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Digital Extension, Climate Information Access, and Livelihood Resilience in Nigerian Fisheries and Aquaculture: A Review and Integrated Framework for Sustainable Development

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Abstract: *Fisheries and aquaculture contribute to food security, employment, income generation, and livelihood sustainability in Nigeria. However, climate variability, environmental degradation, inadequate extension services, limited market information, and financial constraints can undermine production efficiency and the resilience of fishing and aquaculture households. Digital technologies offer opportunities to improve the delivery of extension services, facilitate access to climate information, strengthen production management, and connect producers with markets. Nevertheless, their effectiveness depends on affordability, digital literacy, infrastructure, information quality, and institutional support. This study reviews literature on digital extension, climate information access, fisheries and aquaculture management, digital learning, market participation, and livelihood resilience, drawing on relevant publications from the supplied reference collection and established international sources. A narrative review and thematic synthesis approach was adopted to identify relationships among digital access, information utilization, adaptive capacity, enterprise performance, and livelihood outcomes. The reviewed literature highlights five interconnected dimensions: digital information and extension delivery; climate adaptation and livelihood diversification; aquaculture productivity and resource-use efficiency; market access and enterprise development; and environmental sustainability and institutional support. An integrated conceptual framework is proposed in which digital access supports knowledge acquisition, but its translation into improved production and livelihood outcomes depends on complementary financial, technical, and institutional resources. The review further identifies research opportunities in digital inclusion, climate-smart fisheries management, supply-chain information systems, and the evaluation of digital extension outcomes. It concludes that digital technologies should complement community-based extension, practical training, market development, and environmental governance rather than operate as isolated interventions. The findings provide a literature-informed foundation for policy development and future empirical research on sustainable fisheries and aquaculture in Nigeria.*

Keywords: *Digital extension, climate information, fisheries, aquaculture, livelihood resilience, digital inclusion, Nigeria.*

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1.0 Introduction

Fisheries and aquaculture are important components of food systems, rural livelihoods, employment, and economic development. They provide animal protein, support commercial activities, create opportunities for self-employment, and contribute to the livelihoods of households engaged in production, processing, distribution, and marketing. At the global level, the Food and Agriculture Organization of the United Nations (FAO, 2024) emphasizes the importance of sustainable aquatic food systems, responsible

fisheries management, aquaculture development, and innovation in strengthening food security and livelihoods. In Nigeria, the significance of fisheries extends across coastal communities, inland waters, urban fish markets, and commercial aquaculture enterprises. Nevertheless, the performance and sustainability of these activities depend on effective resource management, access to technical knowledge, reliable markets, and producers' capacity to respond to changing environmental and economic conditions.

The challenges facing Nigerian fisheries and aquaculture are multidimensional. Artisanal fishing communities may experience declining resource availability, pollution, competition over aquatic resources, and changing environmental conditions. Fish farmers face production costs, feed management constraints, water quality challenges, disease risks, and uncertainty about market prices. Fish processors and traders may encounter inadequate storage, limited access to finance, high transportation costs, and post-harvest losses. These challenges are interconnected because weaknesses in production, processing, marketing, and environmental management can reinforce one another. The supplied literature addresses several of these concerns, including artisanal fishing efficiency amid overfishing and pollution (Awolumate & Fregene, 2025), environmental and socioeconomic impacts of mineral exploitation on fisheries (E S.E & Awolumate, 2025), aquaculture resource-use efficiency (Awolumate & Inyang, 2019), and the profitability of fish-processing enterprises (Awolumate & Muyiwa, 2025).

Climate variability introduces additional risks to aquatic food systems. Changes in temperature, rainfall, river discharge, flooding, and coastal conditions can affect aquatic ecosystems, fishing opportunities, aquaculture operations, and household income. The Intergovernmental Panel on Climate Change (IPCC, 2022) identifies climate change as a significant threat to African marine and freshwater fisheries, with consequences for food production, biodiversity, nutrition, and the livelihoods of communities dependent on aquatic resources. The report also emphasizes that climate information services, institutional capacity, livelihood diversification, and financial investment can strengthen adaptation. These findings underscore the need for fisheries-development strategies that connect environmental information with practical decision-making and socioeconomic support.

The vulnerability of fisheries-dependent households is not determined by environmental exposure alone. It also depends on access to productive assets, alternative income sources, technical knowledge, financial resources, and institutional assistance. Awolumate and Williams (2021) examined household vulnerability and livelihood diversification among fisherfolk in coastal communities of the Niger Delta, while Awolumate and Fregene (2023) investigated socioeconomic variables and income diversification among fisherfolk along the Niger and Benue rivers in Kogi State. These research areas highlight the importance of examining livelihood resilience alongside fisheries productivity. A household may possess considerable fishing experience yet remain vulnerable when environmental disruption coincides with limited savings, weak market access, or inadequate opportunities for alternative employment.

Access to reliable information is a critical component of effective fisheries management and adaptation. Fishers and fish farmers require timely information about weather conditions, water quality, production techniques, feed management, fish health, market prices, processing practices, and available support programmes. Agricultural and fisheries extension services traditionally provide such information through field visits, demonstrations, community meetings, radio, television, printed materials, and interpersonal communication. However, the effectiveness of

these services may be constrained by inadequate staffing, limited operational resources, geographical barriers, and weaknesses in communication infrastructure.

The increasing availability of information and communication technologies (ICTs) provides additional opportunities to address these limitations. Mobile phones, messaging applications, digital learning platforms, electronic market-information services, and online extension systems can facilitate communication between producers and extension personnel. Aker (2011) reviewed ICT-based agricultural extension approaches in developing countries and identified opportunities for improving information delivery, while also emphasizing constraints associated with programme design and implementation. Similarly, the World Bank (2019) highlighted the potential of digital technologies to improve information access, market connections, resource management, and the performance of food systems. However, digital technologies can also create exclusion where connectivity, affordability, skills, or complementary infrastructure are inadequate.

Digital transformation is particularly relevant to aquaculture because production decisions involve the continuous management of inputs, water quality, feeding, fish health, harvesting, and sales. The FAO (2024) discusses aquaculture digitalization as a process through which technologies can improve data collection, management decisions, and connections among farmers, suppliers, service providers, and traders. Nevertheless, the effectiveness of digital services depends on the capacity of users to interpret and apply the information received. Providing a farmer with a mobile application or sending periodic advisory messages does not automatically improve production efficiency or profitability. The benefits depend on whether the advice is reliable, locally relevant, understandable, and supported by the financial and physical resources required for implementation.

The supplied reference collection contains several studies relevant to this relationship. Awolumate (2018) examined the adaptability of ICTs in fish farming in Lagos State, while Awolumate and Inyang (2019) investigated threats to fish-farming information-use efficiency in a multi-communication infrastructure system in Akwa Ibom State. Awolumate (2018) also examined mass-media dependency for climate information among agricultural and fisheries extension agents. Inyang et al. (2015) investigated the utilization of ICT-based climate information for household agricultural adaptation in the Cross River Basin. These studies provide a context-specific foundation for investigating the connections among digital access, information utilization, and adaptation.

Education and capacity development are equally important. Digital information becomes more useful when recipients possess the skills to evaluate information, understand recommendations, and apply them within their production systems. Awolumate et al. (2025) examined digital learning resilience and financial access among aquaculture learners in climate-affected communities in Southwest Nigeria, while Awolumate et al. (2026) addressed community-based adaptive education models for fisheries sustainability in Lagos and Ogun States. Agbo et al. (2026) examined innovation skills and institutional support in sustainable aquaculture start-up development among open and distance learning students. These themes indicate that digital extension should be integrated with practical education, enterprise development, and institutional support.

Market information constitutes another important dimension of fisheries sustainability. Producers and traders need reliable information about prices, demand, buyers, product quality, transportation, and market opportunities. Digital platforms may reduce information asymmetry by improving communication between producers and buyers and by

facilitating the exchange of market information. However, financial limitations, poor logistics, inadequate processing facilities, and unreliable electricity may prevent producers from fully benefiting from these services. The supplied literature includes research on digital market information and smallholder fish supply-chain performance (Awolumate, 2026), market-information access and fish supply-chain performance in Lagos State (Awolumate & Obodo, 2026), and financial constraints affecting small-scale roadside fish processors (Awolumate & Muyiwa, 2025).

Although the literature covers digital technology, fisheries production, climate information, education, market performance, and livelihood diversification, these dimensions need to be considered within an integrated framework. Digital access, for example, may improve information availability without necessarily changing production practices. Similarly, adoption of improved production practices may not improve household resilience if market access remains weak or production costs exceed expected returns. A comprehensive analysis should therefore consider the factors connecting information access with knowledge, adaptive capacity, enterprise performance, and livelihood outcomes.

The present study addresses this need through a narrative review of literature on digital extension, climate information access, fisheries and aquaculture sustainability, and livelihood resilience in Nigeria. The specific objectives are to examine the contribution of digital technologies to fisheries and aquaculture extension; analyze the relationships among climate information, adaptation, and livelihood diversification; assess the relevance of digital information to production efficiency and market performance; identify the principal technological, financial, and institutional constraints; and propose an integrated framework for sustainable fisheries and aquaculture development.

The contribution of the study lies in connecting these related research areas within a single conceptual framework. Rather than assuming that digital technology automatically improves livelihoods, the study considers digital access as an enabling condition whose outcomes depend on the quality of information, users' competencies, productive resources, infrastructure, and institutional support. This perspective provides a basis for policy development and empirical research on the conditions under which digital extension can contribute to more resilient fisheries and aquaculture systems in Nigeria.

2.0 Materials and Methods

2.1 Research design

The study adopted a narrative literature-review design supported by thematic evidence mapping. This approach was selected because the subject combines fisheries management, aquaculture production, climate adaptation, digital learning, agricultural extension, market development, and livelihood studies. These research areas involve different populations, methodologies, and outcome measures, making a narrative synthesis more appropriate than a quantitative meta-analysis based solely on bibliographic descriptions.

The principal literature base consisted of the references supplied by the user. Additional sources were identified from established international publications, particularly the FAO's The State of World Fisheries and Aquaculture 2024, the IPCC's assessment of climate impacts and adaptation in Africa, Aker's review of ICT-based agricultural extension, and the World Bank's report on digital technologies in food systems. These additional sources were used to provide broader scientific and policy context.

2.2 Literature selection and thematic classification

The supplied references were examined for relevance to the study objectives and organized into five themes: digital communication and extension delivery; climate information and livelihood adaptation; fisheries and aquaculture productivity; market information and enterprise performance; and environmental sustainability and institutional support.

Studies on ICT adaptability, climate-information sourcing, digital learning, and community-based education were assigned primarily to the digital extension and capacity-development themes. Research on household vulnerability, livelihood diversification, and environmental pressures was used to examine adaptation and resilience. Publications on technical efficiency, feed utilization, aquaculture profitability, fish processing, and fish health provided context for production and resource management. Studies on market information, supply-chain performance, financial constraints, and entrepreneurship were used to examine the economic dimensions of digital inclusion.

The inclusion of a reference in the synthesis was based on its apparent relevance to the research question and its bibliographic description. The review did not assume that every publication directly measured digital extension or livelihood resilience. Instead, some publications were used to establish relevant contextual relationships, while the international sources supplied broader evidence and conceptual foundations.

2.3 Analytical approach

The literature was synthesized through thematic comparison. The analysis examined the principal problem addressed by each group of studies, the mechanisms through which digital information might influence production or adaptation, and the factors that could facilitate or constrain the conversion of information into improved outcomes.

The resulting framework links five components: digital access, information utilization, adaptive and technical capacity, enterprise performance, and livelihood resilience. External factors, including climate variability, environmental quality, market conditions, electricity availability, and institutional effectiveness, were considered potential influences on the relationships among these components.

No new primary data were collected for this study. No regression models, experimental comparisons, or statistical significance tests were performed. Consequently, the framework and research propositions developed in this paper are literature-informed and should be tested empirically.

2.4 Scope and limitations of the evidence

The review is based on the available reference list and selected external sources rather than a documented, exhaustive search of all relevant bibliographic databases. The complete texts of all supplied publications were not available for systematic extraction of their samples, methods, statistical estimates, and conclusions. Accordingly, the paper does not attribute unverified numerical findings to individual studies.

Some entries in the supplied bibliography contain incomplete publication information, inconsistent author formatting, or potentially overlapping records. These details should be checked against the original publications before journal submission. The review therefore distinguishes the thematic relevance of the supplied references from independent verification of their bibliographic records.

3.0 Results and Discussion

3.1 Digital access and the effectiveness of fisheries extension

The reviewed literature indicates that digital access is an important consideration in extending technical and climate-related information to fisheries and aquaculture stakeholders. However, access to a communication technology and effective use of the information it delivers are different outcomes. A producer may own a mobile phone

but lack affordable data, suitable applications, digital literacy, or confidence in the information received. Similarly, extension information may be available but difficult to implement because the recommended inputs or infrastructure are unaffordable.

Awolumate (2018) examined the adaptability of ICTs in fish farming in Lagos State, while Awolumate and Inyang (2019) addressed threats to fish-farming information-use efficiency in Akwa Ibom State. Awolumate and Omosola (2017) also examined the impact of extension services on fish farming in Lagos State. These publications are directly relevant to the relationship between communication systems and fisheries extension, although the precise findings of each study should be confirmed from the original articles before quantitative or causal claims are made.

The wider literature supports the potential value of ICT-based extension. Aker (2011) reviewed approaches involving voice communication, text messages, internet services, and mobile financial systems. The review highlighted opportunities to improve the delivery of extension information while emphasizing the need to address implementation constraints. The World Bank (2019) similarly identified opportunities for digital technologies to improve access to knowledge, markets, and production-management information, while warning that affordability, skills, data governance, and infrastructure can constrain adoption.

In fisheries and aquaculture, digital extension can support the distribution of information on feed management, stocking practices, fish health, water quality, harvesting, processing, and marketing. For artisanal fishers, digital channels can provide weather alerts, safety information, fisheries regulations, and environmental advisories. For processors and traders, they may facilitate communication with suppliers and buyers and improve access to price information.

However, these applications require context-specific design. Services intended for small-scale fish farmers should consider the cost of connectivity, the availability of electricity, local languages, and users' educational backgrounds. Short messages, voice services, visual demonstrations, and offline resources may be more appropriate than complex applications where digital access is limited.

Table 1 summarizes the main digital-extension mechanisms identified in the literature and their potential application to fisheries and aquaculture.

Table 1. Digital extension mechanisms and their potential applications in Nigerian fisheries and aquaculture

Digital mechanism	Potential application	Expected benefit	Principal constraint
Mobile calls and messaging	Extension advice, disease alerts, weather information	Faster communication and improved access to advice	Network coverage and communication costs
Digital learning platforms	Training on farm management, fish health, and entrepreneurship	Wider access to technical education	Digital literacy and electricity reliability
Electronic market-information services	Price updates, buyer identification, and sales coordination	Better-informed marketing decisions	Information accuracy and market participation costs

Digital financial services	Payment facilitation and access to financial information	More efficient transactions and financial management	Affordability, trust, and service availability
Digital monitoring systems	Water-quality monitoring and production records	Better production planning and resource management	Equipment cost and technical capacity
Community-based digital extension	Combining mobile information with local demonstrations	Improved interpretation and practical application	Staffing, logistics, and sustained funding

Source: Author's synthesis of Aker (2011), World Bank (2019), FAO (2024), Awolumate (2018), Awolumate and Inyang (2019), and Awolumate et al. (2026).

Table 1 shows that digital extension involves more than distributing information electronically. Its effectiveness depends on a combination of communication technology, relevant content, user competencies, and practical opportunities to apply advice. The evidence supports a blended extension model in which digital services complement extension officers, community-based education, and field demonstrations.

3.2 Climate information, environmental vulnerability, and livelihood resilience

Climate variability and environmental degradation can affect fishing opportunities, aquaculture production, processing activities, transportation, and household income. The IPCC (2022) identifies substantial risks to African fisheries and aquatic ecosystems under climate change and emphasizes the importance of adaptation, institutional capacity, and livelihood diversification. These concerns are relevant to Nigerian communities dependent on coastal and inland fisheries.

The supplied literature includes studies of climate-information sourcing and extension delivery (Awolumate, 2018; Awolumate & Inyang, 2019), ICT-based climate information and household agricultural adaptation in the Cross River Basin (Inyang et al., 2015), and household vulnerability and livelihood diversification among fisherfolk in the Niger Delta (Awolumate & Williams, 2021). Awolumate and Fregene (2023) further examined household income diversification among fisherfolk along the Niger and Benue rivers.

Taken together, these research areas suggest that adaptation requires both information and the capacity to act on it. Climate information can support decisions about the timing of fishing activities, preparation for extreme weather, protection of production assets, and adjustments to aquaculture practices. Yet information cannot eliminate vulnerability when households lack financial reserves, suitable equipment, alternative employment, or institutional assistance.

The distinction between information access and adaptive capacity is important. A warning about flooding, for example, may be useful only if households have time and resources to protect equipment, move assets, adjust activities, or access safer locations. Similarly, advice on adapting aquaculture operations may have limited value if producers cannot afford the required infrastructure or water-management measures.

Livelihood diversification may complement digital climate services by reducing dependence on a single income source. However, diversification should not be assumed to improve resilience in every circumstance. Alternative activities may require capital, training, market access, and additional labour. Future studies should examine whether diversification produces more stable income and whether digital information helps households identify viable alternatives.

The relationship between climate information and livelihood resilience is therefore conditional. The availability of timely, reliable information is an important enabling factor, but its practical value depends on household resources, local institutions, environmental conditions, and access to alternative livelihood opportunities.

3.3 Digital learning and human-capacity development

The effective use of digital extension depends on the ability of recipients to interpret and apply information. Digital learning can broaden access to training, but participation alone does not establish that learners have acquired the competencies required to improve production or enterprise management.

Awolumate et al. (2025) examined digital learning resilience and financial access among aquaculture learners in climate-affected communities in Southwest Nigeria. Awolumate et al. (2026) addressed community-based adaptive education for fisheries sustainability in Lagos and Ogun States. Agbo et al. (2026) examined innovation skills and institutional support for aquaculture start-up development among open and distance learning students. Amusa et al. (2025) considered lifelong learning and the upskilling of Yoruba entrepreneurs through open entrepreneurship education.

These topics provide a basis for linking digital extension with practical training, entrepreneurship, and institutional support. Training programmes can use digital resources to communicate technical concepts, provide demonstrations, and reinforce learning between extension visits. Community-based learning can complement online materials by allowing participants to discuss problems, observe practical methods, and receive feedback.

For fisheries and aquaculture, relevant competencies include water-quality management, fish feeding, stocking density, disease prevention, production records, cost calculation, product handling, and market assessment. Entrepreneurial training may additionally cover budgeting, cash-flow management, customer relations, and the evaluation of investment opportunities.

A key challenge is ensuring that training is accessible to users with different levels of digital literacy and financial resources. Programmes should consider language, literacy, connectivity, disability access, and the demands of participants' working schedules. Offline learning resources, voice-based services, visual demonstrations, and local-language materials may improve accessibility.

The main implication is that digital learning should be evaluated through learning and behavioural outcomes rather than platform access alone. Relevant measures include knowledge acquisition, skill retention, adoption of recommended practices, the quality of production records, and the ability to make informed business decisions.

3.4 Aquaculture productivity and resource-use efficiency

Aquaculture performance depends on the effective use of production inputs, including feed, water, labour, fingerlings, energy, and infrastructure. Poor input management can increase costs, reduce productivity, and contribute to environmental degradation. Digital extension may support better management by providing timely technical guidance and improving record keeping, but its contribution to measurable production outcomes requires empirical evaluation.

Awolumate and Inyang (2019) examined technical-efficiency differentials in aquaculture resource use among selected fish farms in Kaduna State. Fregene et al. (2011) examined the operational attributes of urban aquaculture systems in Ibadan. Awolumate and Inyang (2020) investigated fish-farm investment management in Akwa Ibom State, while Awolumate and Agbo (2025) addressed

nutrient retention and feed-utilization efficiency in African catfish.

Other supplied publications address fish nutrition, growth performance, and health, including Agbo and Awolumate (2024), Agbo and Awolumate (2026), and Agbo et al. (2026). These studies cover different technical aspects of production and should not be treated as direct evidence of the effects of digital extension. They nevertheless identify production-management processes in which accurate information and appropriate technical advice may be useful.

Digital services could support farmers through feeding schedules, production logs, water-quality records, reminders for routine management activities, and guidance on interpreting fish-health problems. Where suitable monitoring equipment is available, digital records may help farmers identify changes in water quality or production performance and seek advice promptly.

The potential value of these tools depends on their cost and suitability. Sophisticated monitoring equipment may be inappropriate for small-scale farms with limited capital or unreliable electricity. In such settings, simple record-keeping templates, mobile messaging, and regular extension visits may offer more accessible forms of support.

Table 2 presents proposed indicators for evaluating whether digital extension is associated with improvements in aquaculture production and management.

Table 2. Proposed indicators for evaluating digital extension in aquaculture

Performance dimension	Suggested indicator	Interpretation
Production performance	Yield per production cycle	Measures output relative to the production period
Feed management	Feed-conversion ratio	Assesses feed required per unit of biomass gain
Fish health	Survival rate	Indicates the proportion of stocked fish surviving to the assessment point
Resource use	Water and energy use per unit of output	Assesses resource intensity
Financial performance	Production cost per kilogram	Measures the cost of producing marketable fish
Enterprise performance	Net income per production cycle	Assesses the financial outcome after relevant costs
Information use	Proportion of recommendations implemented	Measures reported application of extension advice
Digital inclusion	Frequency and diversity of digital-service use	Describes the extent of engagement with digital channels

Source: Author's proposed evaluation framework informed by the supplied aquaculture literature and FAO (2024). These are recommended indicators, not observed measurements from the present review.

The table provides a basis for future research. A rigorous evaluation should account for farm size, production system, input quality, management experience, and environmental conditions. Without such controls, observed differences between farms with high and low digital engagement cannot reliably be attributed to digital extension.

3.5 Digital market information and fisheries value chains

Market access influences the profitability of fishing, aquaculture, processing, and trading activities. Producers require information about prices, buyers, demand, quality requirements, and transportation options. When information is incomplete or delayed, producers may have difficulty identifying suitable markets, negotiating prices, or planning harvesting and processing.

Awolumate (2026) addressed digital market information and smallholder fish supply-chain performance in Lagos State, while Awolumate and Obodo (2026) examined market-information access and fish supply-chain performance. Awolumate and Muyiwa (2025) investigated financial constraints affecting small-scale roadside fish processors. Awolumate et al. (2022) examined the profitability and challenges of smoked and dried fish marketers, while Awolumate and Inyang (2020) investigated constraints to value-addition investments in commercial aquaculture.

These research areas are relevant to the potential role of digital platforms in improving information exchange along fisheries value chains. Mobile communication and electronic market-information systems may help producers contact buyers, compare prices, coordinate deliveries, and reduce the time required to identify market opportunities. Digital transaction records may also help businesses monitor sales and expenditure.

Nevertheless, the relationship between digital market information and profitability is not automatic. Improved information may have limited value where producers lack transport, storage, working capital, or the ability to meet buyers' quality requirements. Likewise, access to a wider market may not improve income if transaction costs or competition are high.

Digital extension and market services should therefore be integrated with practical enterprise support. Fish farmers and processors may need training in product quality, packaging, record keeping, financial planning, and market negotiation. Market information should also be timely, sufficiently accurate, and relevant to the geographical area and product category of the user.

The performance of digital market interventions can be assessed using indicators such as the time required to locate buyers, the number of market outlets accessed, transaction costs, sales volume, post-harvest losses, marketing margins, and net income. These outcomes should be measured directly rather than inferred from digital-platform registration or message-delivery statistics.

3.6 Fish processing, product quality, and value addition

Fish processing can extend product shelf life, support market access, and create opportunities for value addition. However, the quality and safety of processed products depend on handling, processing methods, storage, and hygiene. Processing enterprises may also face constraints involving energy, equipment, finance, and access to reliable markets.

The supplied literature includes research on the physical, chemical, and microbiological properties of tilapia processed using different heat sources (Awolumate et al., 2022), determinants of profitability among smoked and dried fish marketers (Awolumate et al., 2022), and constraints to value-addition investments in commercial aquaculture (Awolumate & Inyang, 2020). Awolumate et al. (2026) also investigated the potential use of garlic preparations to improve the oxidative stability and sensory quality of hot-smoked fish.

These studies address different aspects of processing and should be interpreted according to their individual methods and findings. Collectively, they identify areas in which accessible technical information could support better practices. Digital extension can distribute guidance on hygienic handling,

temperature control, packaging, storage, and quality management. It may also connect processors with buyers seeking particular product characteristics.

However, digital information cannot replace access to appropriate processing equipment, reliable energy, safe water, or suitable storage facilities. Its value lies in helping users make better use of available resources and identify practical improvements. Future studies should determine whether digital training is associated with measurable changes in product quality, spoilage, processing costs, and profitability.

3.7 Environmental sustainability and fisheries governance

The sustainability of fisheries depends on the condition of aquatic ecosystems and the effectiveness of resource management. Pollution, overfishing, habitat degradation, and poorly managed development can affect fish populations, production opportunities, and the health of communities dependent on aquatic resources.

Awolumate and Fregene (2025) examined artisanal fishing efficiency amid overfishing, pollution, and infrastructure development. E S.E and Awolumate (2025) addressed environmental and socioeconomic impacts of mineral exploitation on fisheries in Imo State. Akeredolu et al. (2025) investigated wetland habitat quality and biodiversity in an urban environment, while Ovioma et al. (2025) examined polycyclic aromatic hydrocarbon bioaccumulation and histopathological alterations in African knife fish from Epe Lagoon.

These research topics highlight the importance of connecting fisheries productivity with environmental quality. Digital technologies may support this connection by facilitating environmental reporting, communicating conservation guidance, disseminating water-quality information, and improving the coordination of monitoring activities. Geospatial tools and digital records may also help researchers and agencies document changes in habitats and resource conditions.

Nevertheless, digital monitoring cannot independently resolve pollution, habitat destruction, or unsustainable fishing. Effective management requires reliable environmental data, regulatory enforcement, institutional coordination, community participation, and appropriate investment. Digital information is most useful when it informs decisions and triggers effective responses.

Environmental sustainability should consequently be incorporated into digital extension programmes. Advisory services should address responsible fishing, waste management, pollution prevention, habitat protection, and compliance with relevant regulations alongside production and profitability. This approach would help prevent the pursuit of short-term output gains from undermining the ecological systems on which fisheries livelihoods depend.

3.8 Livelihood diversification, financial inclusion, and resilience

Livelihood resilience concerns the ability of households and enterprises to withstand disruptions, maintain essential activities, and adapt to changing conditions. In fisheries-dependent communities, resilience may be affected by environmental exposure, income concentration, access to savings and credit, productive assets, and opportunities for alternative employment.

Awolumate and Williams (2021) examined vulnerability and livelihood diversification among fisherfolk in the Niger Delta, while Awolumate and Fregene (2023) investigated household income diversification along the Niger and Benue rivers. Awolumate (2018) also addressed cooperative extension support among low-resource women farmers. These research areas highlight the relevance of household resources, collective support, and alternative economic activities.

Digital services may contribute to resilience by improving access to climate information,

training, markets, financial information, and enterprise opportunities. However, digital access alone is unlikely to provide sufficient protection against major environmental or economic shocks. Households may still require savings, affordable financial services, social protection, infrastructure, and viable alternative income sources.

Financial inclusion is particularly important because the ability to act on information frequently depends on the availability of capital. For example, a fish farmer may receive advice about improved production practices but lack the resources to purchase inputs or upgrade equipment. Similarly, a processor may identify a more profitable market but lack the working capital required to transport or store products.

Table 3 presents an integrated framework connecting digital extension with livelihood resilience.

Table 3. Integrated framework linking digital extension and livelihood resilience

Component	Principal elements	Expected contribution	Factors that may constrain outcomes
Digital access	Mobile devices, connectivity, digital platforms	Expands opportunities to receive information	Cost, network coverage, electricity
Information utilization	Understanding and applying climate, technical, and market information	Supports informed decision-making	Literacy, trust, relevance, information quality
Adaptive and technical capacity	Skills, finance, training, productive assets	Enables implementation of recommended practices	Credit constraints, limited inputs, inadequate training
Enterprise performance	Production efficiency, market participation, income management	May improve productivity and financial stability	Production costs, market volatility, infrastructure
Livelihood resilience	Diversification, risk management, recovery capacity	Supports adaptation to environmental and economic shocks	Severe shocks, limited savings, weak institutions
Enabling environment	Extension agencies, cooperatives, regulation, infrastructure	Strengthens coordination and service delivery	Institutional weaknesses and inadequate investment

Source: Author's conceptual synthesis based on the reviewed literature, Aker (2011), World Bank (2019), FAO (2024), and IPCC (2022).

The framework indicates that digital access is an enabling factor rather than a direct guarantee of livelihood resilience. The benefits of digital information are likely to depend on the strength of the links between access, information utilization, practical capacity, and enterprise performance. External conditions, including climate hazards, market changes, and institutional support, may influence each stage.

The framework also suggests that resilience should be assessed using multiple indicators. These may include income stability, livelihood diversity, recovery following a disruption, adoption of adaptation practices, and access to institutional assistance. Such measures would

provide a broader understanding of livelihood outcomes than production or income alone.

3.9 Research gaps and proposed empirical propositions

The literature considered in this review covers several relevant dimensions of digital inclusion, climate information, fisheries management, and livelihood development. However, the availability of related publications does not establish the magnitude or causal direction of the relationships among these dimensions. In particular, more evidence is needed on whether digital information access produces sustained changes in production practices, enterprise performance, and household resilience.

First, future research should distinguish between digital access, frequency of use, information comprehension, and actual implementation of recommendations. Second, studies should examine the conditions under which digital extension is more effective, including digital literacy, financial resources, gender, age, enterprise size, and institutional support. Third, research should evaluate whether digital market information is associated with improved commercial outcomes after accounting for transportation, storage, input costs, and market structure. Fourth, longitudinal studies are needed to establish whether observed benefits persist across production cycles and periods of environmental stress.

The following propositions are therefore proposed for future empirical testing:

Proposition 1: Access to affordable and locally relevant digital information is positively associated with the utilization of fisheries and aquaculture extension services.

Proposition 2: Digital literacy and practical training strengthen the relationship between digital information access and the adoption of improved production practices.

Proposition 3: The relationship between climate-information access and livelihood resilience is influenced by financial access, livelihood diversification, and institutional support.

Proposition 4: The use of digital market information is associated with improved market participation and enterprise performance, subject to infrastructure and financial constraints.

Proposition 5: Community-based learning and responsive extension services strengthen the translation of digital information into sustainable fisheries and aquaculture practices.

These propositions can be examined using household surveys, farm records, market data, and qualitative interviews. Where appropriate data are available, multivariate regression or structural equation modelling could be used to test the proposed relationships while accounting for confounding variables. Such analyses should report sample characteristics, measurement procedures, effect estimates, uncertainty, and limitations.

4.0 Conclusion

This study reviewed literature on digital extension, climate information access, fisheries and aquaculture productivity, market development, environmental sustainability, and livelihood resilience in Nigeria. The synthesis demonstrates that these areas are interconnected and should be considered within an integrated development framework. Digital technologies can expand opportunities for information dissemination, technical learning, climate-risk communication, production management, and market coordination. Their potential value is consistent with broader international assessments of digital agriculture and aquatic food-system transformation (Aker, 2011; FAO, 2024; World Bank, 2019).

The reviewed literature also indicates that access to information does not automatically translate into improved production or livelihood outcomes. Digital services are more likely to be useful when they provide accurate, timely, affordable, and locally relevant

information and when users possess the skills and resources needed to act on it. Financial inclusion, practical training, extension support, reliable infrastructure, and access to markets are therefore important complementary conditions.

The principal contribution of this paper is an integrated framework linking digital access, information utilization, adaptive and technical capacity, enterprise performance, and livelihood resilience. The framework emphasizes the importance of combining digital communication with community-based learning, responsive extension services, market development, environmental safeguards, and institutional support. It also identifies opportunities for future research into digital inclusion, climate adaptation, production efficiency, and the economic performance of fisheries and aquaculture enterprises.

Because this study is based on a narrative synthesis of available references rather than newly collected field data, the proposed relationships should be treated as research propositions rather than established causal effects. Future empirical studies should measure digital access and use alongside production, market, environmental, and household outcomes. Such evidence would help determine which digital-extension approaches are most effective, which groups benefit, and what complementary investments are required.

Overall, digital extension should be viewed as one component of a broader strategy for sustainable fisheries and aquaculture development in Nigeria. Its contribution to livelihood resilience will depend on the quality of information, the capacity of users to apply it, the availability of productive and financial resources, and the effectiveness of institutions responsible for fisheries management and rural development.

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Declarations

Consent for publication

Not Applicable

Data Availability Statement:

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors have no competing interests to declare that are relevant to the content of this article.

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Not applicable

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All components of the work were carried out by the author