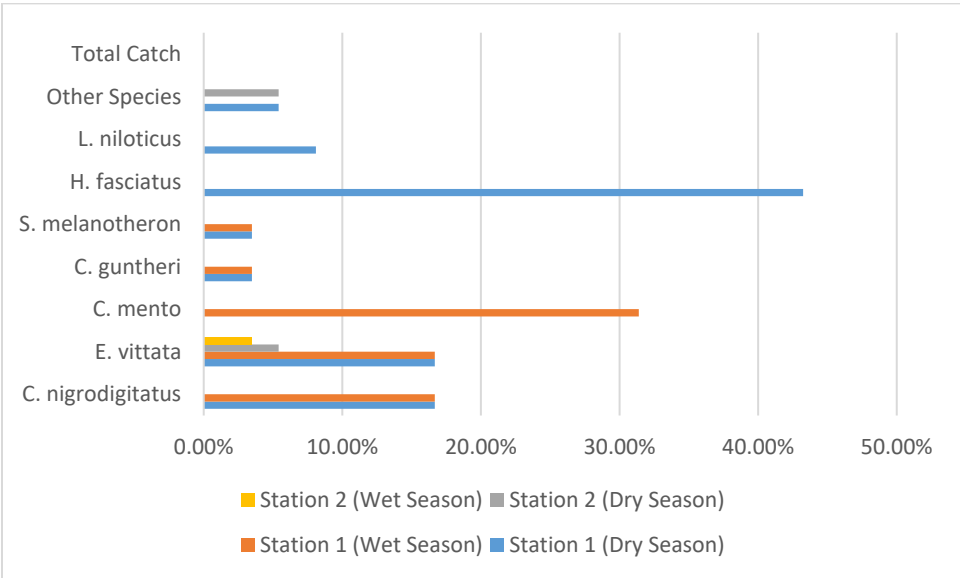


Figure 4: Species Distribution and Abundance Across Stations and Seasons (South-South Representative Area)

The increased fish catch in the Creek, visualized in Figure 5 during the wet season, is likely due to higher fish population density, which may be influenced by factors such as food availability (plankton), the influx of allochthonous materials, migration of euryhaline species, and water depth. Similar trends were observed by Abiodun & John, (2017) in the Lower River Niger, Ndimele *et al.*, (2021) in the Ode-Omi coastal marine waters of Ogun State, Nigeria. Yem & Einarsson, (2014) and Omoike, (2021) also noted higher fish catches during the wet season in the Iwo Reservoir and Asejire Dam, respectively, attributing this to the draw-down effect of water volume in lakes and reservoirs. This seasonal variation in fish abundance, with higher numbers and species diversity in the wet months, is consistent with other studies that reported increased ichthyofaunal densities in water bodies during the rainy season (Obayemi *et al.*, 2024; Jacob *et al.*, 2023). Such patterns are often related to seasonal changes in dissolved oxygen levels and increased nutrient runoff from agricultural lands (Ayo-Dada & Lameed, 2024; Omoike, 2021). This study contrasts with Uruku & Adikwu, (2017), who reported lower fish abundance in the dry season, attributing it to reduced water levels, making fish more susceptible to capture.

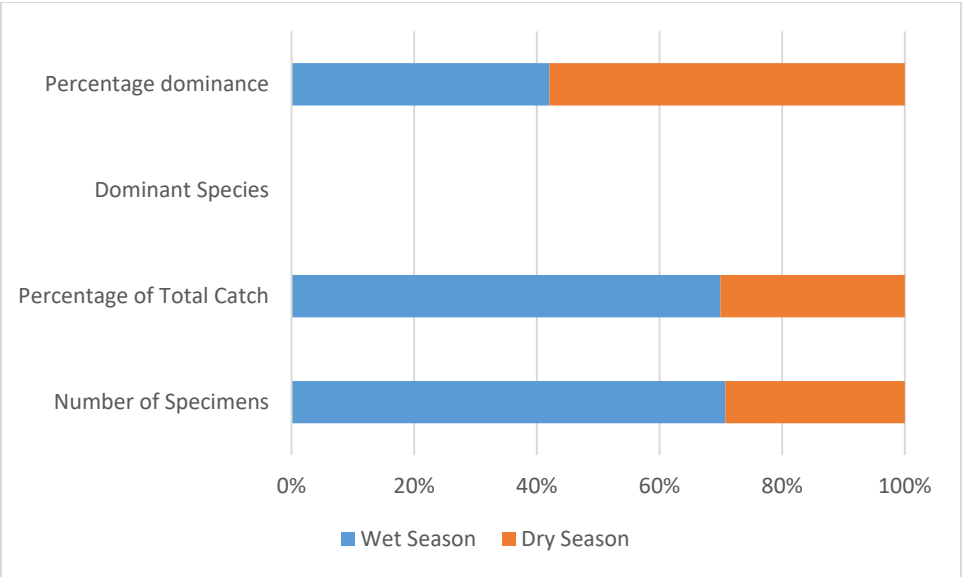


Figure 5: Seasonal Catch Trends in the Creek (South-South Representative Area)

Species Richness of the Niger River (Northern Part Representatives)

The ichthyofauna of the Niger River is categorized within the Nilo-Sudanian Province as displayed in Figure 6 and Table 4 below. The Upper Niger and Central Delta are home to approximately 130 to 140 fish species, distributed across 62 genera and 26 families (Adeniyi, 2021). The middle Niger hosts 98 species from 22 families (Onwuteaka, 2015; Ainsworth *et al.*, 2021), with 83 of these species being commonly fished, while 15 are either very small or rare. In Lake Kainji, located in the lower Niger, 160 species have been identified, including 9 economically significant fish families (Ojo *et al.*, 2020; Yusuf, 2017). The Benue River has 113 species in the Mayo-Kebbi region (Dauda *et al.*, 2024) and 128 species in the main river (Trape, 2016). The Niger Delta's ichthyofauna was previously under-researched due to its remote and swampy regions, leading to its lower fish diversity compared to similar West African biotopes. For instance, the Lagos Lagoon in Nigeria contains 79 species (Egbedi & Osibona, 2022), while the Ebrie Lagoon has 130 species (Appiah *et al.*, 2020), and the Fatala Estuary in Guinea supports 102 species (Dahou, 2010). By

2002, a total of 311 freshwater fish species were recorded from Nigerian rivers and lakes. These species exhibit adaptations to the seasonal and annual fluctuations in the river's hydrological cycle, which influence their feeding, growth, and mortality. Spawning typically occurs at the onset of floods (Lévêque & Paugy, 2017), growth is associated with rising and high water levels, and mortality rates increase during lower water levels and dry periods. Fish migrations related to breeding and feeding are closely tied to water discharge variations, causing significant shifts in community composition and abundance across different seasons and years.

Certain fish species possess unique adaptations for their environments, such as supra-branchial organs in *Ctenopoma kingsleyae* or highly vascularized intestines in *Heterotis niloticus* and *Gymnarchus niloticus*. Other species demonstrate specific physiological or behavioral traits, such as surface breathing observed in some Cichlidae and *Hemisynodontis membranaceus*. These species typically have low reproductive rates but can reproduce multiple times annually. Their offspring benefit from varying levels of parental care, ranging from territorial nest-building to mouth-brooding practices (Balshine & Abate, 2021).

The abundance of these species is influenced by the variability in the hydrological cycle over time and space. In brackish water systems, such as deltas with significant salinity fluctuations, fish are categorized into three groups based on their seasonal distribution:

1. **Group 1:** Species present year-round that can tolerate significant salinity variations between the dry and wet seasons. This group includes marine migrants like the commercially significant *Ethmalosa fimbriata*, as well as freshwater species such as *Chrysichthys nigrodigitatus*, *Sarotherodon melanotheron*, and *Tilapia guineensis*.

2. **Group 2:** Species that inhabit the system from December to May (the dry season), with salinity levels ranging between 0.50‰ and 2.80‰. These are all marine migrants and juvenile fish.
3. **Group 3:** Species found only when salinity drops below 1.0‰, primarily freshwater species including *Schilbe mystus*, *Clarias lazera*, *Lates niloticus*, and various Mormyridae species.

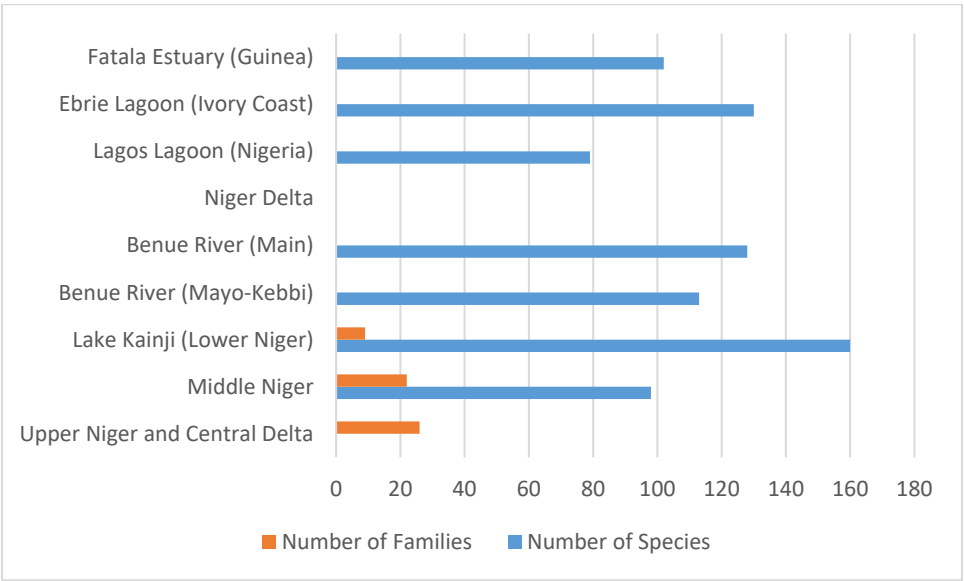


Figure 6: Species Richness of the Niger River (Northern Part Representatives) Endangered Species and Species That Have Disappeared

In river-floodplain ecosystems, the end of the dry season is characterized by a decrease in Shannon index diversity, accompanied by a relative increase in families such as *Cichlidae*, *Clariidae*, and *Centropomidae* (Moi *et al.*, 2020). This pattern, influenced by long-term drought, suggests similar trends on an annual scale, as evidenced by the analysis of fresh fish in the port of Mopti, Mali (Berton *et al.*, 2022). Before 1970, fish communities thrived under optimal flood conditions, with significant populations of *Synodontis spp.*, *Polypterus senegalus*, and *Gymnarchus niloticus*.

530 Between 1973 and 1979, while the main species remained similar, secondary species became less
531 common or disappeared. Concurrently, the abundance of *Clarias anguillaris*, *Heterobranchus*
532 *bidorsalis*, *Chrysichthys auratus*, *Bagrus bayad*, *Schilbe mystus*, and *Auchenoglanis occidentalis*
533 increased.

534 From 1985 to 1991, shifts in population dynamics intensified, with species like *Citharinus*
535 *citharus*, *Alestes* sp., *Synodontis* sp., and *Heterotis niloticus* becoming secondary species.
536 Conversely, *Bagrus bayad*, *Clarias anguillaris*, and *Chrysichthys auratus* saw increased catches.
537 These changes highlight the effects of drought and rising fishing pressure on fish populations,
538 supporting Onyeneke *et al.*, (2020) findings on fish community adaptations to stress. In the Central
539 Delta, some species, including *Heterotis niloticus*, *Distichodus* spp., *Citharinus citharus*, *Bagrus*
540 *docmak*, *Polypterus senegalus*, *Malapterurus electricus*, and *Clarotes laticeps*, were very scarce
541 until the end of the drought period in 1994. Additionally, species like *Gymnarchus niloticus*,
542 *Parachanna obscura*, *Arius gigas*, *Citharidium ansorguii*, *Hepsetus odoe*, and *Alestes*
543 *macrolepidotus* were no longer caught (Iorchor, 2014). However, many of these species are still
544 common in other parts of Mali, such as Lake Selengue, and a return to normal hydrological
545 conditions could lead to their reappearance in the delta, either through migration from other areas
546 or their persistence in upstream or downstream regions.

547 In Niger, field observations have not confirmed claims of declining species diversity. The
548 differences noted between the inventories of Luiselli *et al.*, (2015) and Onwuteaka, (2015) are
549 primarily due to the taxonomic classification of species like *Arius gigas* and *Papyrocranus afer*.
550 During drought conditions, river species are generally less affected compared to those that migrate
551 to adjacent floodplains. While national biodiversity remains stable, local declines are possible.
552 Onwuteaka, (2015) reported concerns over the fisheries in Gaya Bay, located on the Niger-Benin

border. Drought and increased fishing pressure have led to a decrease in the size of fish caught, with juveniles making up a significant portion of landings. Despite these concerns, a collapse has not yet occurred.

In Nigeria, similar to other Niger River, natural lakes and reservoirs receive fish from inflowing rivers, which are replenished by adjacent floodplains each flood season. Disruptions like drought or damming can affect fish diversity in both natural and artificial aquatic systems (Iyiola *et al.*, 2022; Welcomme, 2013). Although the Niger River basin is large, the expected species diversity in Nigeria is not always observed. Nababa *et al.*, (2022) found that the major tributaries, such as the Anambra, Kaduna, and Sokoto/Rima, have lower diversity, with 23, 28, and 22 species, respectively. Lake Kainji, initially hosting 160 species, saw a reduction to about 97 species post-impoundment due to decreased flow rates affecting species reliant on flow conditions. Some species, like certain *mormyrids*, vanished following the impoundment but remain in some inflowing rivers. This decline in diversity is linked to the dam's location near a tributary rather than a river confluence, which impacts species adapted to specific riverine conditions (Oladipo *et al.*, 2020).

Climate Change, Salinity, and Ocean Acidification: Impacts on Fisheries in Nigeria

Climate change influences water salinity in diverse ways, with tropical oceans becoming saltier and polar oceans experiencing reduced salinity. This distinction suggests that tropical regions, including Nigeria, are likely to bear greater impacts from rising salinity levels compared to higher latitudes. The effects of salinity changes vary based on the tolerance of aquatic organisms and the characteristics of their ecosystems, whether freshwater, marine, or estuarine. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), salinity in some freshwater systems is expected to rise due to human-induced climate change. Although estuarine fish species may not

experience direct harm from salinity changes, their habitats can be significantly affected. For instance, increases in salinity have been linked to the destruction of approximately 60% of mangrove forests in Senegal and Nigeria (IPCC, 2007). These losses are profound, as Freeman, (2017) estimated that each acre of mangrove lost translates to a reduction of about 300 kg in marine harvest.

Such habitat degradation poses severe challenges for fisheries in Nigeria, threatening the livelihoods of vulnerable coastal communities. Additionally, Nigeria's status as a major oil producer contributes to environmental degradation through resource extraction, gas flaring, and their associated impacts, including water acidification and declining health indicators. Cooley *et al.* (2011) emphasize the need to assess both direct and indirect chemical effects on essential marine ecosystem services like fisheries. These impacts are already evident in the loss of species biodiversity.

Ocean acidification, closely linked to climate change, further exacerbates the situation. According to Le Quesne and Pinnegar (2011), the direct physiological impacts on marine organisms include reduced growth of calcified structures, impaired otolith development, and decreased fertilization success. These physiological disruptions can cascade into broader organism-level effects, such as diminished growth and reproduction, heightened predation, altered feeding behaviors, reduced immune function, and lower thermal tolerance.

A notable socio-economic impact of ocean acidification in Nigeria is the decline in populations of calcifying organisms like mollusks. This decline threatens the mollusk industry, which plays a significant role in the country's economy and food security. The combined effects of salinity changes, habitat destruction, and ocean acidification underscore the urgent need for mitigation efforts to protect Nigeria's fisheries and coastal livelihoods.

599 **Conserving Fish Diversity: Strategies and Importance**

600 Biodiversity is fundamental to human well-being, providing essential contributions to agriculture,
601 medicine, industry, and scientific research. As a critical component of global biodiversity, fish
602 diversity must be conserved to sustain ecosystems and the services they provide. According to
603 Bello, (2017), several strategies exist for preserving fish and other biological diversity. One
604 approach focuses on protecting species that are highly valued or at risk of extinction. Legal
605 measures, such as the U.S. Endangered Species Act, the Convention on International Trade in
606 Endangered Species of Wild Fauna and Flora (CITES), and the International Whaling Convention,
607 aim to prevent further population declines by addressing threats to these vulnerable species.
608 Another method involves ex-situ conservation, often referred to as the "Noah's Ark" strategy. This
609 approach includes preserving genetic material, such as seeds or semen, in gene banks or
610 maintaining entire organisms in controlled environments like zoos, aquariums, and botanical
611 gardens. These facilities serve as critical backups for species facing severe threats in their natural
612 habitats, ensuring their survival outside of the wild.

613 In contrast, in situ conservation emphasizes the preservation of biodiversity within natural
614 ecosystems. By establishing biological reserves that protect entire habitats, this strategy not only
615 safeguards species of public concern but also conserves less visible yet equally important
616 organisms, such as plants and microorganisms. These reserves provide additional benefits,
617 including controlling soil erosion, maintaining air and water quality, enabling scientific research,
618 and preserving the genetic material that defines species' hereditary traits.

619 **Introduction of Exotic Species**

In Guinea and Mali, the introduction of exotic species has been minimal. Specifically, in Guinea, *Oreochromis niloticus* was introduced from Liberia in 1986 for aquaculture purposes, but it has not become established in natural habitats (El-Sayed & Fitzsimmons, 2023). Similarly, in Niger, there have been no recorded occurrences of exotic species in natural environments such as rivers and ponds. However, there have been reports of the introduction of common carp (*Cyprinus carpio*) from Nigeria (Ogunola *et al.*, 2018). While future introductions for aquaculture cannot be ruled out, it is advisable to use local species for pond fish farming. Research indicates that local strains often exhibit growth performance comparable to, or better than, domesticated or wild strains from other West African rivers (e.g., Senegal) (Day, 2015). This approach helps protect the genetic integrity of local fish species and mitigates risks associated with contamination and genetic introgression.

In Nigeria, nine exotic species have been introduced since the 1970s, primarily for aquaculture. These include *Cirrhinus mrigala* and *Labeo rohita* from India, *Ctenopharyngodon idella* and *Cyprinus carpio* from Austria and Israel, *Hypophthalmichthys molitrix*, *Ictalurus punctatus* and *Micropterus salmoides* from the USA, and *Poecilia reticulata* from the UK (Otubusin, 1986; White, 1983). Among these, *Cyprinus carpio* is the most widely utilized in aquaculture. Species like *Cyprinus carpio*, *Poecilia reticulata*, and *Xiphophorus maculatus* are likely to have established populations in the wild, though their ecological impacts are not well understood (Kiruba-Sankar *et al.*, 2018).

Changes in Fish Distribution

One of the most commonly observed ecological responses of marine species to environmental changes is a shift in fish distribution (Iyiola *et al.*, 2022; Ipinjolu *et al.*, 2014). Fish species tend to adjust their latitudinal and depth ranges in response to factors like rising water temperatures.

Alterations in ocean dynamics may also affect fish migration patterns, leading to potential declines in fish landings, particularly in coastal fisheries across African nations (Urama & Ozor, 2011). These shifts can significantly impact marine fisheries, a critical source of food, by altering the quantity and geographic availability of fish stocks, potentially affecting food security (McClanahan *et al.*, 2015).

The effects of these distribution changes are not uniform across latitudes. Some species are projected to migrate toward northern regions in search of suitable water temperatures, which may result in increased fish harvests in higher latitudes. Conversely, countries in lower latitudes, including Nigeria, are expected to experience losses in fish species and stocks. Research by McClanahan *et al.*, (2015) suggests that fish-stock redistribution could lead to a 30–70% increase in higher latitude regions, while tropical regions could face a decline of up to 40%. This poses a significant threat to artisanal fishers in Nigeria, as migrating fish stocks into economically exclusive zones is financially unfeasible for many.

The redistribution of fish stocks due to environmental changes is likely to shift the economic benefits and costs associated with fisheries. As the Organization for Economic Cooperation and Development (Abdieva, 2023) notes, these changes could create winners and losers, with fishers in regions like Sub-Saharan Africa facing considerable losses due to the economic and logistical challenges posed by shifting fish distributions.

Artisanal Fishing Practices and Gear

Artisanal Fishing Practices

Artisanal fishing in freshwater and brackish environments is highly intensive and exhibits notable seasonal patterns. Fishing efforts typically decrease when fish migrate to floodplains or during the

rainy season. Fishermen adjust their techniques based on the hydrological cycle (Djebou, 2015; Akintola & Fakoya, 2017; Omitoyin & Tosan, 2012). Review of the present state of the environment, fish stocks, and fisheries of the river Niger (West Africa). The impact of environmental degradation has led to the development of diverse fishing methods, incorporating new technologies that aid in fish regeneration and extend fishing activities to new habitats.

Categories of Fishers

Fishers are generally categorized into three main groups (Djebou, 2015). The first group includes artisanal fishers who use basic equipment such as hand nets and harpoons, focusing on fishing in ponds and channels. Although numerous, this group primarily engages in fishing for personal consumption.

Fishing Gear and Catch Dynamics

Artisanal fishing practices adapt to the seasonal flooding and receding of waters over floodplains. Floodwaters enter these areas through channels and backwaters, facilitating the spread of the flood. As water levels drop, fish that had remained in the floodplains for several months migrate back to rivers. Variations in water levels and fish migrations cause significant changes in fish abundance and necessitate shifts in fishing locations throughout the year. Additionally, changes in water salinity in estuaries require the use of different fishing gear seasonally. The correlation between fishing habitats, hydrological seasons, and fishing gear is crucial for maintaining adequate fish yields to meet fishers' needs. In Nigerian estuaries, fishing gears include longlines (locally known as "lingo"), cast nets ("brigi"), clap nets, unbaited longlines with closely spaced hooks ("mari mari"), and various gill nets. Large gill nets and fixed gear dominate the fishing for fish and shrimp. Targeted species include croakers (*Pseudotolithus*), threadfins (*Galeoides*, *Pentanemus*,

687 Polydactylus), soles (Cynoglossus), marine catfish (Arius), brackish water catfish (Chrysichthys),
688 snapper (Lutjanus), grunters (Pomadour), groupers (Epinephelus), and estuarine white shrimp
689 (Palaemon). Bonga (Ethmalosa) is the most prevalent in the pelagic fishery, while catches of shad
690 (Ilisha), sardine (Sardinella), jacks (Caranx spp.), and Atlantic bumper (Chloroscombrus) are
691 modest.

692 Additionally, birds also prey on fish stocks. Lake Kainji and its surrounding areas in Nigeria are
693 home to 74 species of aquatic birds that feed on fish such as *Sarotherodon galilaeus*, *Oreochromis*
694 *niloticus*, and *Chrysichthys nigrodigitatus* (Ayodeji & Kilishi, 2019; Adebambo, 2020). In the
695 Central Delta, bird predation is significant, with some estimates suggesting that birds may be a
696 major source of predation in the floodplains (Chukwuka *et al.*, 2022).

697 **Fishing Gear on the Niger River**

698 Fishing methods employed on the Niger River can be categorized into six main types. Active
699 fishing techniques include hunting tools such as harpoons, primarily used in ponds undergoing
700 drainage, and various types of launched or push nets, including triangular nets, hand nets, and cast
701 nets, which are commonly used by occasional fishers. Seines are another active method, with small
702 seines typically operated by one or two individuals during low water conditions, and larger seines,
703 such as purse seines or beach seines, ranging from 400 to 1,000 meters in length, managed by
704 teams of up to 20 fishers.

705 Passive fishing techniques involve gill nets, which can be made of mono- or multi-filament
706 materials and are used for catching fish at different depths, including near the surface, mid-water,
707 or close to the bottom. These nets can be either fixed or drift nets and are designed with varying
708 mesh sizes to target specific fish species. Traps are used both in shallow water and for larger setups,

up to 5 meters long and 2 meters high, which are employed to block off sections of the river during periods of declining water levels. Lines include both baited lines used near the riverbed and unbaited multi-hook lines designed to trap demersal fish.

In the Central Delta region, the total fish catch was estimated at 48,600 tonnes for the period 1990-1991. Fixed and drift nets were the primary methods, accounting for 40% of the catch, with mesh sizes generally ranging from 20 to 35 mm. Other methods included small traps (15.7%), cast nets (14.9%), multi-hook lines (10.6%), and both large (7.8%) and small (4.3%) seines. The fish were caught by various groups, including migrant fishers (59.2%), sedentary fishers (36.1%), and farmer-fishers (4.7%). A total of 76 fish species were recorded in the landings, with 17 species making up 85% of the catch. Cichlidae were the most dominant family, contributing 26.6% of the total catch, including *Oreochromis niloticus* (10.2%), *Tilapia zillii* (8.3%), *Sarotherodon galileus* (6.2%), and *Oreochromis aureus* (1.9%). The Clariidae family, particularly *Clarias anguillaris*, represented 18.7% of the catch. Other significant families included Characidae (13.6%), with *Brycinus leuciscus* (6.2%), *Hydrocynus brevis*, *Hydrocynus forskali* (5.2%), and *Alestes* (2.2%); Bagridae (11%), with *Chrysichthys* (5.4%), *Bagrus* (2.8%), and *Auchenoglanis* (2.7%); Cyprinidae, including *Labeo* (5.3%); and Centropomidae, with *Lates niloticus* (3.8%) (Djebou, 2015).

Cost Implication

Fishing methods employed on the Niger River can be categorized into six main types. Active fishing techniques include hunting tools such as harpoons, primarily used in ponds undergoing drainage, and various types of launched or push nets, including triangular nets, hand nets, and cast nets, which are commonly used by occasional fishers (Verma *et al.*, 2022). Seines are another active method, with small seines typically operated by one or two individuals during low water

conditions, and larger seines, such as purse seines or beach seines, ranging from 400 to 1,000 meters in length, managed by teams of up to 20 fishers (Solomon *et al.*, 2013).

Passive fishing techniques involve gill nets, which can be made of mono- or multi-filament materials and are used for catching fish at different depths, including near the surface, mid-water, or close to the bottom (Alemtsehay, 2016). These nets can be either fixed or drift nets and are designed with varying mesh sizes to target specific fish species. Traps are used both in shallow water and for larger setups, up to 5 meters long and 2 meters high, which are employed to block off sections of the river during periods of declining water levels. Lines include both baited lines used near the riverbed and unbaited multi-hook lines designed to trap demersal fish (Mohammed *et al.*, 2021).

In the Central Delta region, the total fish catch was estimated at 48,600 tonnes for the period 1990-1991 (Belhabib & Pauly, 2015). Fixed and drift nets were the primary methods, accounting for 40% of the catch, with mesh sizes generally ranging from 20 to 35 mm. Other methods included small traps (15.7%), cast nets (14.9%), multi-hook lines (10.6%), and both large (7.8%) and small (4.3%) seines. The fish were caught by various groups, including migrant fishers (59.2%), sedentary fishers (36.1%), and farmer-fishers (4.7%) (Belhabib & Pauly, 2015). A total of 76 fish species were recorded in the landings, with 17 species making up 85% of the catch. Cichlidae were the most dominant family, contributing 26.6% of the total catch, including *Oreochromis niloticus* (10.2%), *Tilapia zillii* (8.3%), *Sarotherodon galileus* (6.2%), and *Oreochromis aureus* (1.9%). The Clariidae family, particularly *Clarias anguillaris*, represented 18.7% of the catch (Onimisi & Shittu, 2015). Other significant families included Characidae (13.6%), with *Brycinus leuciscus* (6.2%), *Hydrocynus brevis*, *Hydrocynus forskali* (5.2%), and *Alestes* (2.2%); Bagridae (11%), with

Chrysichthys (5.4%), Bagrus (2.8%), and Auchenoglanis (2.7%); Cyprinidae, including Labeo (5.3%); and Centropomidae, with *Lates niloticus* (3.8%) (Dienye & Olopade, 2017).

Economic Contributions of Fisheries

Fish play a crucial role as a source of animal protein for many households globally. The Food and Agriculture Organization (Tacon & Metian, 2013) highlights that fish provide over 60% of the world's protein supply, particularly in developing countries (Khan *et al.*, 2024). In Nigeria, a country with a population exceeding 160 million and a coastline of approximately 853 kilometers, the fish production sector holds significant potential to contribute to the agricultural industry (Imade & Ahmadu, 2022). Nigeria's annual fish consumption demand is approximately 2.66 million tonnes, yet domestic production is only about 780,000 tonnes, resulting in a substantial deficit of 1.8 million tonnes (Septisuwendani *et al.*, 2023). Although fish farming is gaining traction in Nigeria, it remains relatively underdeveloped compared to the considerable market potential (Akinrotimi *et al.*, 2011). The fish supply in Nigeria is sourced from four main channels: artisanal fisheries, industrial trawlers, aquaculture, and imported frozen fish. The Niger Delta region, endowed with abundant fresh, brackish, and marine waters, provides over 50% of the nation's fish supply and supports diverse artisanal fisheries (Ndimele, 2017).

The Nigerian fishing industry is segmented into three primary sectors: artisanal, industrial, and aquaculture. There is growing recognition of aquaculture's potential to enhance domestic fish production (Adewuyi *et al.*, 2010). Aquaculture, which involves cultivating fish in controlled environments, offers a promising solution to the fish supply deficit by enabling precise monitoring of feeding, growth, reproduction, and health (Mitra *et al.*, 2023). As a business, aquaculture has the potential to stimulate significant rural and urban development by increasing family income, creating employment opportunities, and addressing food supply and security challenges (Wuyep

& Rampedi, 2018). Nigeria's extensive aquatic resources, including rivers, streams, lakes, reservoirs, floodplains, irrigation canals, and coastal swamps, present considerable opportunities for aquaculture expansion (Belkhodja *et al.*, 2016). Currently, Nigeria spends approximately ₦100 billion annually on fish imports, with the country's consumption demand exceeding 2.66 million tonnes per year and imports reaching over 750,000 metric tonnes (Zabbey *et al.*, 2019). This high level of importation results in a substantial outflow of foreign currency, estimated at over USD 600 million, and the loss of thousands of potential jobs (USAID, 2010). To address the demand-supply gap, there is a strategic plan to elevate annual fish production from 780,000 metric tonnes to 3.0 million tonnes by 2015, aiming for self-sufficiency in fish production (Nova, 2019).

Species Classification of Aquaculture Production within Nigeria

Aquaculture production in Nigeria encompasses a wide range of fish species, significantly contributing to the country's fish supply. This section details the classification of aquaculture species, their production proportions, and comparative analysis with other forms of fish production.

Major Aquaculture Species

The primary species cultivated in Nigerian aquaculture include catfish (*Clarias gariepinus*), tilapia (*Oreochromis niloticus*), and carp (*Cyprinus carpio*). Catfish is the most dominant species, accounting for approximately 60% of the total aquaculture production. This dominance is due to the species' adaptability to various environmental conditions, fast growth rates, and high market demand (Akinrotimi *et al.*, 2015). Tilapia follows, contributing around 30% of the production. Tilapia is favored for its rapid growth and breeding capabilities, which suit intensive farming

systems (Olukolajo & Hillary, 2012). Carp, though less common, makes up about 5% of aquaculture production, primarily in regions with suitable pond conditions (Adewuyi *et al.*, 2010).

Production Comparisons

Comparatively, aquaculture represents about 40% of Nigeria's total fish production, with wild capture fisheries accounting for the remaining 60%. Within the aquaculture sector, catfish alone contributes to more than half of the output, indicating its crucial role in meeting domestic fish demand. The significant proportion of tilapia in aquaculture highlights its importance, especially in polyculture systems where it coexists with other species like catfish and carp to optimize space and resources (Abiodun & John, 2017).

Regional Variations

Regionally, the Niger Delta is notable for its diverse aquaculture practices, producing over 50% of the nation's fish supply, including both freshwater and brackish water species. This region supports a variety of species due to its unique water resources, which include rivers, estuaries, and floodplains. The Central Delta, in particular, demonstrates higher fish diversity and catch volumes during the wet season, further supporting the aquaculture sector's growth (Abiodun & John, 2017).

Seasonal Impact on Production

Seasonal variations significantly impact aquaculture production, with higher yields typically recorded during the wet season. This is attributed to improved water quality, increased availability of natural food sources, and favorable breeding conditions. For instance, species like *Heterotis niloticus* and *Gymnarchus niloticus* thrive in the wet season, contributing to the increased overall production (Bolarinwa *et al.*, 2015).

819 **Challenges and Diversification Efforts**

820 Despite the growth in aquaculture, challenges such as water pollution, inadequate infrastructure,
821 and limited access to quality feed and fingerlings hinder optimal production. Efforts to address
822 these issues include the introduction of improved farming techniques, better management
823 practices, and policies promoting sustainable aquaculture (Akinrotimi *et al.*, 2015; Ndimele *et al.*,
824 2021).

825 **Overfishing in Nigeria's Inland Fisheries**

826 The overexploitation of Nigeria's inland fisheries can be traced back to the introduction of
827 synthetic fishing materials like polyamide (nylon), polyester, and polyethylene. These modern
828 materials have replaced traditional fishing tools, significantly enhancing the efficiency of fishing
829 gear. While this has improved catchability, it has also led to the depletion of several natural fish
830 stocks. A critical outcome of overfishing is the predominance of immature fish populations
831 characterized by rapid turnover rates and high fecundity, resulting in smaller, faster-growing
832 species. This pattern is increasingly evident in Nigeria's inland waters.

833 For instance, Olopade *et al.*, (2017) observed a reduction in the average size (length and weight)
834 of fish species in Lake Kainji, along with alterations in species composition attributed to
835 recruitment and ecosystem overfishing. Similarly, Amos & Peter, (2018) highlighted the poaching
836 of juvenile fish in Lake Kainji by foreign fishermen using prohibited fishing techniques, such as
837 gillnets and beach seines smaller than three inches, contrary to regulations stipulated by the Inland
838 Water Decree.

839 Given the continued overfishing and its negative impacts on freshwater ecosystems, it is
840 imperative to introduce new legislation that effectively regulates fishing practices in Nigeria's

841 inland waters. Such measures are essential to curb overfishing and ensure the sustainable use of
842 these vital resources.

843 **Irresponsible Fishing Practices**

844 Irresponsible fishing practices refer to methods that harm aquatic ecosystems, deplete fish
845 populations, and disrupt biodiversity. These activities are unsustainable, often illegal, and directly
846 or indirectly result in the decline of fish species diversity, disruption of breeding grounds, and
847 reduced catches for fishermen. Moreover, such practices can lead to unhealthy competition among
848 species, threatening their survival and, in some cases, causing local extinction. Various fishing
849 methods contribute to this problem, particularly the use of certain harmful fishing gear.

850 One such method is the use of beach seine nets, which indiscriminately capture both adult and
851 juvenile fish, leading to a significant decline in fish populations. These nets have been identified
852 as a major factor contributing to reduced fish diversity in Nigerian waters (Oguntade *et al.*, 2014).
853 Similarly, purse seine nets, extensively used in the Niger Delta, target multiple species, including
854 juveniles and adults of *Ethmalosa fimbriata* (Bonga), thereby accelerating population declines in
855 these regions (Arimoro *et al.*, 2014).

856 Another problematic gear type is the drift and gill nets commonly employed in Lake Chad
857 fisheries. These nets, often spanning several kilometers, are non-selective, posing a significant
858 threat to species diversity by endangering a wide range of fish. Additionally, the use of undersized
859 gear remains a critical issue, particularly in Lake Kainji, where it targets both adult and juvenile
860 fish indiscriminately. This practice has severely affected the populations of commercially valuable
861 species and continues to exacerbate the problem of overfishing in Nigeria (Onyeche *et al.*, 2013).

862 **Illegal Fishing Practices: Chemicals, Herbs, and Explosives in Nigeria**

The use of chemicals and local herbs in fishing is a common yet destructive practice in several regions, including parts of Nigeria. Local herbs, often employed as a straightforward means to extract fish from water bodies, pose significant risks to aquatic ecosystems and human health. Uno *et al.* (2018) identified approximately fifty plant species used as fish poisons in West Africa. Despite efforts by local authorities to discourage the practice, it remains prevalent among farmer-fishermen in the Kainji area, particularly among the Larawa, Kamberi, and Gungawa tribes. These groups frequently rely on plant-based toxins to capture fish, a method that indiscriminately impacts fish of all ages and can harm consumers through contamination.

Explosive fishing, also known as blast or dynamite fishing, is another hazardous practice with severe ecological consequences. This method not only kills schools of fish but also devastates the surrounding aquatic ecosystems that sustain them. Furthermore, it poses significant safety risks to fishermen, leading to injuries and accidents. Despite these dangers, the technique is popular due to its efficiency and ability to yield larger catches. Explosives, often crafted from kerosene and fertilizers, have gained traction among fishermen, with Bersaldo and Lacuna (2022) reporting a notable rise in their use globally, including an estimated 70,000 practitioners in the Philippines.

Encouragingly, reports of explosive fishing in Nigeria's Kainji Lake are minimal or nonexistent, indicating that this particular destructive practice may not be a significant concern in that area. Nonetheless, continuous monitoring and the promotion of sustainable fishing practices are essential to mitigate these harmful methods and preserve aquatic biodiversity.

Climate Change and Its Impacts on Fisheries in Nigeria

Climatic variability, particularly at decadal scales, has historically influenced fisheries and their management effectiveness (Garcia & Rosenberg, 2010). Projections for the next 50 to 100 years

indicate significant changes, including atmospheric and oceanic warming, rising sea levels from thermal expansion and glacier melt, and a decline in ocean pH due to increased carbon dioxide absorption. Additionally, ocean circulation patterns may shift on local, regional, and global scales (Garcia-Soto *et al.*, 2021; Munday *et al.*, 2008). Coastal ecosystems such as estuaries, mangroves, and deltas are expected to experience significant impacts (Hansen *et al.*, 2013).

The responses of these habitats and the species they support to climate change will vary, reflecting the complexity and diversity of ecosystems. While it is challenging to predict the specific impacts on fisheries in Nigeria, the country is not exempt from global climate change trends, which are linked to fluctuations in fish stocks. These fluctuations can have profound economic repercussions, especially for communities and economies heavily reliant on fisheries for their livelihoods (Brander, 2010).

In Nigeria and across sub-Saharan Africa, the impacts of climate change on fisheries can be grouped into physical and biological effects. Physical impacts include rising sea surface temperatures, elevated sea levels, salinity changes, and ocean acidification. Biological impacts involve alterations in primary productivity and shifts in fish stock distribution. These interconnected factors compound the pressure on already strained fishery resources, threatening their sustainability and the livelihoods they support.

Nigeria fisheries: Interplay between physical changes, biological changes, and species migration on

One of the significant challenges facing Nigeria's inland waters, including aquaculture, is the rising surface water temperature. Research by Abiodun *et al.* (2013) suggests that seasonal temperature increases in the region, including Nigeria, are expected to exceed global annual mean warming in

all seasons. Such a temperature rise poses a threat to fish biodiversity, as most fish species have specific thermal ranges that support their physiological functions (Abowei, 2010). If temperatures surpass the upper tolerance limits of certain species, their survival could be at risk. Another major concern is sea level rise, which could negatively affect fish production due to increased salt stress on fish stocks and their habitats. Additionally, fish landing, processing, and marketing infrastructure may be compromised. Although limited studies exist on the impact of rising sea levels on Africa's coastal zones, assessments of some densely populated coastal cities in West and East Africa indicate that Nigeria is particularly vulnerable due to its extensive, fragile coastline. The country's 800-kilometer low-lying shoreline, stretching from Lagos to Calabar, is highly susceptible to seawater intrusion into freshwater resources, which could significantly impact inland fisheries and aquaculture. Coastal communities that historically relied on fishing have already experienced severe disruptions to their livelihoods due to rising waters (Urama & Ozor, 2011).

Anthropogenic climate change is also predicted to increase the salinity of freshwater ecosystems (Olson, 2019), which can disrupt aquatic food webs. Changes in salinity levels can impair the ability of both planktonic organisms and larger fish species to maintain osmotic balance (Harcotă, 2024). Empirical evidence highlights that fluctuations in salinity have adverse effects on zooplankton populations, particularly in freshwater environments, further threatening fish productivity. Research indicates that salinity fluctuations negatively impact zooplankton populations, particularly in freshwater ecosystems. Etim and Gbaji (2024) highlight that even slight increases in salinity levels in low-lying coastal lakes, tidal wetlands, and estuarine environments can disrupt zooplankton communities, which in turn affect fisheries. Salinity is a crucial factor influencing the survival of aquatic organisms in estuarine ecosystems, either through

direct physiological stress or indirectly by altering habitats, including essential breeding and nursery areas (Abowei, 2010). Although estuarine fish species are generally euryhaline, meaning they can tolerate a range of salinity levels, their resilience varies by species, potentially influencing their distribution patterns (Whitfield, 2015). While some fish may not be directly affected by increased salinity, habitat degradation due to salinity intrusion can pose significant threats. For instance, rising salinity levels have been linked to the destruction of approximately 60% of mangrove forests in parts of Senegal and Nigeria, further compromising critical fish habitats (Dada *et al.*, 2024).

In addition, as a major oil-producing nation, Nigeria experiences significant resource extraction activities, including gas flaring, which contribute to ocean acidification and associated ecological and health challenges. Human communities dependent on marine resources must consider both direct and indirect chemical impacts on essential marine services like fisheries (Cooley *et al.*, 2012). Biodiversity losses in some species are already evident, signaling the urgent need for comprehensive assessments. Direct effects of ocean acidification include disruptions to physiological processes such as impaired development of calcified structures, reduced otolith growth, and decreased fertilization success. These physiological changes may culminate in organism-level impacts, such as diminished growth, lower reproductive success, heightened vulnerability to predation, altered feeding behaviors, weakened immune systems, and reduced thermal tolerance (Le Quesne & Pinnegar, 2011). The destruction of habitats and consequent loss of biodiversity are global issues, particularly prevalent in developing countries where a significant proportion of the population depends on natural resources for survival (Gasu *et al.*, 2021). Over-exploitation of fish populations often results in the decline of fisheries before species are entirely lost (Nwabeze *et al.*, 2011). Historical records show that species such as *Protopterus annectens*

and *Xenomystus nigri*, previously reported in the Ikpa River, Akwa Ibom State, Nigeria, were not observed in more recent studies, reflecting the impact of habitat changes and human activities (Ekpo, 2013).

Species extinction is frequently linked to anthropogenic disturbances, including modifications to eco-hydrological regimes, habitat quality, water conditions, substrate properties, and biotic interactions (Ekpo, 2013). Additionally, the introduction of exotic species by humans often disrupts ecological balance, as invasive species can replace native ones, further threatening biodiversity. In Lake Oguta, species such as *Papyrocranus afer*, *Heterotis niloticus*, *Gymnarchus niloticus*, and others are considered endangered due to overfishing and habitat degradation (Njoku *et al.*, 2010). In the Hadeja-Jama'are Komadugu Yobe Basin, 15 fish species are reportedly under threat, with *Gymnarchus* and *Citharinus* facing the highest risk. Conversely, species such as *Alestes*, *Lates*, and *Hydrocynus* have lower threat frequencies, though they remain vulnerable to overfishing driven by high demand (Ladu *et al.*, 2013). Some species may also be affected by aquatic macrophyte invasion, which alters habitat conditions. Interestingly, three new species, *Arius*, *Heterotis*, and *Momyrops*, were recently documented in the basin, likely migrating through tributaries from the River Niger (Ladu *et al.*, 2013).

Infrastructural Challenges limiting fish production and distribution in Nigeria

The actual production figures from small-scale fisheries (SSF) in Nigeria are likely significantly undervalued due to inadequate data on fisheries resources nationwide. Many water bodies remain unassessed for their fisheries potential, and existing stock assessments are outdated and limited in number. For instance, artisanal shrimp fisheries, part-time fishers, and brackish water fisheries may see an underestimation of catches ranging from 100,000 to 180,000 metric tons annually

975 (Akintola & Fakoya, 2017). Coupled with the lack of accurate data on freshwater fisheries, this
976 underreporting results in a substantial gap in the recorded total fish landings in Nigeria.

977 Fishing communities are often highly dispersed across remote and inaccessible settlements due to
978 the absence of proper roads and their vulnerability to flooding during the rainy season. These
979 communities also face limited access to essential social infrastructure, including cold storage and
980 processing facilities, which are severely underdeveloped. Consequently, fishers depend heavily on
981 traditional methods of fish processing and preservation, which are characterized by inefficiency
982 and improper handling, particularly during peak fishing periods (Abelti & Teka, 2024).

983 Post-harvest losses (PHLs) are a major issue for SSF in developing nations, including Nigeria. It
984 is estimated that PHLs in the country exceed 30% of total catches. Seasonal gluts, particularly
985 from November to May for species such as sardines and Bonga (Clupeids), exacerbate this issue.
986 During these periods, fisherfolk often struggle to manage large catches, resulting in significant
987 quantities of spoiled fish. This spoilage leads to waste accumulation on beaches and buried fish,
988 further increasing losses (Vakily *et al.*, 2012; Jim-Saiki *et al.*, 2014).

989 The prolonged holding of fish in tanks within Nigerian markets, coupled with the absence of cold
990 storage chains across these markets, presents significant risks to fish quality and public health.
991 Traders and processors often operate without proper licensing in unsanitary environments, creating
992 additional sources of fish contamination. These conditions are linked to the supply of low-quality
993 fish to various processing units such as restaurants, street vendors, and low-income households
994 (Delia, 2015).

995 The hygiene practices of fish processors in such value chains are often inadequate, as evidenced
996 by poor food safety knowledge and attitudes among handlers in Nigeria (Grema *et al.*, 2019). This

issue is further exacerbated by the high ambient temperatures characteristic of tropical Sub-Saharan Africa, which promote the growth of pathogens and the release of toxins due to the extended exposure of fish to unsanitary conditions. These factors contribute to the transmission of foodborne diseases to consumers.

Additionally, inadequate preservation methods and fish spoilage within the supply chain contribute to significant food wastage. This waste undermines food security by reducing the availability of fish for human consumption and further exacerbates losses in the food system (FAO, 2017).

Overfishing and Harmful Fishing Practices in Nigeria's Inland Fisheries

The overfishing of Nigeria's inland fisheries can be traced to the introduction of synthetic fishing materials, such as polyamide (nylon), polyester, and polyethylene, which have replaced traditional fishing tools. These modern materials significantly increase the efficiency of fishing gear, resulting in the depletion of natural fish stocks. Overfishing often leads to immature fish populations characterized by rapid turnover and high fecundity, favoring smaller and faster-growing species, a trend observed in many Nigerian inland waters (Olopade *et al.*, 2017).

For example, in Lake Kainji, a noticeable decline in the average size of fish species, including their mean length and weight, has been attributed to overfishing and recruitment challenges within the ecosystem. This issue is further exacerbated by poaching, with foreign fishermen exploiting juvenile fish populations using illegal fishing gear such as gillnets and beach seines smaller than the 3-inch minimum specified by the Inland Water Decree. These activities highlight the urgent need for updated regulations to mitigate overfishing in Nigeria's freshwater systems (Ajibade, 2012).

Obnoxious fishing practices, including the use of explosives and poisons, pose additional threats by damaging aquatic ecosystems, killing non-target species, and compromising sustainable fish yields. Toxic substances derived from certain plants, which are used as poisons in fishing, have been documented in Nigerian inland waters, specifically in the Lake Kainji basin (Akinsanya *et al.*, 2016; Olopade *et al.*, 2017). These destructive practices hinder conservation efforts for water bodies such as Lake Kainji and Jebba Lake, as noted by Nwabeze and Erie (2013).

Artisanal Inland Fisheries and Sustainability Challenges in Nigeria

Artisanal inland fisheries play a critical role in Nigeria as a vital source of animal protein and a significant contributor to the economy, accounting for approximately 5% of the nation's gross domestic product (GDP) (Nwosu *et al.*, 2011). Between 1991 and 2003, these fisheries provided over 85% of domestic fish production, yielding 615,507 metric tons of fish in 2007 (Nwabeze & Erie, 2013). Additionally, artisanal fisheries contribute to foreign exchange earnings, create employment opportunities, generate income, and supply raw materials for the food and animal feed industries (Wuyep & Rampedi, 2018). Globally, the export value of fish and fishery products reached a peak of USD 102 billion in 2008, while Nigeria's fish export earnings were USD 50 million in 2001, against an import expenditure of USD 375.03 million (Sogbesan, 2014). Despite their contributions, the sustainability of inland fisheries in Nigeria faces threats due to overexploitation of fish stocks and the adoption of unsustainable and destructive fishing practices (Akeem, 2011). Effective fisheries management is crucial, as the livelihoods of millions depend on these resources.

Artisanal fishing pressure, which measures the intensity of harvesting wild fish from inland and marine waters, significantly affects future fish catches. While artisanal fisheries are generally considered more sustainable than industrial-scale operations, they also pose environmental risks.

Overfishing and destructive or unregulated fishing practices contribute to high levels of by-catch, which includes non-target species or immature individuals of the target species (Amos & Peter, 2018). Excessive fishing pressure disrupts ecosystem structures, affecting biodiversity, productivity, and food web dynamics. Unsustainable practices, such as the use of gear that indiscriminately captures unintended species or underdeveloped fish, exacerbate ecological imbalances (Ekundayo & Sogbesan, 2011). The resulting by-catch not only depletes non-target species but also jeopardizes the sustainability of future fish populations, undermining the ecological and economic stability of aquatic ecosystems.

For millions of people, especially in low-income, food-deficient regions, the ability to harvest fish is vital to meeting daily nutritional requirements. Fish provide over 3 billion people worldwide with approximately 15% of their average per capita intake of animal protein, making it a crucial food source (Boyd *et al.*, 2022). Without access to fishing resources, many communities would face significant challenges in addressing their dietary protein needs. Artisanal fishing plays a significant role in the global economy, accounting for approximately 90% of all fishing jobs, 45% of the world's fisheries, and nearly a quarter of the global fish catch (Kelleher *et al.*, 2012). In Nigeria, where an estimated 1% of the population is directly engaged in fisheries, over 24 million people depend on fishing activities for their livelihoods (Rabo *et al.*, 2014).

Compared to commercial fisheries, artisanal fisheries are notably labor-intensive, employing more than 12 million fishers globally, while using only one-eighth of the fuel consumed by industrial fisheries to produce the same amount of fish for human consumption, approximately 30 million tons annually (Teh & Pauly, 2018). Developing countries contribute 70% of the world's total fish catch, with over half of this output coming from small-scale fisheries (Kolding *et al.*, 2014). Despite their contributions, small-scale fisheries face numerous challenges, including vulnerability

to natural disasters, fuel price fluctuations, and market volatility for fish products (Pelletier *et al.*, 2014). Additionally, unsustainable exploitation of marine resources imposes substantial economic losses, estimated to exceed \$50 billion annually, more than half the global seafood trade's total value (Pham *et al.*, 2023).

Disease challenges that affect Nigerian fish and harm aquaculture production

Aquaculture diseases spread easily due to high stocking density, intensive feeding, and shared water sources between ponds and farms, as well as the movement of fish, fry, fingerlings, and broodstock without proper precautions. Emmanuel *et al.*, (2014) and Kaleem & Sabi, (2021) highlighted that diseases in aquaculture can lead to significant financial losses, especially in extensive culture systems, with risks of complete crop loss being higher than in other agricultural activities. In Nigeria, awareness of the impact of diseases on aquaculture is low, as reported by Omitoyin & Osakuade, (2021), Mukaila *et al.*, (2023), Ijah *et al.*, (2020), and Alfred *et al.*, (2020). Parasitic diseases are prevalent worldwide and are particularly significant in tropical regions (Mitra & Mawson, 2017). Fish are the most parasitized vertebrates (Leung, 2014), and parasitic infections in fish farming can cause high mortalities and economic losses which includes cestodes and platyhelminthes, as well as pose public health risks due to the zoonotic potential of some parasites (Ziarati *et al.*, 2022; Torgerson & Macpherson, 2011). In overcrowded environments like aquaria and fish farms, parasitic diseases spread rapidly, causing significant mortalities (Torgerson & Macpherson, 2011). In aquaculture, certain parasites are highly pathogenic, leading to high fish mortalities and economic loss, while in natural systems, they may threaten the abundance and diversity of native fish species (Marcogliese, 2023). *Clarias gariepinus*, a widely accepted and highly valued fish species in Nigeria, is known for its resistance, but it is still susceptible to parasitic infections, necessitating further research to address potential threats (Isa, 2019; Guta,

2024). Edeh & Solomon, (2016) observed that out of 107 *Clarias lazera*, only three were free from helminth parasites, with a single fish harboring an average of twelve helminth parasites. Adedeji & Okocha, (2011) also reported helminth infestations in fishes from Owo in South Western Nigeria. Effective management, including maintaining hygiene, ensuring good water quality, and using disease-resistant species, can help reduce the incidence of diseases. Dimelu *et al.*, (2018) noted that the lack of skilled aquatic veterinarians with expertise in disease prevention and control is a major challenge in Nigeria's aquaculture industry, a situation exacerbated by insufficient focus on Fish and Wildlife Medicine in the veterinary curriculum of Nigerian universities.

Among the bacterial diseases reported by farmers, fin or tail rot, myxobacteriosis, and septicemia were the most prevalent, with fin or tail rot being the most frequently observed, affecting 75% of farms. Myxobacteriosis and septicemia were reported in 30.5% and 38.2% of farms, respectively. Although 48.6% of respondents mentioned the occurrence of fish tuberculosis, this condition is relatively less common. The findings align with FAO (2014), which highlights that bacterial diseases rank highest among disease-causing agents in aquaculture. Fin or tail rot is typically caused by *Aeromonas* and *Pseudomonas* species, which, if left untreated, can result in significant fish mortality. Farmers treat bacterial infections by draining the pond, applying salt, and refreshing the water. In severe cases, antibiotics like oxytetracycline are used, although Pandey *et al.* (2012) recommend improving water quality through large water changes and substrate cleaning as the primary measure. The use of antibiotics must be managed cautiously to avoid public health risks due to residual effects, particularly when withdrawal periods are not observed. Additionally, access to adulterated or ineffective drugs remains a significant concern, potentially driving up production costs.

1109 Mycotic/Fungal infections were less common in fish farms, with only two occurrences reported in
1110 the past two years. Approximately 29% of respondents observed cotton wool disease, and 24%
1111 noted cataracts in their fish populations (Foster & Smith, 2015). Cotton wool disease is a fungal
1112 infection affecting the skin, fins, and mouth, often following previous infections or injuries.
1113 Farmers primarily treated fungal infections with antifungal drugs and salt. According to Foster and
1114 Smith (2015), a more effective and cost-efficient method involves disinfecting equipment and
1115 maintaining a clean farm environment. Cataracts, another fungal condition, impair the lens's ability
1116 to transmit light. Farmers use antifungal medications such as eye fungicides to treat this condition,
1117 although improper dosage can pose risks. A balanced diet with fresh commercial food may help
1118 prevent cataracts and other nutrition-related issues.

1119 A common viral disease, **dropsy**, was identified as the most common viral disease, affecting 13.6%
1120 of fish farms. The primary cause of dropsy is the accumulation of excessive fluid in the fish's
1121 tissues, often due to environmental stress or inadequate water elimination. Farmers treated dropsy
1122 by adding salt to the water, which helps remove excess fluid and improve the fish's health.
1123 Additionally, antibacterial diets containing antibiotics like tetracycline were used over 10 days
1124 (Magada & Mercy, 2016). Salt treatment and antibiotics were reported to be effective in managing
1125 dropsy outbreaks.

1126 **Dominantly Commercially Produced Species: Catfish**

1127 Nigeria has established itself as the largest producer of African catfish globally, a species
1128 recognized as one of the most commercially significant freshwater fish in Africa. African catfish
1129 dominate Nigeria's local fish markets due to their high demand and adaptability to aquaculture
1130 systems (Ajayi *et al.*, 2022; FAO, 2023). The rapid growth in catfish production during the early
1131 2000s can be attributed to the introduction and adoption of advanced breeding technologies, which

facilitated the mass production of fingerlings and significantly boosted production capacity (Ajayi *et al.*, 2022). As the leading aquaculture producer in Sub-Saharan Africa, Nigeria has experienced considerable expansion in aquaculture production over the years. Production volumes increased steadily from approximately 2,000 metric tonnes in 1960 to over 300,000 metric tonnes by 2015 (Ogunji & Wuertz, 2023). However, this growth was interrupted by external challenges, including the COVID-19 pandemic, which led to a decline in production to 260,000 metric tonnes in 2020, down from 290,000 metric tonnes in 2019. Recent statistics show a modest recovery, with production levels reaching 275,645 metric tonnes (FAO, 2023). In Nigeria, catfish (*Clarias gariepinus*) is the most dominantly commercially produced species, representing the backbone of the country's aquaculture industry. Several factors contribute to this dominance, including the fish's adaptability to a variety of environmental conditions, high growth rates, strong consumer preference, and disease resistance. Catfish can thrive in different farming systems such as earthen ponds, concrete tanks, and recirculating aquaculture systems. They exhibit rapid growth, reaching marketable size within six months under optimal conditions, which enhances profitability and turnover rates for farmers. Nigerian consumers favor catfish for its taste, texture, and nutritional value, ensuring a steady income for producers. Additionally, catfish are relatively hardy and resistant to many common fish diseases, reducing the risks and costs associated with fish farming (Castanheira *et al.*, 2017). The dominance of catfish in Nigeria's aquaculture sector significantly boosts the country's fish supply. With an annual production exceeding 400,000 tonnes, catfish farming plays a critical role in bridging the gap between fish demand and supply in Nigeria. Given Nigeria's annual fish consumption demand of approximately 2.66 million tonnes, catfish aquaculture helps mitigate the shortfall caused by limited wild capture fisheries and reduces the reliance on imported fish (Ibidapo-Obe & Yusuff, 2024). The economic impact of catfish farming

in Nigeria is profound. It provides direct and indirect employment opportunities for thousands of Nigerians, from hatchery operations to feed supply and fish processing. Catfish farms are often located in rural areas, contributing to rural development by improving local economies and infrastructure. Catfish farming is a lucrative business, with farmers earning substantial income from the sale of live fish, smoked fish, and value-added catfish products (Jimoh, 2021).

Despite its dominance, catfish farming in Nigeria faces several challenges. The cost of high-quality feed constitutes a significant portion of the production expenses, affecting profitability. Maintaining optimal water quality is crucial for catfish health and growth, requiring continuous monitoring and management. Farmers sometimes struggle with market access and fluctuating prices, impacting their income stability (Subasinghe *et al.*, 2021). Opportunities for enhancing catfish production include the development and use of cost-effective, locally produced feeds to reduce production costs. Providing farmers with training on best management practices can enhance productivity and sustainability. Investing in processing facilities to produce smoked, dried, and packaged catfish can increase market value and shelf life, opening up new market opportunities both domestically and internationally (Morrissey & DeWitt, 2014). In conclusion, catfish remains the cornerstone of Nigeria's aquaculture industry due to its adaptability, high growth rates, and strong market demand. By addressing existing challenges and leveraging opportunities for improvement, Nigeria can further strengthen its catfish production, contributing significantly to food security, economic growth, and rural development (Alawode *et al.*, 2016).

International agreements or frameworks that guide Nigeria's sustainability efforts and Implementation Status

Efforts by the Nigerian government to implement sustainable management of maritime ecosystems have been the focus of various studies. Okon and Okon (2019) analyzed Nigeria's *National Policy*

on the *Environment* and highlighted its emphasis on ecosystem management, biodiversity conservation, and sustainable development. Their study underscored the importance of strategies like integrated coastal zone management, ecosystem-based approaches, and the inclusion of stakeholders in decision-making processes. The researchers also stressed the need for effective implementation, institutional collaboration, and capacity-building initiatives to achieve policy objectives.

Similarly, Motsumi (2017) evaluated the *National Biodiversity Strategy and Action Plan (NBSAP)* and its relevance to maritime ecosystem preservation. The analysis detailed NBSAP's goals, including ecosystem restoration, sustainable resource use, and biodiversity protection. Akindele *et al.* (2021) further emphasized the integration of biodiversity considerations into broader policy frameworks, the enhancement of protected area management, and the promotion of community-based conservation initiatives to advance ecosystem sustainability.

Bayode Jr, (2024) examined specific sustainability practices in fisheries management and marine pollution control in Nigeria. The study found that fisheries co-management approaches, which involve institutional collaboration, stakeholder participation, and enforcement of regulations, are effective in promoting sustainable fishing practices and supporting livelihoods in coastal communities (Loch & Riechers, 2021). Bayode Jr, (2024) also highlighted Nigeria's efforts to address marine pollution through legislative and regulatory measures, enhanced monitoring systems, public awareness programs, and investments in pollution mitigation technologies, all aimed at protecting marine ecosystems and public health.

Additionally, the Nigerian government has incorporated sustainable development principles into maritime industry policies, as reflected in the *Sustainable Development Goals (SDGs) Plan* of the Nigeria Maritime Administration and Safety Agency (Audu, 2024). This initiative aligns with

1201 global commitments under the UN Sustainable Development Goals, focusing on advancing
1202 sustainable shipping practices, reducing marine pollution, and conserving marine biodiversity.

1203 The effective implementation of maritime governance systems and sustainability initiatives in
1204 Nigeria faces numerous challenges. A significant issue lies in inadequate institutional capacity and
1205 weak regulatory enforcement mechanisms. According to Loch and Riechers (2021), regulatory
1206 agencies often struggle to monitor and ensure compliance with fisheries management standards.
1207 This enforcement gap exacerbates issues such as illegal fishing, habitat destruction, and marine
1208 pollution, undermining sustainability efforts (Adam *et al.*, 2020).

1209 Institutional fragmentation and overlapping mandates among government agencies also impede
1210 integrated and comprehensive approaches to maritime governance. Lloyd *et al.* (2019) noted that
1211 poor coordination among institutions leads to inefficiencies in addressing complex environmental
1212 challenges. Another critical barrier is the lack of community involvement and stakeholder
1213 engagement in decision-making. Loch and Riechers (2021) observed that many local communities
1214 resist resource management initiatives due to perceived inequities in benefit-sharing and
1215 insufficient participation in policy formulation.

1216 Furthermore, Adam *et al.* (2020) highlighted that limited awareness and understanding of marine
1217 conservation issues among stakeholders contribute to low compliance with sustainability
1218 measures. Akindele *et al.* (2021) emphasized that increasing public education and fostering
1219 inclusive participation are essential for overcoming resistance and ensuring the successful
1220 implementation of conservation programs.

1221 **Strategic Initiatives and Future Directions**

1222 **Specific Strategy for Fisheries in Nigeria**

1223 *Fish Seed Multiplication Project*

1224 During Nigeria's Third National Development Plan (1975–1980), aquaculture received minimal
1225 attention, prompting the Federal Department of Fisheries to commission the Asiaphil Fisheries
1226 Corporation (AFC) of Manila, Philippines, to reassess its potential. Based on the AFC's
1227 recommendations, aquaculture was given greater prominence in the Fourth National Development
1228 Plan (1980–1987). This shift led to the establishment of zonal fish seed production and training
1229 centers between 1978 and 1980, under the oversight of the River Basin Development Authorities
1230 (RBDAs). These authorities were encouraged to develop commercial fish farms and demonstrate
1231 aquaculture's economic feasibility (Ogunji & Wuertz, 2023). The Fish Seed Multiplication Project
1232 was initiated to provide fish farmers with fingerlings for pond stocking. Supporting this initiative,
1233 the government set up aquaculture technology centers, including the Mando model fish farm in
1234 Kaduna (1980), Oyo model fish farm in Oyo State (1980), Umuna/Okigwe model fish farm in Imo
1235 State (1980), and Panyam fish seed multiplication center in Plateau State (1978). Ensuring a steady
1236 supply of quality fish seeds is critical for aquaculture development, and greater emphasis should
1237 be placed on establishing small, localized hatcheries to meet demand and adapt to changing
1238 conditions (Issa *et al.*, 2022).

1239 *Pilot Fish Farm Projects*

1240 In tandem with the fish seed multiplication farms, the Pilot Fish Farm Projects (PFFP) were
1241 implemented to showcase effective fish farming methods to current and potential fish farmers.
1242 These projects offered technical training on various aspects of aquaculture, including selecting fish
1243 species, pond preparation, fertilizer use, feed management, and pond health maintenance. The pilot
1244 projects also sought to diagnose the root causes of issues affecting fish production, such as limited
1245 availability and high costs of quality fingerlings and fish feed. Through collaboration with

commercial hatcheries and fingerling nurseries, the project identified areas for improvement and developed innovative strategies to enhance fingerling distribution. Additionally, it aimed to connect small-scale fish farmers with agro-dealers and suppliers to ensure closer access to critical inputs, with recommendations for establishing new supply channels in underserved areas (Ogunji & Wuertz, 2023).

Harnessing Aquaculture to Address Nigeria's Fish Supply Deficit: Opportunities, Challenges, and Economic Potential

An analysis of fisheries in Nigeria from 2009 to 2013 reveals a persistent gap between the demand for fishery resources and domestic output. The average annual deficit of 314,430.2 tons highlights Nigeria's reliance on fish imports to meet its needs, as local production from both capture fisheries and aquaculture remains insufficient. This aligns with prior findings that Nigeria allocates significant financial resources to fish imports, surpassing its earnings from fish exports. Despite extensive fishing efforts involving an average of 648,157 vessels (motorized and non-motorized), the annual output averaged only 10.555 tons per vessel, underscoring the inefficiency of this approach relative to the substantial investment required for operation (FAO, 2018).

The productivity of the fisheries sector reveals further disparities. Capture fisheries achieve an average of 0.39 tons (390 kg) of fish per laborer annually, compared to 16.75 tons (16,750 kg) per laborer in aquaculture. This discrepancy indicates that aquaculture workers are significantly more productive than those in capture fisheries. Redirecting investment toward aquaculture could enhance fish production, particularly as the sector has demonstrated greater output efficiency. Additionally, the growing population in Nigeria, coupled with per capita fish consumption of 9.9 kg in Africa, necessitates substantial investment in commercial aquaculture. Transitioning from

1268 subsistence-based inland pond aquaculture to large-scale commercial practices, including offshore
1269 mariculture, could address production deficits and reduce dependency on fish imports.

1270 Offshore mariculture, given Nigeria's vast coastline and exclusive economic zones, presents an
1271 opportunity to expand fish farming operations and establish the country as a global fish exporter.
1272 Developing this sub-sector could not only meet local fish demand but also generate employment
1273 and enhance foreign revenue through exports. The need for an augmented gap analysis approach
1274 is evident to provide empirical data for informed investment in and policy development for
1275 offshore mariculture. Such a strategic focus could enable Nigeria to sustainably bridge the fish
1276 supply gap while fostering economic growth and reducing capital flight associated with fish
1277 imports (Ateme, 2021).

1278 **Enhancing Fisheries and Aquaculture in Nigeria: Policy Interventions, Development** 1279 **Programs, and Sustainability Initiatives**

1280 Successive administrations in Nigeria have introduced various initiatives aimed at addressing the
1281 country's significant fish supply deficit by diversifying the economy and increasing aquaculture
1282 and food production (Akinrotimi *et al.*, 2011; Edun *et al.*, 2018). The government, alongside other
1283 organizations, has actively supported fish farming, recognizing its potential for boosting fish
1284 production. Key policy initiatives have focused on promoting fish breeding, improving access to
1285 aquaculture inputs, fostering hatchery development, and standardizing breeding processes (Issa *et*
1286 *al.*, 2022; FMARD, 2016).

1287 From 1980 onward, two major aquaculture development projects were implemented by the Federal
1288 Department of Fisheries: the Fish Seed Multiplication Project (FSMP) and the Pilot Fish Farm
1289 Project (PFFP) (Ogunji & Wuertz, 2023). The FSMP utilized Nigeria's extensive water resources,

such as irrigation dams and inland waters, to enhance fish production. Zonal seed production and training centers were established between 1978 and 1980 to support these efforts. According to Issa *et al.* (2022), the River Basin Development Authorities (RBDAs) were tasked with overseeing the project and establishing commercial fish farms that demonstrated the economic feasibility of aquaculture. These farms also served as central hubs for aquaculture development, supplying fish farmers with fingerlings for pond stocking. Additionally, aquaculture technology centers were created in key regions of Nigeria, such as Kaduna State.

Despite these interventions, the anticipated outcomes were not fully achieved, prompting the Federal Government to introduce additional agricultural policies and programs. One such program was the National Fadama Development Programme (NFDP), which sought to enhance agricultural productivity, including aquaculture. However, the challenges in realizing substantial improvements in fish production persisted, necessitating further strategic investments in aquaculture development.

The National Fadama Development Project (NFDP) began with Phase 1, or Fadama I, implemented from 1993 to 1999. Its primary focus was on crop production, utilizing affordable, improved irrigation technologies financed by the World Bank (Tiarniyu *et al.*, 2015). This phase facilitated access to boreholes and pumps for farmers through simple credit schemes but overlooked critical postproduction processes, such as storage, marketing, and commodity processing. Despite this shortcoming, Fadama I was considered a significant success (Onoyemeakpo, 2023).

Fadama II launched in 2004, expanded the scope to include fish farming and aimed to enhance the incomes of farmers through community-driven initiatives (Tiarniyu *et al.*, 2015; Alawode & Oluwatayo, 2019). This phase adopted a bottom-up approach to empower rural communities and

1313 improve government outreach to underserved populations. Over its six-year duration, Fadama II
1314 introduced and disseminated specific technologies to support fish farmers, leading to economic
1315 benefits such as increased output, higher income levels, and reduced production costs. Additional
1316 benefits included technological advancements, technical capacity building, and social
1317 improvements. It was recommended that future development projects replicate the demand-driven
1318 and community-centric approach of Fadama II to address rural poverty (Temowo, 2018).

1319 In 2010/2011, the Federal Government of Nigeria launched the Agricultural Transformation
1320 Agenda (ATA) to reform the agricultural sector and transform Nigeria into an agriculturally
1321 industrialized economy (Ejiogu, 2017; FMARD, 2011). This strategy, which spanned from 2011
1322 to 2015, included specific objectives for the fisheries sector. These objectives involved producing
1323 1.25 billion fish seeds and 400,000 metric tons of fish feed annually, alongside the annual
1324 production of 250,000 metric tons of table fish. Additionally, the initiative sought to create 100,000
1325 jobs annually over five years starting in 2011 (FMARD, 2011).

1326 The Federal Government of Nigeria implemented the Growth Enhancement Support (GES)
1327 scheme as a key component of the Agricultural Transformation Agenda (ATA) to simplify farmers'
1328 access to essential inputs such as fertilizers (Uduji *et al.*, 2019). The initiative aimed to foster
1329 collaboration among stakeholders to enhance productivity, strengthen household food security,
1330 and boost farmers' incomes. Under the ATA, fish farming received several forms of support,
1331 including the installation of fish cages in 21 strategic locations across the country, the
1332 establishment of fish markets in select regions, the facilitation of shrimp and fish exports, and the
1333 issuance of catch certificates to exporters (Uwakwe, 2015). However, significant challenges in
1334 Nigeria's aquaculture sector hindered the realization of the ambitious goals set under the ATA
1335 (Ejiogu, 2017).

1336 Nigeria, with its extensive coastline along the Gulf of Guinea, faces significant challenges in
1337 marine governance, including pollution, illegal fishing, and weak law enforcement. According to
1338 Ateme (2021), the country's maritime governance framework is characterized by a fragmented
1339 institutional structure, where multiple agencies oversee different aspects of marine resource
1340 management. This fragmentation often leads to overlapping responsibilities and coordination
1341 challenges. Similarly, Adam (2018) highlights that corruption and weak enforcement exacerbate
1342 the degradation of Nigeria's marine ecosystems. Despite the existence of policies such as the
1343 Environmental Impact Assessment Act and the Fisheries Act, inadequate institutional capacity and
1344 a lack of political will hinder effective implementation and enforcement.

1345 In contrast, Belize has been recognized for its successful approach to sustainable fisheries
1346 management and marine conservation. Karlsson and McLean (2020) note that Belize has
1347 developed a comprehensive marine governance framework, which includes participatory decision-
1348 making processes, marine protected areas (MPAs), and community-based management strategies.
1349 Belize's commitment to marine conservation is exemplified by the establishment of the Belize
1350 Barrier Reef Reserve System, designated as a UNESCO World Heritage Site. Furthermore, Cohen
1351 *et al.* (2016) emphasize the effectiveness of co-management agreements in Belize, where local
1352 communities collaborate with government agencies in resource management. These agreements
1353 empower communities to participate in decision-making, resulting in better compliance with
1354 regulations and greater resilience of marine ecosystems.

1355 A comparison between Nigeria and Belize highlights Belize's notable progress in marine
1356 governance. Belize's approach integrates grassroots community involvement with comprehensive
1357 legislative frameworks, resulting in better conservation outcomes and sustainable resource
1358 management. In contrast, Nigeria's fragmented administrative structure and weak enforcement

mechanisms have significantly hindered the effectiveness of its marine resource management and conservation efforts. However, both countries face similar challenges, including pollution, illegal fishing, and the impacts of climate change. Strengthening institutional capacity, enhancing regulatory enforcement, and fostering stakeholder engagement are essential steps to advancing marine governance in both Belize and Nigeria.

Technological Innovations in the Nigerian fisheries sector

Two key institutions support research in fisheries and aquaculture in Nigeria: the Nigerian Institute for Oceanography and Marine Research (NIOMR) and the National Institute for Freshwater Fisheries Research (NIFFR) (FAO, 2013). Additionally, aquaculture industry workers in Nigeria receive training through the African Regional Aquaculture Centre. At the regional level, NEPAD and ECCAS have collaborated through a memorandum of understanding to enhance the implementation of fisheries policies in Central Africa (AU-IBAR, 2021).

Established in 1975, NIOMR has contributed significantly to the Nigerian fisheries sector by driving three major developments. First, it has influenced government legislation on access to and management of fisheries resources. Second, it has advanced the geographical identification and cataloging of aquatic resources in the country. Third, it has promoted the mechanization and modernization of fishing tools. For instance, NIOMR's research has led to the replacement of papyrus boats with motorized and non-motorized canoes and the substitution of nets made from natural fibers with synthetic materials. In contrast to NIOMR's focus, the Chinese Academy of Fishery Sciences (CAFS) and other related research institutes in China have prioritized improving aquaculture productivity through innovative breeding techniques, the development of abundant and high-quality fish feed, the sustainable production of diverse aquatic products, the creation of

new production methods, and the intensive cultivation of fish rather than emphasizing mechanization (Ramesh, 2013).

In Nigeria, aquaculture is predominantly focused on catfish farming, particularly in high-density tank systems. In southern Nigeria, fresh catfish is the primary product, though lower-quality or smaller catfish are often smoked for sale in southern markets. In contrast, smoked catfish is more popular in the northern regions of the country. The growth of peri-urban catfish farming is evident around major urban centers (Seid, 2015). For instance, by 2009, Lagos State had approximately 3,120 catfish farms, while Kaduna State had 136 farms in 2008 (Cocker, 2014). The proximity of these farms to urban areas facilitates easier access to large markets and helps reduce post-harvest losses, which can occur due to poor transportation, storage, and other infrastructure challenges. Estimated losses during transport are between 10% and 15% (Gorman & Webber, 2010). These losses in both volume and quality are issues that traders and retailers frequently encounter, and many farmers seek to minimize these post-harvest handling problems. There is also a desire to establish more direct connections with traders and retailers higher up the value chain (Adetoyinbo & Otter, 2021). By doing so, farmers could enhance the quality of their products and secure the profit margins that are currently captured by primary wholesalers, often female, who may not share vital information, such as current market prices, with producers. A common issue in the value chain is the reluctance of participants to collaborate due to a lack of leadership, distrust among competitors, insufficient information, or the absence of economies of scale (Martin Webber & Labaste, 2010). Consequently, farmers frequently sell their catfish at the same price per kilogram, regardless of whether they are selling to wholesalers, processors, or directly to consumers (Cocker, 2014).

Conclusion

1404 The aquaculture sector in Nigeria holds immense potential to bolster the nation's food security,
1405 economic stability, and rural development. Dominated by the production of catfish (*Clarias*
1406 *gariepinus*), this sector has proven to be a resilient and lucrative component of the agricultural
1407 landscape. The adaptability, rapid growth, consumer preference, and disease resistance of catfish
1408 make it a cornerstone of Nigeria's fish farming industry, accounting for a substantial portion of
1409 the country's aquaculture output. The significant contributions of aquaculture, particularly catfish
1410 farming, help to bridge the gap between the country's fish demand and supply. With an annual fish
1411 consumption demand of approximately 2.66 million tonnes and domestic production significantly
1412 bolstered by aquaculture, the sector plays a crucial role in reducing reliance on fish imports.
1413 Moreover, the economic impact of catfish farming is profound, providing employment, enhancing
1414 rural development, and generating substantial income through various value-added products.

1415 Despite its successes, the sector faces several challenges, including high production costs, water
1416 quality management issues, and market access difficulties. Addressing these challenges through
1417 the development of cost-effective feeds, farmer training, and investment in processing facilities
1418 can further enhance productivity and sustainability. Overall, the diversity of fish species in
1419 Nigeria's waters, coupled with the growing recognition of aquaculture's potential, underscores the
1420 need for continued investment and development in this sector. By leveraging the opportunities for
1421 improvement and addressing the existing challenges, Nigeria can further strengthen its aquaculture
1422 production, ensuring a sustainable and prosperous future for its fisheries industry. This will not
1423 only contribute to national food security but also drive economic growth and development,
1424 particularly in rural communities.

1425 Fisheries and aquaculture are essential contributors to Nigeria's food security, employment
1426 generation, and economic growth. However, unlocking the full potential of this sector demands

1427 targeted policy interventions and stronger commitments from both the government and the private
1428 sector. To address existing challenges and foster sustainable growth, several critical actions are
1429 recommended. First, increased investment in aquaculture is imperative. Greater funding should be
1430 allocated to research institutions such as the Nigerian Institute for Oceanography and Marine
1431 Research (NIOMR) and the National Institute for Freshwater Fisheries Research (NIFFR). These
1432 funds would advance breeding techniques, improve fish feed production, and support sustainable
1433 aquaculture practices. Additionally, creating incentives to attract private-sector investment would
1434 further enhance the sector's growth.

1435 Improving infrastructure is another priority. The establishment of modern fish-processing
1436 facilities, the expansion of cold-chain storage, and the development of reliable transportation
1437 networks are essential to minimize post-harvest losses. Building on initiatives from the
1438 Agricultural Transformation Agenda (ATA), such as the installation of fish cages and the creation
1439 of dedicated fish markets, these efforts should be expanded nationwide to ensure broader impact.

1440 Capacity building and training are equally critical. Institutions like the African Regional
1441 Aquaculture Centre should be strengthened to provide workers with modern skills in sustainable
1442 fishing techniques, aquaculture management, and the use of advanced technologies. Such training
1443 initiatives will empower the workforce and enhance productivity across the sector.

1444 Combating illegal, unreported, and unregulated (IUU) fishing requires more robust enforcement
1445 mechanisms. Increasing monitoring efforts, deploying surveillance technology, and strengthening
1446 legal frameworks are essential to protect Nigeria's aquatic resources from exploitation and
1447 depletion.

1448 Regional and international collaboration must also be prioritized. Leveraging partnerships with
1449 organizations such as the New Partnership for Africa's Development (NEPAD) and the Economic
1450 Community of Central African States (ECCAS) can help address transboundary fisheries
1451 challenges. Aligning national policies with global standards outlined by the Food and Agriculture
1452 Organization (FAO) will further enhance sustainability in fisheries and aquaculture.

1453 Finally, fostering innovation in production is key to boosting efficiency and output. Drawing
1454 inspiration from countries like China, Nigeria should prioritize research into mechanization and
1455 new breeding techniques. Efforts should also focus on producing high-quality fish feed,
1456 diversifying aquatic products, and intensifying fish cultivation to meet domestic and export
1457 demands.

1458 Realizing these goals requires a collaborative, multi-stakeholder approach that engages
1459 government bodies, private-sector participants, research institutions, and local communities. By
1460 adopting these measures, Nigeria can not only overcome its current challenges but also establish
1461 itself as a leader in sustainable fisheries and aquaculture development across Africa.

1462 This review offers a distinctive and comprehensive perspective on the state of fisheries and
1463 aquaculture in Nigeria, contributing valuable insights that address key gaps in existing literature.
1464 While numerous studies have focused on individual aspects of the sector, such as aquaculture
1465 practices or the challenges of illegal fishing, this review synthesizes these elements into a cohesive
1466 framework that highlights the interplay between policy, research, and practice.

1467 One of the review's unique contributions lies in its analysis of the institutional roles of the Nigerian
1468 Institute for Oceanography and Marine Research (NIOMR) and the National Institute for
1469 Freshwater Fisheries Research (NIFFR). By examining their historical and current contributions,

1470 the review underscores the critical need for sustained investment in research and development,
1471 which has often been underexplored in previous literature. It highlights how advancements in
1472 breeding techniques, mechanized tools, and the identification of aquatic resources have shaped the
1473 sector and where opportunities for further innovation remain.

1474 Additionally, the review provides a detailed evaluation of the Agricultural Transformation Agenda
1475 (ATA), with a focus on its fisheries and aquaculture components. While prior studies have noted
1476 the ATA's broader impact on Nigerian agriculture, this review emphasizes its specific benefits for
1477 fish farming, such as infrastructure development, export support, and job creation, while candidly
1478 addressing the challenges that limited its full realization. This nuanced assessment bridges a
1479 critical gap by offering a balanced account of both successes and shortcomings.

1480 The review also brings to light the significance of regional and international collaborations, such
1481 as those between Nigeria and organizations like NEPAD and ECCAS. These partnerships are
1482 rarely explored in detail in the context of Nigerian fisheries, and this analysis highlights their
1483 potential to address transboundary challenges and align national policies with global best practices.

1484 Perhaps most importantly, this review contributes actionable policy recommendations that
1485 synthesize lessons from both local and international contexts. By integrating insights from
1486 Nigeria's own experiences with examples from other countries, such as China's innovative
1487 aquaculture techniques, it charts a path forward for sustainable fisheries and aquaculture
1488 development.

1489 In filling these gaps, this review not only enriches the understanding of Nigeria's fisheries and
1490 aquaculture sector but also provides a robust foundation for future research and policy-making. It

highlights the need for a holistic, multi-stakeholder approach to address challenges, unlock potential, and position Nigeria as a leader in sustainable fisheries within Africa and beyond.

The findings of this review provide practical insights that can directly inform and enhance fisheries management practices and government policy in Nigeria. By identifying gaps in infrastructure, training, and enforcement, policymakers can prioritize investments in areas such as modernizing fish-processing facilities, establishing cold-chain logistics, and strengthening monitoring systems to combat illegal fishing activities. Research-driven innovations, such as advanced breeding techniques and sustainable aquaculture practices developed by institutions like NIOMR and NIFFR, can be scaled up to boost productivity and environmental sustainability. Additionally, the emphasis on regional and international collaboration offers a roadmap for aligning local policies with global best practices, ensuring long-term viability. These findings can guide strategic policy decisions, enabling targeted interventions that improve resource management, increase incomes for stakeholders, and foster economic growth within the fisheries and aquaculture sectors.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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