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Rice–Fish Integration as a Pathway to Sustainable Livelihoods Among Smallholder Farmers: Evidence from DPSIR-Informed Analysis in Sub-Saharan Africa

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Abstract

Smallholder rice farmers in sub-Saharan Africa face persistent livelihood challenges due to declining returns from monocropping, limited diversification opportunities, and vulnerability to climate and market shocks. This study integrated the Drivers–Pressures–State–Impact–Response (DPSIR) framework with the sustainable livelihood approach to evaluate how the transition from rice monocropping to integrated rice–fish farming influences productivity, profitability, and household welfare in Nigeria's leading rice-producing region. Using a mixed-methods, three-year panel (2021–2023) of 228 households across three communities in Kebbi State, descriptive statistics, regression models, and thematic analyses were combined to assess changes in livelihood capitals, system pressures, and response mechanisms. Adoption of rice–fish systems was associated with substantial improvements: 96.1% of farmers reported increased income, 56.3% improved food security, and 30.6% greater dietary diversity. Regression analyses confirmed that access to more land ($p < 0.001$ for healthcare and education; $p = 0.011$ for social status), labor affordability ($p < 0.001$), and farm size ($p < 0.05$) were consistent predictors of gains in healthcare, education, and social status, while pesticide and herbicide use negatively affected food access and wellbeing ($p < 0.05$). The DPSIR assessment revealed that rice–fish integration altered the state of rice production systems through reductions in input-related pressures and generated positive livelihood impacts. The results align with Sustainable Development Goals (SDGs) related to poverty reduction, food and nutrition security, sustainable production, and biodiversity conservation, and provide the first large-scale, longitudinal evidence from West Africa that integrated rice–fish systems support food security, income diversification, and sustainable resource management.

Keywords: integrated agriculture–aquaculture; rice–fish; livelihoods; diversification; food security; DPSIR; rural transformation

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1. Introduction

Rice is one of the most important staple crops that sustains the diets of more than half of the world's population and serves as a critical source of income for millions of smallholder farmers [1]. In sub-Saharan Africa, rice cultivation has expanded rapidly in response to growing dietary demand and economic gains [2]. However, profitability remains low, which leaves many rural households vulnerable to livelihood challenges, particularly food insecurity and poverty [3,4]. Small-scale rice farmers are further constrained by their heavy reliance on rice monocropping and their limited knowledge of farm diversification practices, which together restrict their opportunities for income diversification [5,6]. Relying on a single crop as the main source of livelihood leaves many rice farmers unable to cover even their most basic needs, and this vulnerability often translates into unstable incomes, reduced food security, poorer health, and limited access to education for their households [1,6]. To overcome these challenges, strategies that not only improve agricultural productivity but also increase the ability of farmers to cope with risks and improve their livelihood outcomes in the long term are required. In this regard, diversification emerges as a possible pathway to reduce dependence on a single crop, maximize revenue, and strengthen resilience [7,8]. Within this context, integrated rice–fish farming represents a promising diversification strategy that offers farmers an opportunity to combine rice cultivation with aquaculture in ways that optimize land and water resources more efficiently, recycle nutrients, reduce pest pressures, and generate additional income [9]. Asia has demonstrated different benefits of rice-based systems with fish additions, including higher income to families and better food security, and ecological benefits, including higher biodiversity and less agrochemical application [9–11]. In sub-Saharan Africa, uptake has largely been confined to small plots, pilot projects, and experimental stations, with a few tests under real-world conditions involving farmers [12–14]. The absence of large-scale empirical studies has continued to hinder wider application across the continent, and the limited evidence on livelihood outcomes has in turn constrained policy support and investment in integrated systems. Recent assessments by the Food and Agriculture Organization of the United Nations show that diversified agrifood systems contribute directly to Sustainable Development Goals (SDGs) targets related to poverty reduction, food and nutrition security, sustainable production landscapes, and ecosystem restoration because of their capacity to improve productivity, stabilize income, enhance ecological efficiency, and strengthen resilience in smallholder contexts [15–17]. A growing body of evidence from Asia further demonstrates that integrated agriculture–aquaculture systems contribute directly to Sustainable Development Goals related to poverty reduction, food security, sustainable production, and ecosystem restoration, especially through their capacity to enhance livelihood security, improve dietary quality, promote ecological intensification, and support biodiversity conservation conditions [9,18,19]. However, in sub-Saharan African contexts, a critical evidence gap persists as to whether rice–fish integration can deliver these multidimensional benefits under real farming conditions. This study addresses that gap by evaluating the impacts of rice–fish farming on livelihoods among smallholder rice farmers in Nigeria. We hypothesize that a shift from rice monocropping to rice–fish farming can enhance the efficient use of natural resources, diversify income streams, and strengthen livelihood resilience among rural farming households. Specifically, we ask the following questions: (i) How do household capitals and vulnerability contexts shape the adoption and performance of rice–fish systems? (ii) What are the measurable impacts of adoption on household livelihood outcomes? (iii) What systemic challenges and enabling conditions influence the sustainability and scalability of rice–fish farming? This study aimed to help fill the knowledge gap on integrated rice–fish farming as a lever for economic

development and improving resource-use efficiency and livelihoods in rural communities of sub-Saharan Africa.

2. Methodology

2.1. Study Area

The study was conducted in Kebbi State, Nigeria, a region recognized as one of the country's leading rice-producing areas and among the most food-insecure regions (Figure 1). The research focused on three rice-producing communities within the state: Argungu, Ngaski, and Wawu (Jega). These locations were selected due to their historical and ongoing successes in rice farming. This study aimed to leverage this agricultural tradition to explore the potential for innovation by integrating fish farming into existing rice fields, thus serving as a proof of concept for addressing livelihood challenges and enhancing agricultural productivity.

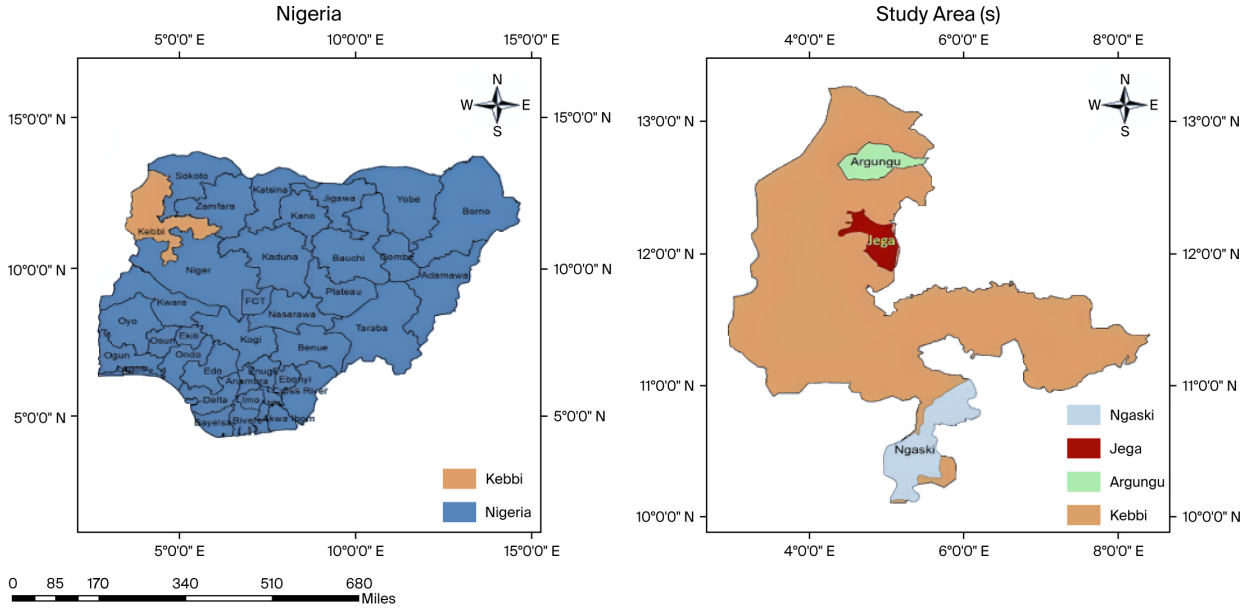

Figure 1. Map of Nigeria highlighting Kebbi State (brown), with study sites marked as follows: Argungu (green), Ngaski (blue), and Jega (Wawu) (red). (Created using ArcMap 10.5).

2.2. Research Design

This study employed a mixed-method longitudinal design anchored in a modified sustainable livelihood framework of DFID [20] (Figure 2). The modified sustainable livelihood framework was complemented with a Drivers–Pressures–State–Impact–Response (DPSIR) lens to structure the analysis of how rice–fish diversification reshapes household livelihood systems and production environments. The sustainable livelihoods framework (SLF) offers a structure for examining how farmers' capital, vulnerabilities, and livelihood strategies interact, while the DPSIR framework clarifies the systemic pathways through which diversification alters rice–fish production systems. Using both frameworks enabled simultaneous examination of household-level livelihood adjustments and the broader system conditions shaping those adjustments. Within this integrated framework, macro- and household-level motivations related to productivity, income generation, food and nutrition security, poverty alleviation, wetland management, and climate risk management were treated as Drivers. Environmental and human decision-related stresses, including modification of rice fields, water use regimes, pest and disease control practices, and expansion of cultivated areas, were considered as Pressures. The observed conditions with regard to water availability, field configuration, soil fertility, biodiversity, and access to infrastructure

and services represented State. Economic, nutritional, social, and ecological effects of rice–fish adoption were interpreted as Impacts, while farmer-led initiatives, cooperative action, technical training, and institutional support mechanisms constituted Responses. The resulting DPSIR–livelihood framework guided the categorization of indicators and the interpretation of the observed changes associated with rice–fish integration. The study was implemented over three years (2021–2023) in three sequential phases. The first phase involved a situational analysis through baseline assessments that documented farmers' livelihood capitals (natural, human, financial, social, and physical), vulnerability contexts, and prevailing rice production practices. The second phase focused on intervention and adaptation, with farmers modifying rice fields through the construction of trenches and reinforcement of bunds, combined with training and rice–fish co-culture. The third phase involved follow-up evaluation through endline surveys and qualitative interviews that assessed adoption levels, livelihood outcomes, and challenges to allow for comparative analysis between baseline conditions and post-intervention outcomes.

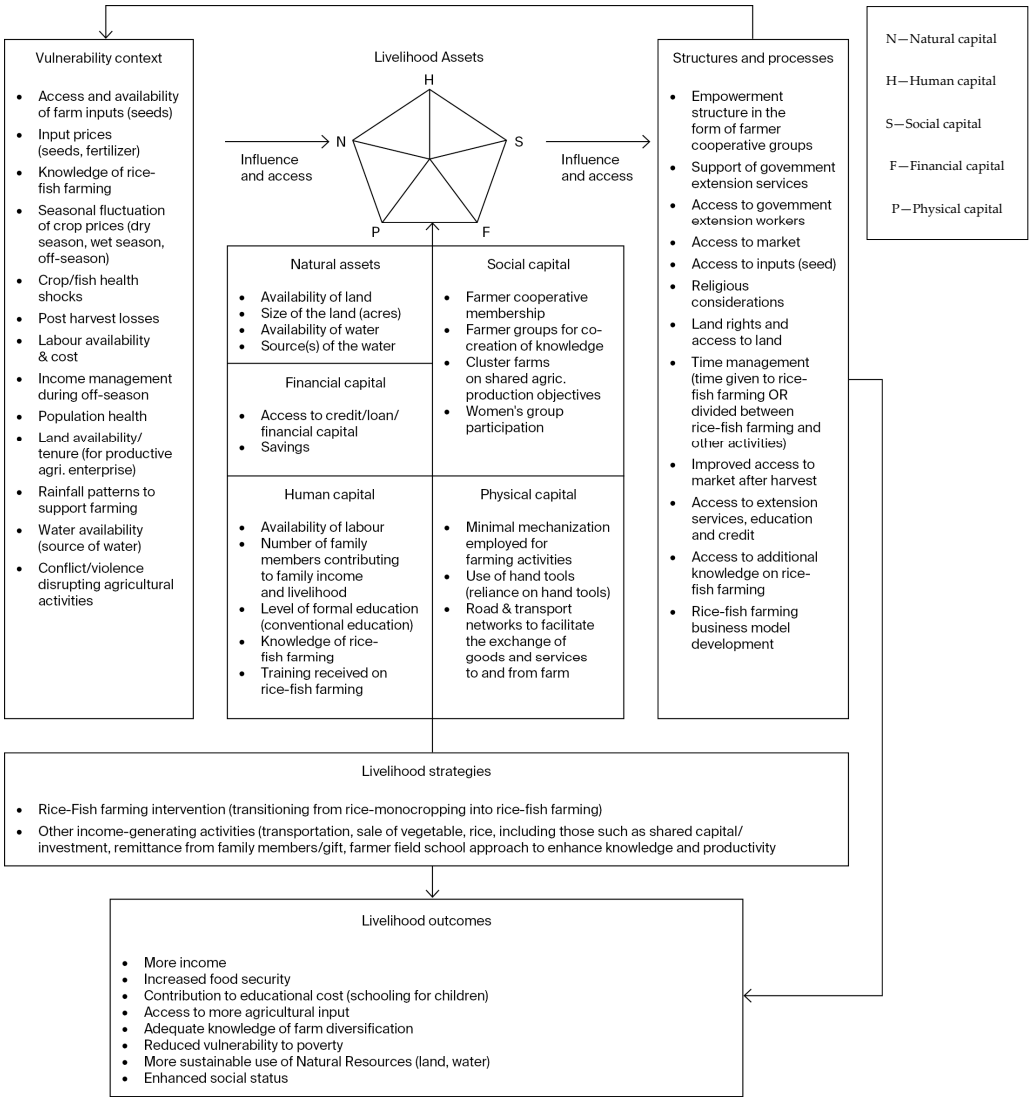

Figure 2. Sustainable livelihood framework for rice–fish farming system (source: authors' design; adapted from DFID [20]).

Conceptual model of how livelihood capital, vulnerability contexts, strategies, structures and processes, and outcomes are connected within the sustainable livelihood approach, as used in this study.

2.2.1. Survey Instrument Design

A structured household survey was developed to translate the components of the sustainable livelihood framework and the DPSIR framework into measurable indicators suitable for quantitative analysis. The instrument captured numerical values for livelihood assets, transforming structures, vulnerability factors, livelihood strategies, and livelihood outcomes based on the baseline situational assessment. The baseline survey documented existing livelihood capitals, production practices, and exposure to shocks before rice–fish integration, while the endline survey recorded changes following adoption. A longitudinal format enabled systematic comparison of conditions over time and supported statistical examination through descriptive and inferential techniques. All items were designed to produce numeric or categorical responses to allow estimation through frequency distributions and linear regression.

2.2.2. Measurement of Variables from SLF and DPSIR Frameworks

The conceptual elements of the sustainable livelihood framework and the DPSIR framework illustrated in Figure 2 were operationalized as structured survey indicators to enable quantitative analysis. Each livelihood capital was measured through items capturing core attributes relevant to the rice–fish context. Natural capital included land availability, land size, water access and water source, while human capital was measured through household labor availability, the number of contributing members, formal education level, and knowledge of rice–fish farming. Financial capital encompassed access to credit, availability of savings, and complementary financial resources. Social capital was represented by cooperative membership, participation in farmer groups, and engagement in peer-to-peer learning. Physical capital was assessed through mechanization level, ownership of farm tools, transport access, and field modifications such as trenches and bunds.

The vulnerability context was captured using categorical indicators of exposure to input price fluctuations, post-harvest losses, climate shocks, flooding, labor shortages, tenure insecurity, and health- or conflict-related disruptions. Transforming structures and processes included access to extension services, input supply systems, market access, land rights, and cultural or religious considerations, along with access to credit and training programs. Livelihood strategies were quantified through the extent of transition from rice monocropping to rice–fish farming, the number of annual production cycles, and involvement in additional income activities. Livelihood outcomes were measured as numeric changes in income, food access, dietary diversity, healthcare and education expenditure, input access, perceived financial stability, and social status. These indicators formed the dependent variables in the linear regression models used to examine relationships among capitals, vulnerability factors, and livelihood outcomes.

2.3. Sampling and Sample Size

The sampling frame comprised approximately 350 rice farmers identified in Argungu, Ngaski and Wawu–Jega. Eligibility screening relied on three criteria: active engagement in rice cultivation, access to a rice field suitable for rice–fish modification, and willingness to participate in training and monitoring activities. A total of 247 farmers met these criteria and were invited to participate, and 228 provided informed consent and completed both the baseline and endline surveys. This final group of 228 households practiced rice monocropping at baseline, and this provided a consistent reference point for assessment of subsequent livelihood changes. Purposive sampling [21] was used to focus the study on farmers who transitioned to integrated rice–fish systems.

2.4. Data Collection

Quantitative data were collected through structured household surveys administered at baseline and endline. Surveys covered socio-economic characteristics, resource access, livelihood assets, livelihood strategies (farm practices), input use, and livelihood outcomes. Qualitative data were collected through focus group discussions, key informant interviews with extension officers, and participatory observation at demonstration sites. These data provided contextual insights into adoption decisions, vulnerability factors, and institutional support mechanisms.

2.5. Data Analysis

Quantitative data were coded and analyzed using SPSS 25.0 and Microsoft Excel (Microsoft 365 Apps for enterprise). Descriptive statistics, frequency distributions, and cross-tabulations were used to summarize household characteristics and adoption patterns. Normality tests were conducted before inferential analysis. Linear regression models were estimated to identify predictors of key livelihood outcomes that included income, food access, healthcare, education, dietary diversity, input access, financial stability, and social status. Predictor variables included farm size, access to more land, labor affordability, and pesticide and herbicide use, among others. Model diagnostics included checks for multicollinearity through variance inflation factors, residual distribution, and overall model fit through R^2 values. Tests of normality (Kolmogorov–Smirnov and Shapiro–Wilk) indicated deviations from normal data distribution ($p < 0.05$) across most variables. However, given the large sample size (n = 228), the models remain robust, as multiple regression is relatively insensitive to normality violations when sample sizes exceed 200 [22,23]. Patterns and narratives were triangulated with quantitative findings to provide a holistic understanding of rice–fish integration [24]. Quantitative and qualitative data were subsequently organized within the DPSIR framework. Variables reflecting underlying motivations, input costs, tenure conditions, climatic shocks, and market volatility were grouped as Drivers and Pressures. Indicators of water access, field structures, input and service access, and institutional support were treated as State descriptors. Livelihood and ecological outcome variables, including income, food access, dietary diversity, healthcare and education expenditure, perceived social status, and reported biodiversity gains, represented Impacts. Adoption of rice–fish systems, field modifications, cooperative arrangements, and extension support were classified as Responses. Descriptive statistics and regression models were interpreted as empirical links between Drivers/Pressures, State conditions, and Impacts. Thematic analysis of qualitative data identified how farmer and institutional Responses emerged along these pathways. The linear regression model outputs are presented in Supplementary Tables S1 and S2.

2.6. Ethical Considerations

All participants were informed of the purpose and scope of the study and provided verbal consent before participating. Participation was voluntary, and respondents were free to withdraw at any stage. Data confidentiality was assured through anonymization of responses during analysis and reporting.

3. Results

3.1. Socio-Demographic Profile of Rice–Fish Farmers

The socio-demographic profile of participating farmers (Table 1) showed that middle-aged men dominated rice–fish farming. The mean age was 41.26 years (±9.4), with 92.14% male and only 7.86% female. Households were large, averaging 10.28 members (±3.1), which reflects extended family structures characteristic of rural northern Nigeria. These

household sizes implied high dependency ratios that placed considerable pressure on limited resources.

Table 1. Socio-demographic profile of the rice–fish farmers (n = 228) (source: authors' survey data).

Variable	Mean/% (±SD)	Notes
Average age (years)	41.26 (±9.4)	Predominantly middle-aged
Gender (male)	92.14%	Female = 7.86%
Household size	10.28 (±3.1)	Large, extended households

3.2. Livelihood Capitals of Rice Farmers for Adopting Rice–Fish Farming

The distribution of key livelihood capitals among participating farmers is summarized in Table 2.

Table 2. Capitals, vulnerabilities, and livelihood structures (n = 228) (source: authors' survey data).

Indicator	Measurement	Value
	A. Natural Capital	
Land access	Yes/No	95.2% yes, 4.8% no
Land ownership	Personal/Not owned/Community-owned	86.03% personal; 10.04% not owned; 3.93% community-owned
Mode of land access	Inherited/Rented/Purchased/Gift/ Borrowed/Community/Joint/Other	67.69% inherited; 11.35% rented; 10.92% purchased; 5.68% gift; 1.75% borrowed; 1.31% community; 0.87% joint; 0.44% other
Farm size distribution	<1 acre/1 acre/2 acres/3 acres/ 4 acres/≥5 acres	33.19% < 1 acre; 29.69% = 1 acre; 16.16% = 2 acres; 7.86% = 3 acres; 6.11% = 4 acres; 6.55% ≥ 5 acres
Access to more land	Yes/No	68.12% yes; 31.88% No
Water access	Yes/No	89.52% yes; 10.48% No
Water sources	Rivers, tube wells, rainfall, groundwater, boreholes, reservoirs, lakes	55.46% rivers; 49.34% tube wells; 44.54% rainfall; 30.57% groundwater; 10.40% borehole; 5.34% irrigation; 1.75% reservoir; 1.75% lake; 0.44% other
	B. Human Capital	
Labor availability	Yes/No	94.76% yes, 4.8% no
Ability to afford additional labor	Yes/No	65.07% yes, 34.93% no
Rice–fish knowledge before adoption	Adequate/inadequate	46.72% adequate; 51.09% inadequate
Access to healthcare	Yes/No	70.31% yes, 29.69% no
Knowledge gains	Rice only/Aquaculture only/Both	58.52% rice, 22.71% aquaculture, 22.27% both
Adoption of flood control adaptations	Plastic lining, channels, bund elevation	Qualitative (present in text)
	C. Financial Capital	
Main income source	Sale of stored crops	58.08%
Access to savings	Yes	55.02%
Access to loans	Yes/No	23.14% Yes, 76.86% no
Access to remittances	Yes	10.92%
Casual labor during lean periods	%	20.09%
	D. Social Capital	
Cooperative membership	Yes/no	Present (qualitatively reported)
Cluster farming/peer learning	Yes/No	Present in Argungu and Wawu

Table 2. *Cont.*

Indicator	Measurement	Value
Participation in training	% reached by extension	85.59%
Ownership of farming tools	Farm tools ownership	Widely owned (reported qualitatively)
E. Physical Capital		
Access to mechanization	Yes/no	Low mechanization (reported qualitatively)
Road condition	Good/poor	Predominantly poor (reported qualitatively)
Field modifications	Ditches/Bunds/Ponds/None/Other	41.92% ditches; 31.00% bunds; 17.47% ponds; 8.30% none; 1.31% other
F. Vulnerability Factors		
High input prices	Yes/no	Present (reported qualitatively)
Fluctuating crop prices	Yes/no	Present (reported qualitatively)
Post-harvest losses	Yes/no	18.78% yes; 81.22% no
Pesticide/herbicide use	Yes/no	60.26% yes; 39.74% no
Flooding	% affected	50.22%
Pest and disease outbreaks	Yes/no	Present (reported qualitatively)
Tenure insecurity	Yes/no	Present (reported qualitatively)
Labor shortage	Yes/no	Present (reported qualitatively)
Security threats (theft, conflict)	Yes/no	1.31% yes; 98.69% no
G. Adoption Conditions and Production Practices		
Rice–fish seasons	Dry/wet	78.6% dry; 69% wet
Access to rice seed	Yes/No	83.84% yes; 15.72% no
Access to fish seed (baseline)	Yes/No	51.97% yes; 47.16% no
Fish feed source	Purchased/Kitchen waste/Self-made/Other	74.24% purchased; 20.98% kitchen waste; 6.55% self-made feed; 8.73% other
Market access improvement	% Yes	67.25% improved
Fish price	Mean, median	NGN 1046.28 mean; NGN 1000 median
Purpose of adopting rice–fish	Sale + consumption/Sale only/Consumption only	73.6% both; 19.65% sale; 6.99% consumption
Production cycles per year	One/Two/Three	40.61% one; 53.71% two; 5.68% three

3.2.1. Natural Capital

Land access was reported by 95.2% of farmers, although farm sizes were small, with 33.19% cultivating less than one acre, 29.69% cultivating about one acre, 79.04% cultivating less than three acres, and only 6.55% cultivating more than five acres. Most land was individually owned (86.03%), with inheritance representing the dominant mode of access (67.69%). Importantly, 68.12% reported access to more land, suggesting opportunities for expansion. Water access was also high (89.52%), with rivers (55.46%), tube wells (49.34%), rainfall (44.54%), and groundwater (30.57%) as the main sources, complemented by boreholes (10.4%), reservoirs (1.75%), and lakes (1.75%).

3.2.2. Human Capital

Human capital was relatively strong, with labor availability reported by 94.76% of respondents. However, knowledge of rice–fish farming was uneven, with 51.09% reporting inadequate knowledge at the point of adoption. Farmers adapted to technical challenges by using plastic lining to reduce seepage and constructing channels to manage floods. Access to healthcare was relatively high, with 70.31% reporting proximity to clinics or hospitals.

3.2.3. Financial Capital

Most households depended on crop sales (58.08%) and personal savings (55.02%). Only 23.14% accessed loans, and 10.92% relied on remittances. A minority (20.09%) supplemented income with casual labor or non-farm activities during lean periods.

3.2.4. Social and Physical Capitals

Social capital was evident through networks and cooperatives. Farmers formed learning groups around demonstration sites, which facilitated peer-to-peer transfer of knowledge. Cluster farms were common in Argungu and Wawu, where collective experimentation and diffusion supported adoption. Most farmers owned basic farming tools and lacked access to advanced mechanization equipment. Infrastructure, such as rural roads, is reported to be poor. Poor rural road infrastructure reduced farmers' access to markets and resulted in higher transaction costs for inputs and the sale of farm produce.

3.3. Vulnerability Context Limiting Sustainable Livelihoods

Key vulnerability factors affecting rice-farming households are presented in Table 2. The vulnerability stressors reported by farmers to constrain their livelihood security before adopting rice–fish farming included high input costs, fluctuating crop prices, insecure tenure, low technical knowledge, water scarcity, post-harvest losses, pest and disease outbreaks, health-related shocks, and community conflict-related disruptions. These represent core Drivers and Pressures within the DPSIR framework that created incentives for diversification into rice–fish systems. During adoption, access to input (seeds) remained uneven. Rice seed was available to 83.84% of farmers, but only 51.97% had access to fish seed initially. Access to fish seed after adoption remained low, as farmers reported that access constraints persisted after adoption. Fish feed access was more problematic, with 74.24% purchasing feed, 20.98% relying on household waste, 18.78% adopting non-fed systems, and 6.55% producing their own feed. Labor was available to 94.76% of households, and 65.07% could afford hired labor. Rice–fish farming was practiced in both dry (78.6%) and wet (69%) seasons, but climate shocks persisted. Flash floods were reported by 50.22%; 19.21% practiced opportunistic farming during floods by channelling runoff water into a reservoir (water storage). Security concerns included theft of fish and equipment, while tenure insecurity discouraged investment in permanent field modification for some.

3.4. Livelihood Structures and Processes Linked to Rice–Fish Farming

Field modifications, extension support, and market conditions supporting rice–fish adoption are summarized in Table 2. Farmers adopted a range of field modifications to support rice–fish co-culture. The most common was ditch construction (41.92%), followed by reinforced bunds (31.0%) and in-field ponds (17.47%), while 8.3% made no modification. Demonstration plots and extension services reached 85.59% of farmers, which facilitated knowledge transfer, and market access improved, with 67.25% reporting better opportunities for rice, fish, and by-product sales. Farmers sold fish at an average price of NGN 1046.28 (USD 1.50), with a median of NGN 1000. Cooperative membership offered some credit access, though this was not always adequate during periods of peak input demand.

3.5. Livelihood Strategies of Rice Farmers

Before adoption, 79.04% of farmers relied exclusively on rice farming, with some supplementing income through fishing or horticulture. Intensification through fertilizer application was common, but yields and incomes remained inadequate. Adoption of rice–fish marked a shift from intensification to diversification. Motivations varied, with 73.6% citing both sales and consumption, 19.65% prioritizing profit, and 6.99% focusing solely on

household consumption. Training through on-farm demonstrations improved knowledge on rice, aquaculture, and rice–aquaculture, with 22.27% reporting gaining rice-specific knowledge, 22.71% gaining aquaculture knowledge, and 58.52% gaining knowledge on both. Rice–fish farming was practiced once (40.61%), twice (53.71%), or three times (5.68%) per year. Profitability increased by 49.04% compared with rice monocropping and 64.14% compared with standalone fish farming. Nonetheless, 63.76% retained monocropping fields in addition to a rice–fish farm, while 24.45% fully transitioned to rice–fish farming. These observed shifts in livelihood strategies are consistent with the regression results, where access to more land, farm size, and labor affordability emerged as significant predictors of improved livelihood outcomes (Table 3).

Table 3. Overview of important predictors of livelihood outcomes among rice–fish farmers (linear regression models of important livelihood outcomes) (source: survey data examined by the authors).

Outcomes	Key Predictors (Significance)
More income	None
Food access	Farm size ($p < 0.001$); pesticide/herbicide use ($p = 0.017$, negative)
Healthcare	Access to more land ($p < 0.001$); labor affordability ($p < 0.001$); farm size ($p = 0.032$); pesticide/herbicide use ($p = 0.037$, negative)
Education support	Access to more land ($p < 0.001$); labor affordability ($p = 0.004$); farm size ($p = 0.049$)
Dietary diversity	Access to more land ($p < 0.001$)
More access to agricultural input	Access to more land ($p = 0.034$); labor affordability ($p < 0.001$); farm size ($p = 0.017$)
Financial stability (less worry about money)	Farm size ($p = 0.031$); household size ($p = 0.002$, negative)
Enhanced social status	Access to more land ($p = 0.011$); labor affordability ($p < 0.001$); farm size ($p = 0.015$); pesticide/herbicide use ($p < 0.001$, negative)

3.6. Livelihood Outcomes

The economic, nutritional, social, and ecological changes reported among adopters (Table 4) constitute the principal Impacts within the DPSIR framework. Increases in income, improved food access, enhanced capacity to meet health and education expenses, perceived gains in social status, and opportunistic harvests of additional aquatic organisms together illustrate how rice–fish diversification reorients the system towards more desirable livelihood and ecosystem services outcomes. Income increased for 96.1% of farmers, food security for 56.3%, and dietary diversity for 30.6%. Health improvements were seen through increased capacity to spend on healthcare (35.1%), while 28.4% reported improved ability to pay school fees, and social status improved for 27.9% of adopters. Ecological benefits in terms of enhanced aquatic biodiversity were also qualitatively reported, which include increased sightings (compared to previous cycles of rice monocropping) and opportunistic harvests of crabs, snails, and crickets that added to both diet and income.

Table 4. Livelihood outcomes among rice–fish adopters (n = 228) (source: authors' endline survey data).

Outcomes	% Improved	% No Change	% Declined
More income	96.1	3.1	0.8
Food security (access)	56.3	43.7	0.0
Dietary diversity	30.6	69.4	0.0
Healthcare spending capacity	35.1	61.9	3.0
Education support (school fees)	28.4	66.3	5.3
Enhanced social status	27.9	69.0	3.1
More access to agricultural input	24.9	75.1	0.0

3.7. Regression Analysis of Livelihood Predictors

Nine regression models tested associations between household capitals and outcomes, with the key predictors presented in Table 3. R^2 values ranged from 0.057 to 0.402. Given the modest explanatory power of several models, these results are interpreted as indicative associations rather than definitive causal relationships. Access to more land and affordability of labor emerged as the most consistent positive predictors. Farm size was significantly associated with improved food access, healthcare, education, input access, financial stability, and enhanced social standing. In contrast, pesticide and herbicide use was negatively associated with food access, healthcare, and social status.

References to regression findings in the discussion correspond to the results presented in Section 3.7 (Table 3).

4. Discussion

4.1. Livelihood Strategies and Vulnerability Management

Resource (capital) management served as the principal mechanism that connected the shift from rice monocropping to integrated rice–fish farming and the corresponding improvements in livelihood outcomes. Within the DPSIR framework, access to inputs (seed, feed), insecure tenure, climate variability, and weak credit and advisory systems constituted fundamental Drivers and Pressures that constrain existing rice-based livelihoods. The prevailing State, characterized by small landholdings, lack of knowledge on diversification and water management under integrated crop-aquaculture systems, limited physical infrastructure, and insufficient institutional support, restricted farmers' capacity to respond. The adoption of rice–fish farming, elevation of bunds, construction of trenches/refuge channels, clustering of fields by farmers, and engagement with cooperatives and extension agents are concrete farmer- and meso-level Responses that altered this State and generated positive Impacts in terms of income growth, food security gains, risk reduction, and other social benefits. This relationship was shaped by farmers' capacity to adapt to and mitigate vulnerabilities such as high input costs, insecure land tenure, limited knowledge of efficient resource-use practices, health challenges that affect labor availability, and recurrent flooding. The regression results substantiate these patterns, with access to more land emerging as a significant predictor of healthcare expenditure ($p < 0.001$), education support ($p < 0.001$), dietary diversity ($p < 0.001$), and access to agricultural inputs ($p = 0.034$). Farm size similarly influenced multiple dimensions of livelihood improvement, including food access ($p < 0.001$), healthcare ($p = 0.032$), education ($p = 0.049$), financial stability ($p = 0.031$), and social status ($p = 0.015$). These associations confirm that natural capital and operational scale were critical mechanisms linking the adoption of rice–fish systems to observed livelihood gains, while recognizing that wider household and institutional dynamics extend beyond the scope of the models. Financial capital was fragile since most households depended on crop sales or savings, and only a minority accessed credit. The absence of strong credit institutions echoes findings from other African contexts, in which financial exclusion constrains diversification opportunities [25]. The physical structural field adaptations of elevating the bunds of the field and improving the drainage system with water inlet and outlet points, as a Response to potential flash floods, mirror experiences from the floodplains of Bangladesh, where resilience has been closely associated with adaptive field design and the reinforcement of key protective structures [26]. Negative relationships between pesticide and herbicide use and livelihood outcomes reflected ecological and economic mechanisms similar to those documented in China and Vietnam, where lower chemical use in rice–fish systems reduced costs and enhanced biodiversity, in addition to pest control and enhanced food availability [27,28]. The negative coefficients associated with pesticide and herbicide use in this study (food access, $p = 0.017$; healthcare

expenditure, $p = 0.037$; and social status, $p < 0.001$) confirm that chemical dependence undermined both ecological functioning and household welfare prior to diversification. Security threats further compounded vulnerability, as theft and wildlife predation were common in areas with scattered plots and distant markets. Experiences from Asia, where farmers adopted collective guarding systems and shared infrastructure such as net sets and culvert screens [9], offer relevant parallels for community-driven approaches that are adapted to local socio-cultural conditions for the cluster farms in Argungu and Wawu. Demonstration sites and extension services closed knowledge gaps, and participatory on-farm trials strengthened knowledge diffusion through behavioral patterns consistent with social learning and hands-on teaching in new farming skills [29–31].

4.2. Livelihood Management

Reported profitability increases of roughly a half relative to monocropping align with Asian evidence that rice–fish farming can raise gross margins by one-third to two-thirds [32]. These results confirm that diversification stabilizes income and creates opportunities for upward mobility in rural economies. The combination of two agricultural outputs (rice and fish) improved field hydrology (water management) and reshaped agricultural operation planning. Labor affordability significantly predicted improvements in healthcare ($p < 0.001$), education ($p = 0.004$), input access ($p < 0.001$), and social status ($p < 0.001$). The strength of these associations confirms that effective labor management constituted a central mechanism through which diversification translates into tangible livelihood gains. Access to more land predicted dietary diversity ($p < 0.001$), while financial stability was predicted by farm size ($p = 0.031$) and household size ($p = 0.002$, negative). These associations demonstrate that households with stronger natural and financial capital were better positioned to adjust to market and resource-related pressures. The evidence highlights the centrality of resource capital within the DPSIR structure and illustrates how differences in land availability, labor capacity, and financial resources shaped adaptive responses that influenced the scale of livelihood improvements. Observations from Asia show that integration allows hedging against rice price collapses, reduces vulnerability to single pest shocks, and is a productive option during wetter years [9,33]. Evidence from this study indicated similar early patterns. In several cases, rice–fish farmers retained separate rice-only fields to deal with possible risks. Interpreted through the lens of DPSIR, this cautious retention of some monocrop plots alongside integrated rice–fish fields represented an adaptive Response to persistent market and climate Pressures, consistent with stepwise diversification behavior in risk-prone production systems [34].

4.3. Livelihood Outcomes

Natural capital, ecological benefits, and vulnerability reduction: Optimizing the use of natural capital was central to the success of the diversification process. These observed shifts from chemical-intensive practices towards ecological intensification, coupled with higher and more stable incomes and improved food access, correspond to favorable Impacts in the DPSIR sequence and indicate that rice–fish adoption can partially relieve households from the adverse Drivers and Pressures that characterized the pre-intervention state. Diversification optimized land and water use in an area initially designated for rice monocropping to co-produce fish. Reductions in chemical input use correlated with better food access and improved health outcomes, which points to ecological rather than chemical intensification [28]. Farmers also observed richer biodiversity within rice fields, which aligns with evidence from Freed et al. [9], which showed that integrated plots support natural pest control and aquatic biodiversity regeneration.

Income and financial sustainability: Income represented the most immediate and visible outcome of adoption, with 96.1% of farmers reporting higher earnings. This aligns with studies in Asia where integrated rice–fish systems have been associated with substantial gains in profitability relative to monocropping [32,35]. In this study, average profitability rose by about half when fish production was integrated with rice, which reduced financial insecurity and allowed households to meet essential obligations such as purchasing agricultural inputs, paying school fees, and accessing healthcare. Profitability gains relative to rice monocropping and standalone aquaculture indicate lower exposure to single-commodity price risk and better factor productivity on small plots. These results are consistent with the argument presented by Ellis [36] that livelihood diversification reduces vulnerability to income shocks by spreading risk across multiple income sources. The regression results, which show farm size and access to more land predict financial stability and related outcomes, fit the scale-management narrative often observed in Asia [10,32]. Even modest increments in operational area enable better scheduling of transplanting, water control (management), and stocking of fish, which reduces idle capacity and transaction costs. A small share reported no income change or declines, which cautions against blanket generalization since flood risk, high feed prices, and tenure insecurity can offset gains where vulnerabilities to such shocks and stresses persist.

Food security and nutritional resilience: Food security improved for more than half of households, with survey results showing fewer worries about running out of food and better capacity to afford diverse diets. These gains reflect the double role of fish as a cash product and as a nutrient-dense food consumed within the household. Along with increased harvests of rice, households harvested fish and other aquatic organisms, such as crabs and snails, which they consumed and sold at nearby markets. These and other findings have been witnessed in Cambodia, China, Lao PDR, and Vietnam, where food of animal origin and other significant micronutrients that are not found in rice monocultures have become more accessible through integrated farming systems [37–40]. Moreover, fish sales tend to keep families afloat in times of food and cash shortages. More than half of the farmers reported having stopped being afraid of running out of food—one of the main indices of shock resistance on the Food Insecurity Experience Scale [41]. These findings confirm that enhanced productivity and food security can be achieved through optimizing the use of concomitant resources (capitals) available for agrifood production. Although African studies remain limited, the improvements observed in this study align with evidence from Kenya [42], Guinea [43], and Cameroon [44] which shows that integrated rice–fish systems enhance food access, reduce seasonal shortages and support more stable consumption patterns, with these effects shaped by conditions such as reliable water supply, access to essential inputs, secure tenure, labor availability, credit access and modest expansion in operational area. Rice–fish farming thus serves as an important food-based safety net that supports farming households (for food and cash from sales) during the period before the next production and harvest cycle. However, it has to be noted that increased food supply alone does not necessarily lead to improved household dietary quality in contexts where purchasing power for other food commodities remains unstable, intra-household food distribution/portion is unequal, or nutrition education and awareness is low [45]. It could therefore be inferred from this study that, although food availability and access increased, corresponding improvements in dietary diversity could not be confirmed. This indicates that diversification interventions should be complemented with nutrition education to strengthen nutritional outcomes.

Skills development: The diversification process led farmers to acquire new skills in water management, rice cultivation, and fish culture. There was an initial barrier to adoption due to gaps in knowledge; however, on-farm demonstrations, peer diffusion, and extension

support closed these gaps, and most farmers reported new flood mitigation practices that reduced fish escape. Similar to experiences in China and Vietnam, where training and collective learning were key to scaling rice–fish systems [11,46,47], knowledge expansion in this study was both a driver and an outcome of adoption. Human capital gains extended beyond technical skills as higher and more stable incomes raised the capacity to fund healthcare and schooling. Households reported better ability to pay medical bills and school fees after adoption, outcomes that arise where integration smooths income and reduces vulnerability to medical or tuition shocks. This supports Sen's [48] argument that livelihoods are sustainable when they enhance the capacity to improve wellbeing and expand future opportunities. Observations that labor was widely available and often affordable suggest that the integration of fish culture into rice farming did not displace essential caregiving or learning time in most farming households, although a dedicated time-use study would be the correct instrument for confirmation.

4.4. Factors Influencing Adoption and Performance

The results of this study indicated that the system-level Responses remain only partially developed in relation to the underlying Drivers and Pressures identified. In particular, training, demonstration plots, collective learning, labor availability, and emerging markets provide important local Responses that support rice–fish integration and begin to shift State conditions in favor of diversification. These elements improve knowledge and enhance social capital, which in turn reinforces positive livelihood Impacts. However, weak and uneven institutional and infrastructural Responses, including inadequate access to inputs (seed and feed), limited access to credit, poor rural roads, tenure insecurity, and insufficient public investment, constrain the extent to which the system can transition from a vulnerable State to a resilient State at scale. The contrast with Asian experiences, where coherent policy, input markets, and extension services provide robust Responses to similar Drivers such as population pressure, income demand, and climate risk, illustrates that the persistence of constraints in sub-Saharan Africa is not due to a lack of potential Impacts but due to incomplete Response mechanisms and fragile State conditions [32]. Kinkela et al. [49] and Koide et al. [14] reported similar patterns across sub-Saharan Africa, confirming that the livelihood gains from rice–fish systems remain conditional where systemic constraints persist. Their review showed that limited access to quality seed and feed, inefficient extension support, and inadequate water management infrastructure continue to restrict the capacity of farmers to sustain performance. These assessments align closely with the constraints identified in this study and collectively demonstrate how input bottlenecks, credit gaps, infrastructural deficits, and knowledge of water management under integrated systems restrict the extent of potential performance gains. Positive drivers included training, demonstration sites, collective learning, labor access, and market opportunities. Knowledge sharing at pilot sites created rapid feedback loops where farmers gained practical skills in aquaculture and rice production and applied these skills, for example, in raising the bunds that surround the rice fields to improve water retention for rice–fish co-culture and by adopting rice transplanting in specific spacing instead of the traditional broadcasting method of scattering seeds by hand, which often leads to shallow and weaker root systems [50]. Access to land and water, the ability to pay for labor at key moments, and proximity to markets supported performance, while social recognition encouraged plot clustering, which reduced guarding costs and made extension more efficient [26,27]. In countries such as China, Vietnam, and Bangladesh, rice–fish systems have been scaled to millions of hectares, supported by strong institutional frameworks, extension services, and market linkages [32,35,37,47]. In contrast, adoption in sub-Saharan Africa has remained limited, often constrained by weak input supply chains, knowledge

gaps, and inadequate policy support. This study demonstrates that adoption is feasible when these constraints are partially addressed through demonstration sites, extension, and farmer collective learning and peer-to-peer knowledge diffusion among farmers. The challenge is to institutionalize these support mechanisms and ensure equitable access to input resources. Without such support, adoption risks being confined to demonstration plots and to a small number of better-resourced farmers who have easier access to commercial input supply chains. Although the evidence from sub-Saharan Africa (specifically Nigeria in this study) converges with findings from Asia on profitability, food security, biodiversity gains, and the centrality of knowledge systems, the divergences appear majorly in input market maturity and institutional policy support. These convergences and divergences argue for locally tailored packages rather than direct transplantation of Asian designs [51]. Figure 3 synthesizes the empirical findings within the integrated SLF–DPSIR structure by illustrating how farmer motivations (Drivers) and production stresses (Pressures) influence system conditions (State); generate economic, nutritional, and ecological changes (Impacts); and elicit farmer- and institution-led adjustments (Responses).

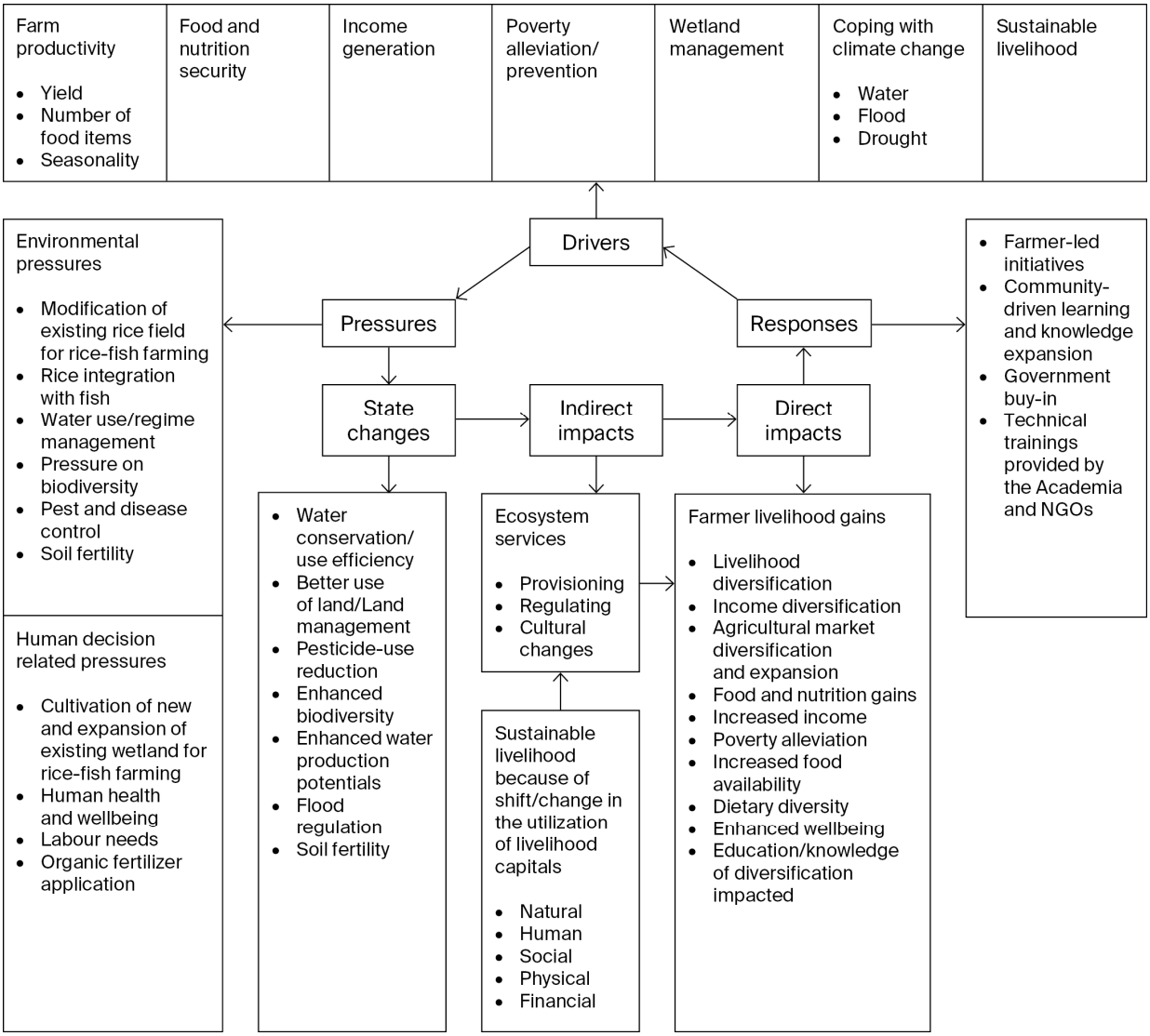

Figure 3. DPSIR-based conceptual framework of rice–fish diversification and livelihood transformation (source: authors' design).

The framework synthesizes the interactions within the DPSIR–SLF structure by linking farmer motivations, production pressures, and system conditions to economic, ecological, and social livelihood outcomes. It illustrates how shifts in natural, human, social, physical, and financial capitals shape adaptive responses, influence the trajectory of diversification, alter pressures, restructure state conditions, and generate impacts that feed back into livelihood resilience.

4.5. Limitations of This Study

The purposive selection of early adopters and the absence of a non-adopting comparison group limit the causal interpretation of the observed livelihood changes. The reliance on self-reported data introduces the possibility of recall and desirability biases, particularly for income, food access, biodiversity observations, and agrochemical use. Although the DPSIR categories were applied to organize systemic interactions, the framework was not fully operationalized in regard to biophysical measurements such as water quality indicators, biodiversity counts, agrochemical residue assessments, and independently verified yield data, because the present study was primarily designed as a livelihood-focused assessment with an emphasis on household capitals, vulnerability contexts, adaptive strategies, and livelihood outcomes rather than on biophysical and agronomic evaluation. Future research would benefit from integrating longitudinal ecological monitoring, objective productivity metrics, and experimental or quasi-experimental approaches in order to refine causal pathways, strengthen ecological validity, and expand the applicability of the results.

5. Conclusions

Evidence from this study indicated broad benefits: almost all households reported higher income, more than half experienced greater food security, and many reported improvements in education and healthcare. Beyond household gains, integration appeared to support cooperative structures, encouraged farmer-led adaptation, and facilitated knowledge exchange. The findings suggest that rice–fish integration operates as a multi-capital strategy where natural, human, social, physical, and financial assets interact with institutions to shape resilience and observed livelihood outcomes. The opportunities and constraints observed in this study indicate that lessons from rice–fish systems must be adapted to the socio-economic and ecological realities of sub-Saharan Africa. The evidence presented indicates that rice–fish integration contributes to several global sustainability priorities. The increased income for almost all adopters supports poverty reduction efforts consistent with SDG 1, while gains in food access, reduced anxiety about food shortage, and enhanced dietary options strengthen food and nutrition security in line with SDG 2. The rise in households that reported an improved capacity to meet educational expenses suggests an indirect pathway toward SDG 4 through improved financial stability and greater investment in schooling. Furthermore, the reductions in agrochemical dependence and the more efficient use of land and water are consistent with progress towards sustainable production patterns aligned with SDG 12, particularly in relation to ecological intensification and improved resource management. The findings indicate that rice–fish farming contributes to livelihood improvements under the examined conditions, and the integration of ecological monitoring and structured comparative designs in future research will help clarify its transformative potential and relevance for broader scalability.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su18010498/s1, Table S1: Multiple linear regression between livelihood outcomes as dependent variables and livelihood components as independent variables; Table S2: Tests of normality.

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