Agricultural Systems 228 (2025) 104383

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

From pond to lowland scale, a systemic approach to better understanding small-scale rice-fish farming dynamics: Case study in Guinea

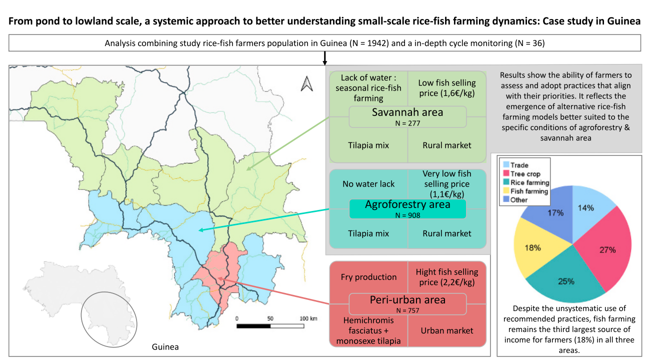
Lucas Fertin [a,b,*], Anne Perinelle [c,d], Teatske Bakker [e,f,g]

[a] CIRAD, UMR ISEM, F-34398 Montpellier, France
[b] ISEM, CIRAD, CNRS, EPHE PARIS, IRD, PSL, Université de Montpellier, Montpellier, France
[c] CIRAD, UPR AIDA, Antsirabé, Madagascar
[d] AIDA, CIRAD, Université de Montpellier, Montpellier, France
[e] CIRAD, UMR INNOVATION, Parakou, Bénin
[f] INNOVATION, Université de Montpellier, CIRAD, INRAE, Institut Agro, Montpellier, France
[g] Laboratoire de recherche sur l'innovation pour le developpement agricole (LRIDA), Université de Parakou, BP 1269 Parakou, Bénin

HIGHLIGHTS

- Fish farmers know the technical basics, but have a lack of male fry and difficulty regulating fish density.
- 41 % of fish farmers do not use *Hemichromis fasciatus* and 60 % do not use male monosex, slowing down intensification.
- Peri-urban fish farmers adopt more technical basics and sell larger fish to the regional market.
- Fish farming contributes 18% of rural incomes, making it the 3rd largest source of agricultural income in the region.
- Rural areas are developing integrated systems adapted to local water and market constraints.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Laurens Klerkx

Keywords:
Integrated rice-fish systems
Small-scale farming
Guinea
Food security
Agricultural innovation

ABSTRACT

Context: Rice-fish farming supports rural livelihoods in Guinea, but practices and outcomes vary widely due to differences in environmental conditions and market access. These disparities affect farmers' ability to adopt advanced aquaculture techniques, highlighting the need for context-specific approaches.
Objective: This study explores the practices, constraints, and income contributions of rice-fish farming systems in Guinea, with a focus on the drivers of technical adoption and their effects on household livelihoods.
Methods: A census of 1942 rice-fish farmers was combined with in-depth monitoring of 36 production cycles from 16 farms across three agro-ecological zones. Analyses included descriptive statistics, Kruskal-Wallis tests, mass balance, labor productivity calculations and qualitative analysis of semi-structured interviews. Market accessibility was identified as a significant influencing factor through statistical association with fish prices and practice adoption, and interpreted in light of qualitative information such as proximity to regional markets and the presence of wholesale fish buyers.

* Corresponding author at: CIRAD, UMR ISEM, F-34398 Montpellier, France.

https://doi.org/10.1016/j.agsy.2025.104383
Received 17 January 2025; Received in revised form 29 April 2025; Accepted 5 May 2025
Available online 8 May 2025

Results and conclusions: Although farmers generally understand fish farming principles, only 59 % use *H. fasciatus* and 30 % adopt monosex tilapia. Many recycle small fish as fingerlings, limiting growth potential. Rice-fish farming contributes 18 % of household income, on par with rice (22 %) and plantation crops (21 %). In peri-urban areas, better market access encourages the adoption of advanced practices, leading to higher prices (25,000 GNF/kg vs. 16,000–20,000 elsewhere). In contrast, savannah farmers face challenges such as water scarcity and poor market connectivity, often integrating dry-season horticulture into ponds.
Significance: The study highlights farmers' adaptability in developing context-specific practices. It underscores the need for tailored support to enhance the sustainability and resilience of rice-fish farming systems in Guinea.

1. Introduction

Today, 811 million people suffer from hunger (FAO, 2024). Aquatic food products are increasingly being recognized as vital for food security and nutrition (ibid.). To solve hunger and nutrition issues, fish-farming has been seen as a promising livestock industry capable of providing animal protein to the African continent since the post-colonial era (Lazard, 2012). Tilapia (*Oreochromis niloticus*) is a particularly noteworthy example. Easily reproduced and raised in intensive systems, tilapia has become a global aquaculture success (El-Sayed and Fitzsimmons, 2023). Since 2013, 58 % of the fish consumed globally has been produced through aquaculture, surpassing the volume of fish caught in the wild (FAO, 2024). The African continent, however, appears to be an exception to this trend. Fish farming has been seen as a promising source of animal protein in Africa since the post-colonial era, and aquaculture production on the continent has been increasing steadily. Yet Africa currently accounts for only a small fraction (2.7 %) of global aquaculture production (Babatunde et al., 2021). Apart from Egypt, industrial aquaculture models have been little developed in Africa, with most systems relying on extensive (Low animal density, minimal human intervention, reliance on natural resources) and semi-intensive (moderate density, limited feed inputs and human interventions) techniques (El-Sayed and Fitzsimmons, 2023). Several factors may explain this situation, including the divergence and inadequacy of financing tools and policies (Oswald and Mikolasek, 2016), high production costs, and competition from cheap fish imports that come from industrial marine fishing (Ragasa et al., 2022).

Nonetheless, some initiatives have been implemented. Small-scale rice-fish farming based on the ecological principles of dam pond systems has been developing since the 1990s (Boyd and Tucker, 2012; Dabbadie, 1996; Mischke, 2012). This production system aims to diversify the income of small-scale cocoa farmers who are vulnerable to fluctuations in global market prices (Morissens et al., 1996; Oswald, 2013; Oswald and Chamoine, 2000). For example, a model was developed in Côte d'Ivoire to establish family-owned, commercially-oriented tilapia production combined with rice cultivation in Africa (Copin and Oswald, 1993; FAO, 2001; Lethimonnier et al., 2022). The model promotes innovations such as polyculture (Thomas et al., 2021), incorporating three fish species—*Oreochromis niloticus*, *Heterotis niloticus*, and a predator, *Hemichromis fasciatus*—to regulate fish density and enhance productivity (Glasser and Oswald, 2001; Lazard and Oswald, 1995). Key practices include the use of monosex male tilapia, low stocking densities, and small ponds for fry production, with an emphasis on strengthening the professional organization of fish farmers.

Since 2000s, these technical references have been spreading into neighbouring regions, particularly in Guinea, through the administrative region of Forest Guinea (Halftermeyer, 2009; Mikolasek and Oswald, 2017). Guinea has vast lowland rice-growing areas (Gazull et al., 2023) suitable for the development of rice-fish farming. Demand for animal protein is high in the country due to food insecurity (WorldBank, 2020). In this context, the French Development Agency (AFD) and Guinean public authorities have supported small-scale fish farming initiatives, initially through the PPGF (*Projet Piscicole de Guinée Forestière*) project from 1999 to 2008 (Simon and Benhamou, 2009), and later through the PDRP-GF (*Projet de Développement de la Rizi-Pisciculture de Guinée Forestière*) project from 2014 to 2017 (Rangé and Pallière, 2017).

Finally, the PisCoFam (*Pisciculture Commerciale et Familial*) project, implemented from 2019 to 2024, aims to expand portion-sized fish farming (330 g) to villages and urban centres across Forest Guinea (Rangé and Pallière, 2017; Simon and Benhamou, 2009). However, some studies also have found differences between Guinea and Côte d'Ivoire in the development of fish farming dynamics (Barthes, 2007). These differences may be explained by smaller pond sizes, lower quantities of fish brought to market, and more acidic soils in Guinea compared to Côte d'Ivoire (Oswald, 2013). Furthermore, unlike their Ivorian counterparts, some Guinean fish farmers are not implementing key techniques that are essential to the proposed fish farming technical itinerary, such as using monosex male tilapia and *Hemichromis fasciatus* (Pallière and Rangé, 2018). Despite these original choices, the number of fish farmers in Guinea increased from 100 in 2009 (Simon and Benhamou, 2009) and the production basin currently has 1942 fish farmers 2022 (ANAG, 2022). This development may pave the way for a new smallholder fish farming strategy in Guinea which differs from the methods traditionally used in Côte d'Ivoire.

However, it remains difficult to fully understand the underlying motivations of Guinean farmers practicing fish farming. These uncertainties complicate the development of effective technical support approaches, raising the central question of this study: What are the underlying rationales guiding Guinean farmers in their fish farming practices, and how do these rationales influence the adaptation and success of aquaculture systems?

There are two main approaches for studying aquaculture systems. The first considers ponds and modern aquaculture technologies independently, without considering their direct link with the environment (Dabbadie and Mikolasek, 2015). The second, inspired by Farming Systems Theory (Darnhofer et al., 2010), aims to integrate aquaculture into agricultural systems, promoting a more holistic approach (Dabbadie and Mikolasek, 2015; Pallière and Rangé, 2018). As our study is focused on small-scale rice-fish farming systems, we adopted the latter approach. This approach considers the links between different farm components, such as the cropping system, livestock system, fodder system, workforce, and equipment/facilities (Meynard et al., 2023). The farming system can also be represented as combination of biotechnical systems and information and decision systems of farmers, linked together by agricultural practices and information flows (Coquil et al., 2010; Osty and Landais, 1993). Systemic coherence at the farm level is therefore linked to the technical choices in the functioning of the agroecosystem and to the rationales behind farmers' actions (Meynard et al., 2023). The diversification of production systems through rice-fish farming can be seen as a way for farmers to cope with variability through the diversification of activities and income streams (Darnhofer et al., 2010).

Our study aimed to analyze the adoption in Guinea of technical practices that were originally designed in Côte d'Ivoire, and to explore their links to the economic strategies employed by fish farmers. To accomplish this, we calculated the number of Guinean fish farmers who apply Ivorian technical references and compared this to the number of those who do not. We then deepened the analysis by studying a small group of fish farmers to gain insight into their perception of farming practices and to better understand the reasoning behind their decision making. Finally, we evaluated and compared the impacts of fish production on families in relation to other agricultural and non-agricultural activities. This allowed the study to achieve its secondary objective, which was to determine role of fish farming in the overall income of Guinean family farms. The findings of this study could be used to assist technical and policy institutions in making informed decisions about supporting family fish farming in Guinea and other regions of the Global South.

2. Method

2.1. Study area

We studied the main rice-fish production basin in Guinea, which corresponds to the southern part of Upper Guinea and Forest Guinea (Fig. 1). The study area has three distinct zones. We chose to analyze the results of these zones separately based on the assumption that farming systems in each one would differ depending on where the zone was situated along a pedoclimatic and urban gradient. Zone 1, called the 'Savannah zone,' is in the northern part of the production basin (prefectures of Farannah, Kissisdougou, Kerouane & Beyla)). Zone 2, called the 'agroforestry zone,' covers the southern part of the production basin (prefectures of Gueckedou, Macenta, Lola & Yomou). Finally, Zone 3, called the 'peri-urban zone,' corresponds to the prefecture of N'Zérékoré a highly urbanized capital city also located in the southern part of the production basin (Fig. 1). Zone 1 has a drier tropical climate, while Zones 2 and 3 have an equatorial climate (Gazull et al., 2023). Out of 1942 fish farmers in production, 930 are located in Savannah area, 254 in Agroforestry are, and 957 in Peri-urban area (ANAG, 2022).

2.2. General principles of the fish farming model developed in Côte d'Ivoire and proposed in Guinea

This small-scale fish farming system (Fig. 2) aims to improve family income through the production of tilapia (approximately 1000 kg/ha/year) and paddy rice (approximately 2500 kg/ha/year) that is transplanted into the fishponds (steps E to F, Fig. 2) in rural areas. The system follows a polyculture model that was originally developed in Côte d'Ivoire (APDRA, 2017; Oswald et al., 2003). The aim is to optimize multiple trophic levels during the growth cycle (steps C to D, Fig. 2) by regulating fish density with *Hemichromis fasciatus*, a predator introduced alongside male tilapia (step C, Fig. 2) (Glasser and Oswald, 2001). *Hemichromis fasciatus* are used to eliminate unwanted tilapia fry that result from errors in sexing the fry (step B, Fig. 2). The focus is on breeding male tilapia, which grow faster than females. To produce marketable tilapia weighing approximately 300 g, which is considered the optimal size to ensure profitability, meet demand, and match the purchasing power of rural areas, three main practices are recommended:

- Production of monosex male fry in fry ponds (steps A to B, Fig. 2);
- Use of monosex male tilapia at a density of 0.1 to 0.3 tilapia/m^2 during the growth cycle, in the dam ponds;
- Use of the predator *Hemichromis fasciatus* at a ratio of 2 predators for 10 tilapias during the growth cycle, in the dam ponds.

2.3. Data collection and analysis

We combined two complementary data sources, namely the population of rice-fish farmers in the production basin and a in-depth cycle monitoring (Table 1). Data were drawn from the rice-fish farmers population during a census of the 1941 fish farmers in production. Data from the small sample were collected during a detailed follow-up of 16 fish farmers. The complementary nature of these two data sources enabled

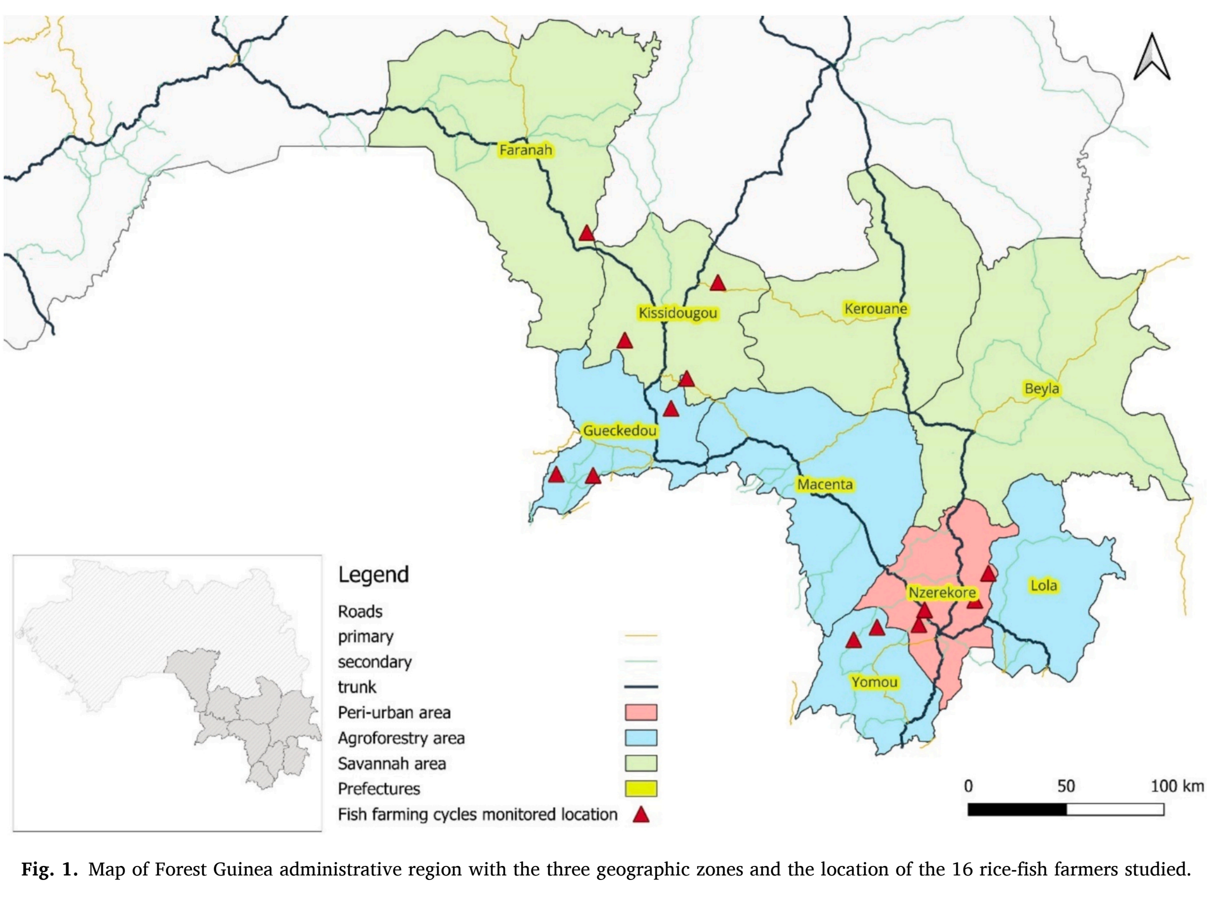


Fig. 1. Map of Forest Guinea administrative region with the three geographic zones and the location of the 16 rice-fish farmers studied.

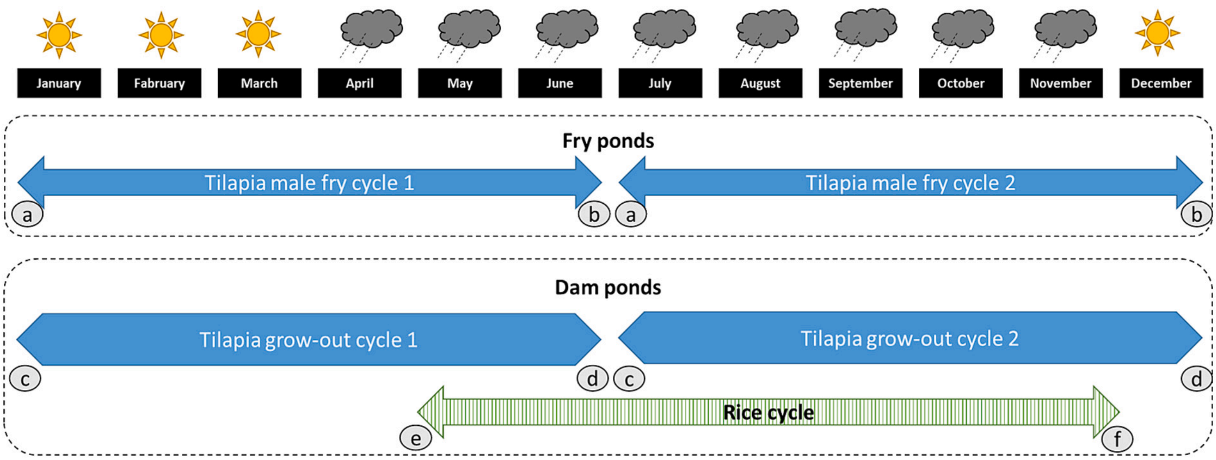


Fig. 2. Schematic theoretical representation of rice-fish farming cycles.

Table 1
Main characteristics of the population and the in-depth cycle monitoring of rice-fish farmers in the three study zones.

Sample description	Rice-fish farmer population				In-depth cycle monitoring			
	Savannah	Agroforestry	Peri-urban	Tot.	Savannah	Agroforestry	Peri-urban	Tot.
N farmers	277	908	757	1942	7	5	4	16
N monitored rice-fish growing cycles	–	–	–	–	12	19	5	36
N grow-out ponds	342	1533	1189	3064	11	11	4	26
N nursery ponds	274	943	712	1929	12	21	8	41
Tot. Ponds	616	2476	1244	3151	23	32	12	67

the cross-analysis of quantitative and qualitative data, thereby strengthening the validity of the results.

2.3.1. *Data from the population of rice-fish farmers*

The PISCOFAM project conducted a census of the 1942 fish farmers in the region between September 2022 and September 2023. The census, based on a closed questionnaire, was designed to assess the adoption of the previously mentioned technical practices and fish farmers answered four key questions:

- Do you implement a monosex male fry stocking cycle?
- Do you use monosex male tilapia in your grow-out cycle?
- Do you employ *Hemichromis fasciatus* predators in your grow-out cycle?
- At what price do you sell your fish?

The last question helps to determine whether farmers who adopt the practices sell their fish at a higher price, thus validating the hypothesis that there is an economic advantage associated with the adoption of these practices. Data from this census were recorded in a specific database and analyzed using descriptive statistics. The Shapiro-Wilk test indicated that data for all variables did not follow a normal distribution ($p < 0.05$). We therefore chose to use non-parametric tests, with the median as the main comparison statistic. The main results from the census are presented, taking into account the three geographical zones and the following six descriptive variables: Year of first stocking, Number of grow-out ponds, Number of nursery ponds, Fish sale price (GNF/kg), and Rice-fish farming area (the entire area of the pond flooded with water measured in are) (Table 1). The Kruskal-Wallis test with correction for multiple comparisons was used to highlight the three variables showing significant differences between the three zones: 1) surface areas, 2) fish sale prices, and 3) date of first fish stocking. We also analyzed the median sale price of fish based on six categories of density management practices observed. To do this, a Kruskal-Wallis test with correction for multiple comparisons was used to test if there was a difference in fish sale prices between fish farmers who implement the practices outlined in the technical reference (with.males/H.fasciatus) and other observed practices for managing densities (mix/H.bimaculatus; with.males/H.bimaculatus; mix/H.fasciatus; with.males/H.fasciatus; mix/no predator and with.males/no predator). We differentiated between *Hemichromis fasciatus* and *Hemichromis bimaculatus* because the latter is not a predator of fish larvae, and therefore cannot be used to regulate densities (Hyslop, 1987; Lévêque et al., 1990).

2.4. *Additional data from in-depth cycle monitoring*

We developed a methodology to monitor the agronomic performance of rice-fish systems and more qualitative indicators concerning the application of the proposed systems. This participatory method was inspired by the Management Advice for Family Farms (Faure et al., 2004) and co-evaluation methods developed for co-design (Périnelle, 2021; Salembier and Meynard, 2013). Data were collected from 16 volunteer rice-fish farmers between September 2022 and September 2023. A total of 36 rice-fish growing cycles were closely monitored, with several participants managing more than two within the year. The sample was selected to reflect diverse production conditions based on three key criteria: number of ponds (as a proxy for production capacity), distance from the regional market of N'Zérékoré, and average fish sale price. Each variable was divided into quartiles to ensure a representation of the observed situations (Table 2).

The farmers were monitored by six technicians from APDRA, an NGO, specialized in small-scale fish farming. These fish farmers, distributed across the savannah zone (7), the agroforestry zone (5) and the peri-urban zone (4) were located in 13 localities (Fig. 1) and represented the diversity of issues faced by producers in the production basin.

Data were collected using the mass balance method, inspired by flow studies in intensive aquaculture systems (Mathonnet et al., 2022). The main volumes of inputs, rice, and fish biomass were weighed at entry to and exit from the pond by a technician/fish farmer pair. The net fish

Table 2
Distribution of monitored rice-fish farming cycles by quartile-based of 3 criteria.

Criteria	Classes by quartiles	N farmers	N monitored rice-fish growing cycles
N ponds	Low pond intensity (1–3)	9	12
	Moderate pond intensity (4–5)	4	8
	High pond intensity (6–11)	3	16
Distance from N'Zérékoré (km)	Close proximity (15–62)	5	8
	Intermediate distance (63–250)	4	12
	Remote location (251–451)	7	16
Fish price (gnf/kg)	Low 14,000–15,000	5	11
	Moderate 16,000 < –>20,000	9	19
	Hight 21,000 < –> 25,000	2	6

yield (final biomass – initial biomass adjusted per hectare and per year) was only measured for in-depth cycle monitoring as it was impossible to weigh all of the fish from the 1941 fish farmers population.

We also studied the value produced by the different crop cycles (coffee, cocoa, cola, palm, rice, vegetable farming) and the aquaculture activities carried out within family farms using agronomic diagnostic methods (Ferraton and Touzard, 2009). Studying other types of farm production helps to determine the economic importance of aquaculture within a family's overall activities. To do this, we recorded the production volume of each crop and its selling price to estimate the related income. Moreover, income earned from off-farm activities, such as small businesses or mentoring services (experienced local farmers are paid small fees to share their fish farming expertise with less experienced fish farmers), also was considered.

The value generated by both the agricultural and non-agricultural activities of each monitored farm was recorded in a database throughout the year as harvests and sales occurred. We assumed that when farmers work for themselves, their priority is to optimize the profitability of their labour by choosing production systems that offer the best return relative to the effort invested (Ferraton and Touzard, 2009). To compare the performance of different activities, we used daily remuneration as an indicator. This was calculated as the annual added value for a specific system on a given area divided by the total labour time required per year on that area (in hours per day). Added value was determined by subtracting costs (intermediate consumption of rice and fish, plus depreciation of fish stocks, structures, and small fishing equipment) from total products (revenue from fish sales, value of self-consumed fish, and value of self-consumed rice). After each of the 36 fish catching and rice harvest session, individual open-ended interviews were conducted to gather fish farmers' perspectives on their rice-fish results, including concerns, criteria for evaluating cycle outcomes, and their willingness to make changes in practices. We have standardized the results to improve comparability between fish farmers with different raw numbers by providing a common 0–10 scale that simplifies interpretation, statistical analysis and visualization. When analyzing the 36 interview reports, we counted how many times each farmer mentioned each concern, performance indicator and desire for change. For each category (concerns, performance indicators, willingness to change), we identified the minimum and maximum number of mentions among all the farmers. We then transformed these raw counts into a common scale from 0 to 10, using the following normalization calculation: Normalized value = ((raw value-minimum value)/(maximum value-minimum value)) × 10. In order to obtain an overall view of the region, an average of the scores for the 3 zones was calculated by weighting the results by the number of fish farmers in each zone. The interviews were conducted using a structured guide, with translations provided in Kissi, Guerzé, and Malinké, and a facilitator ensured smooth discussions. The significance level for statistical analyses was set at $\alpha = 0.05$, with all tests conducted using R software version 4.2.2. Figures were generated using IBM SPSS Statistics version 23.

3. Results and discussion

3.1. Farmers have a strong understanding of fish-farming principles

As shown in Table 3, the viewpoints of fish farmers vary across the three zones, but there are some common challenges that they all face. Commonly cited issues include a lack of male fry, difficulties in feeding fish, and invasions of wild fish and plants (Table 3, category "Concerns"). In the peri-urban and agroforestry zones, managing fish densities is a key problem, while the savannah zone struggles with water scarcity and limited market access. These concerns are related to two of the three main practices (monosex and density) outlined in the technical guidelines. However, the technique that involves *Hemichromis fasciatus* seemed to be notably missing from results. Rice-fish farmers assess the success of their cycle using indicators such as fish size at harvest, the proportion of males produced during pre-growing cycles, and the income generated (Table 3, category "Key Performance Indicators"). In the savannah zone, a successful cycle depends on a steady water supply, while in the peri-urban and agroforestry zones, it depends on a minimal presence of wild fish. The will to change also is broadly similar across zones (Table 3, category "Willingness to change"). Farmers expressed interest in producing more male fry, improving sexing techniques, making their own fish feed, and better managing their stocking density. In the savannah zone, there was a specific wish for more ponds that retain water during the dry season, enabling fish storage and supporting a horticultural cycle during pond drying periods.

In summary, fish farmers in the savannah zone have the biggest median surface areas (med: 16,5 ares, IQR: 4–39,25) and are primarily concerned about the lack of water during part of the year and the difficulty of storing their fish during the dry season. As highlighted by these fish farmers, this seasonal challenge often results in the loss of fish during the dry period, which then prevents the start of male monosex fish growing cycles at the beginning of the rainy season. They also try to diversify their fish farming areas by integrating vegetable cycles when the ponds have dried up, as one of them summarized: "We also want to test fish exchanges between those who have water and those who don't during the dry season. I want to do a vegetable cycle during the dry season." In the savannah zone, fish farmers also emphasized marketing problems, which could indicate greater difficulties in accessing the market, unlike the agroforestry zone where this concern seems less present. Surveys and recent work on the subject have shown that in the peri-urban zone, fish traders are in contact with fish farmers, buying fish at the edge of ponds and reselling them at the N'Zérékoré market (Lanta, 2023). In the rural agroforestry zone and the savannah zone, producers sell their products themselves or through their wives who market them in neighbouring villages (Desprez, 2023).

The agroforestry zone and the peri-urban zone seem quite similar, except for the surface area dedicated to rice-fish farming, which is lower in the agroforestry zone (med: 13 ares, IQR: 7–20) (Fig. 3). However, the peri-urban zone has greater experience of 6 years (IQR: 2–9), as well as a higher fish price (med: 20,000 GNF/kg, IQR: 10,000–20,000). The concerns of the agroforestry and mostly peri-urban zones focus on intensifying their fish farming system through improved feeding, fertilization, and optimization of male fingerling production. As one fish farmer explained: "I try to set up more fingerling ponds to produce more, and I also try to introduce pig waste to fertilize my ponds."

Table 3
Occurence of concerns, performance indicators, and willingness to change of each fish-farmers within the 36 interviews of of in-depth cycle monitoring. Items common to all 3 zones are shown in bold.

Area		Savannah	Agroforestry	Peri-urban	Total
Concerns	Lack of male fry	3	10	10	9
	Fish feeding	4	8	4	6
	Inadequate stocking density management	0	10	1	5
	Water fertilization	0	6	5	5
	Invasion of unwanted wild species (fish or plants)	3	6	3	4
	Fish size at the end of growth	5	6	0	4
	Lake of water	10	0	0	1
	Planning of rice and fish cycles	0	2	0	1
Farmer performance indicators	Fish size at the end of growth	9	10	10	10
	Number of male fry produced	3	2	6	4
	Few invasive wild fish	0	3	4	3
	Fish recovery rate	1	3	3	3
	Generated income	4	1	1	1
	Water availability	10	0	0	1
Willingness to change	Producing and using more monosex males	6	10	8	9
	Learning to make and provide local feed	4	7	5	6
	Fewer wild fish	2	3	10	5
	Knowledge of sexing	1	4	8	5
	Rationalizing stocking density	2	4	3	3
	Fish size at harvest	0	0	8	3
	Fertilizing	0	6	0	3
	Aquaculture infrastructure able to prevent drying out and store fry with other fish farmers	10	0	0	1
	More service ponds	0	0	3	1
	Fewer invasive plants	0	0	3	1
	Diversification through vegetable cultivation in fish ponds during drying periods	4	0	0	1

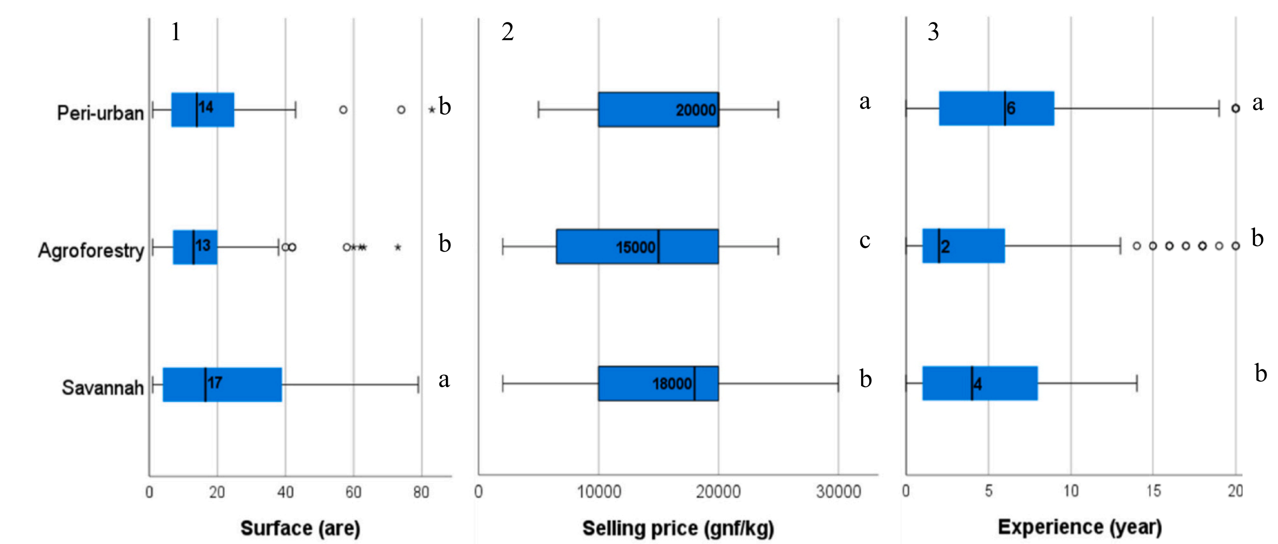


Fig. 3. Comparison of 1) fish farming surface, 2) fish selling price, and 3) experience in fish farming of the population of 1942 fish farmers based in the three zones. *Results of the Kruskal-Wallis test followed by a* post hoc *test with correction for multiple comparisons. The boxes represent the median (bold central line), the 1st and 3rd quartiles (edges of the box), and the whiskers indicate the range of values, excluding outliers (individual points). Groups with different letters are significantly different ($p < 0.05$).*

3.2. The main technical references from the Ivorian model are not used systematically by fish farmers in Guinea

While farmers appear to have mastered the management principles of fish farming, census data shows that, on average, only 59 % use *H. fasciatus*, and a mere 30 % use male monosexes (Fig. 4). Results also indicate that 14 % of fish farmers use *Hemichromis bimaculatus*, a fish visually similar to *Hemichromis fasciatus*, but not a predator of fry, due to confusion among farmers in identifying the species capable of regulating densities.

The 'Males + Hf' practice is the one most widely used by fish farmers (22 %) in the peri-urban zone, which is also located closest to the main production basin market. The fish farmers in N'Zérékoré thus seem to be drawn to the possibility of selling larger fish in the regional market, just as in Côte d'Ivoire, which encourages them to adopt the proposed practices.

Finally, out of the 1942 fish farmers, 65 % have a nursery pond. Among this group, 8,5 %, 17,7 %, and 25,1 % of fish farmers from the savannah, agroforestry, and peri-urban zones, respectively, reported having carried out a nursery cycle in 2022 to produce male monosexes, i.e. only male fishes. These results show that one-third of fish farmers make do without a nursery pond, and those who have nursery ponds do not systematically produce fry. In practice, when fish farmers empty their grow-out pond, they reuse net bottoms, i.e. fishes that are typically small or of lower commercial value compared to targeted species, including juveniles, non-commercial species, or fish damaged during

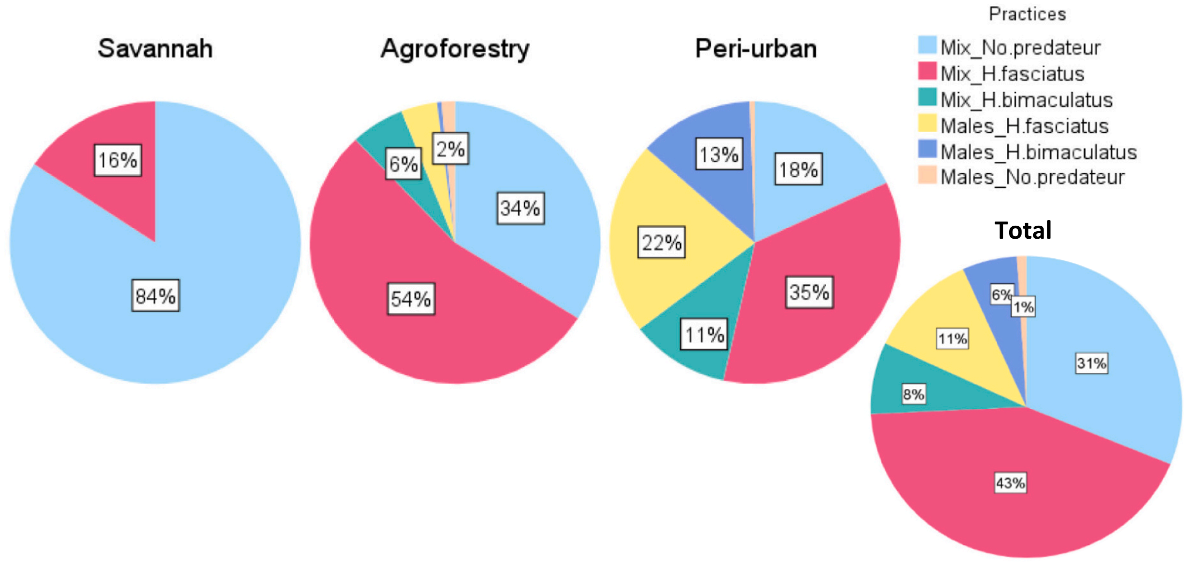


Fig. 4. Proportions of the 1942 fish farmers with respect to the six observed practices and three study areas.

capture, to restock the same pond to start a new cycle. This extensive practice does not allow for the growth potential provided by fry from an independent nursery cycle, which produces homogeneous individuals (same size and same age). Small fish that have been recycled as fry may not necessarily be the same age, leading to a high risk of using small, older fish that will grow little, which reduces the overall yield potential of the stock (APDRA, 2017). However, this practice enables fish farmers to continue producing fish for their families and villages, demonstrating great resilience. These technical decisions clearly demonstrate that the farmers are justified in their approach to adapting to their circumstances and knowledge, as has been demonstrated in other agricultural case studies (Andrieu et al., 2015).

3.3. Guinean fish farmers who implement the main Ivorian technical references sell their fish at a higher price than others

The results indicate that, thanks to a thriving market that allows the sale of larger fish at higher prices, fish farmers in the peri-urban zone adopt technical practices more frequently than those in other zones. The Kruskal-Wallis test with correction for multiple comparisons confirms that fish are sold at significantly higher prices (med = 25,000 GNF/kg, IQR: 20,000–25,000, or 2.8€/kg) by fish farmers using the reference technical practices (monosexes + *H. fasciatus*) compared to the other practice categories (Fig. 5). These prices are consistent with the prices of farmed fish sold at the pond-side in the sub-region: 2.3€/kg in Côte d'Ivoire (Amian et al., 2017), 1.8€/kg in Ghana (Duodu et al., 2020), and 1.6€/kg in Senegal (Diédhiou et al., 2020).

The observations in Fig. 5 and those in section 3.2 suggest that market accessibility in peri-urban area is a significant influencing factor through statistical association with fish prices and practice adoption. Other variables could also explain this link between peri-urban area and fish prices, such as the proven presence of a wholesale organization capable of visiting rice-fish farmers located near the urban center to buy their entire catch at once and resell it on the large market in the regional urban center (Lanta, 2023). This aligns with findings in other contexts, where market access serves as a motivation for small-scale farmers to invest in innovative technologies and strategies (Shiferaw et al., 2009).

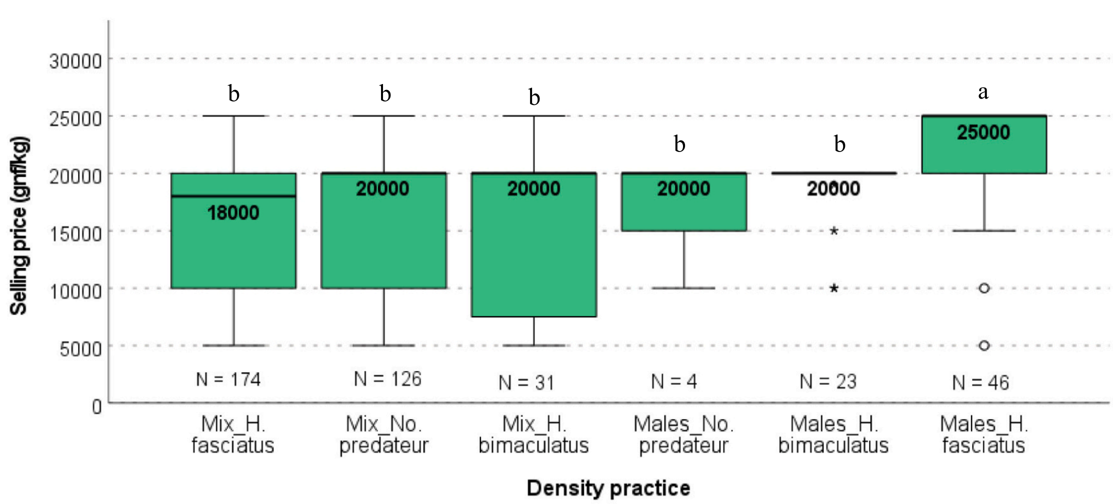


Fig. 5. Price of tilapia sold based on practices implemented by the 1952 farmers surveyed. €1 = 9086 GNF. *Results of the Kruskal-Wallis test followed by a* post hoc *test with correction for multiple comparisons. The boxes represent the median (bold central line), the 1st and 3rd quartiles (box edges), and the whiskers indicate the range of values, excluding outliers (individual points). Groups with different letters are significantly different (p < 0.05).*

3.4. Fish farming production results highlight a distinct rural aquaculture dynamic in Guinea

Fig. 6 shows that peri-urban cycle from in-depth cycle monitoring sold the largest proportion of fish (49 % of the biomass produced over one year of monitoring). Savannah and agroforestry areas accounted for the highest levels of fish consumed and given away (21 %, 7 % and 11 %, 5 % respectively). Except for peri-urban area, these results indicates that a smaller proportion of fish is sold in Guinea compared to producers in Côte d'Ivoire, where more than half of the fish is sold (Oswald, 2013). Figs. 6 and 7 shows the high proportion of fish reused within the system, regardless of species or size, demonstrates the farmers' deliberate choice to repopulate their grow-out ponds with 'net bottoms' (see 3.2). Furthermore, the median overall yield is 511.3 kg/ha/year (IQR: 254.2–953.6), aligning with data in regional and international literature on rice-fish farming (Hossain et al., 2015; Kouadio et al., 2024b; Qiuming and Yi, 2004).

However, the size of the fish sold differs from studies conducted in Côte d'Ivoire, which report sale sizes of 250 g (Copin and Oswald, 1993; Lazard and Oswald, 1995; Oswald et al., 2003; Simon and Benhamou, 2009) to 330 g at the end of the production cycle (Lethimonnier et al., 2022).

Fig. 7 shows that the primary species sold is tilapia in the 100–200 g size range with 29 % of sales (median: 142.9 g, IQR: 125.0–176.5). This is followed by the 30–100 g tilapia with 18 % of sales (median: 50 g, IQR: 34,2–67,7) and *Heterotis niloticus* broodstocks with 17 % (median: 2 kg, IQR: 1,1–2,6). These findings confirm earlier observations about the production of small fish in Guinea (Oswald, 2013; Pallière and Rangé, 2018) and our findings on the unsystematic implementation of intensification practices proposed by support organizations. The sale of small farmed fish, starting from 70 g, has also recently been documented through studies of marketing channels (Desprez, 2023; Lanta, 2023).

These results suggest a spectrum of socio-technical dynamics between two contrasting agroecosystems in the region:

1_Peri-urban zone in the south: Located closer to the major regional market in N'Zérékoré, this area seems to offer greater economic security for producing and selling larger fish and in higher quantities. The low amount of biomass that is consumed or donated suggests that farming-fishing near urban areas could be expanded, with support focused on technical improvements in aquaculture. Traditional strategies proposed in Guinea and Côte d'Ivoire, such as maximizing yields of portion size (330 g) monosex male fish, using *H. fasciatus*, and optimizing fertilization and stocking densities, remain relevant. The development of more intensified peri-urban fish farming (as in Côte d'Ivoire) may remain limited due to the competitiveness of frozen fish from sea stocks sold very cheaply in town (Ragasa et al., 2022). One solution is to sell more expensive fish to those with greater purchasing power, but in this case only wealthy families will be able to buy it, and they are not the main targets of development projects.

2_Savannah zone and broader rural areas: This zone appears conducive to developing aquaculture systems for small fish integrated into lowland farming practices, including rice farming and horticulture. A more systemic approach is required to support lowland-based production that is aimed at isolated rural markets and self-consumption. The production of these small, protein-rich fish reinforces dietary diversity in remote rural areas, a crucial factor in addressing food insecurity in African contexts (Longley et al., 2014; Thilsted, 2012). This particular development dynamic is different from the peri-urban dynamics described above or those observed in Côte d'Ivoire. This could be the subject of future, more in-depth research to determine the socio-technical factors that have influenced the development of fish farming in these border territories in two different ways.

3.5. In Guinea, small-scale fish farming makes a non-negligible contribution to family income, on a par with other crops

Fig. 8 shows that fish farming is a highly effective way to diversify income sources. Among the 16 farmers monitored over one year, it was their third highest source of income, and contributed 18 % of the daily income earned by agricultural workers. The main source of income is plantation farming, accounting for 27 % (i.e., palm, coffee, cocoa, cola), followed by rice cultivation (25 %), and finally fish farming (18 %). It is important to note that rice income is enhanced by fish farming in the lowland areas. Our data show that when rice cultivation is not associated with fish farming, whether in lowlands or on slopes, it seems to generate a lower income per day of work, amounting to 1526 (± 1187) GNF / asset / day ($N = 4$), compared to rice cultivated in a rice-fish pond, which generates 3347 (± 2263) GNF / asset / day ($N = 15$). These results, although not statistically significant due to the small sample size, are supported by the literature (Berg et al., 2023; Tsuruta et al., 2011).

Furthermore, only 7 out of 9 farms were able to pay their workers above the poverty threshold set at 16,423 GNF (€1.6) per person per day in 2020 (WorldBank, 2020). This highlights the high levels of poverty experienced by families in rural Guinea. Without rice-fish farming, only 4 out of 16 farms would be able to provide pay above this threshold. Despite differences in practices (cf. 3.2) and sizes of fish sold (cf. 3.4), rice-fish farming is the third largest source of farm income in Guinea and Côte d'Ivoire, accounting for 17 % of daily earnings per asset (Kouadio et al., 2024a).

The results show that farmers have the capacity to assess and adopt practices that align with their priorities. The economic importance of fish farming in the savannah zone and remote areas suggests that the low adoption rate of certain practices in these regions should not be seen as a

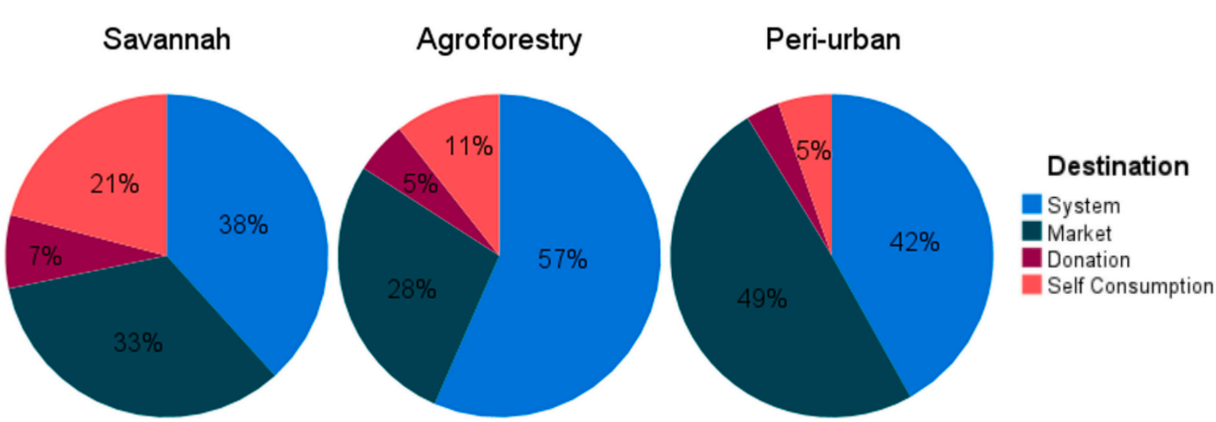


Fig. 6. Volume of fish self-consumed, given away, sold and reused within the system by the thre e zones. Data are from 67 ponds managed by 16 fish farmers in the in-depth cycle monitoring. *ON = Oreochromis niloticus (Tilapia); HN = Heterotis niloticus; CZ = Coptodon zillii.*

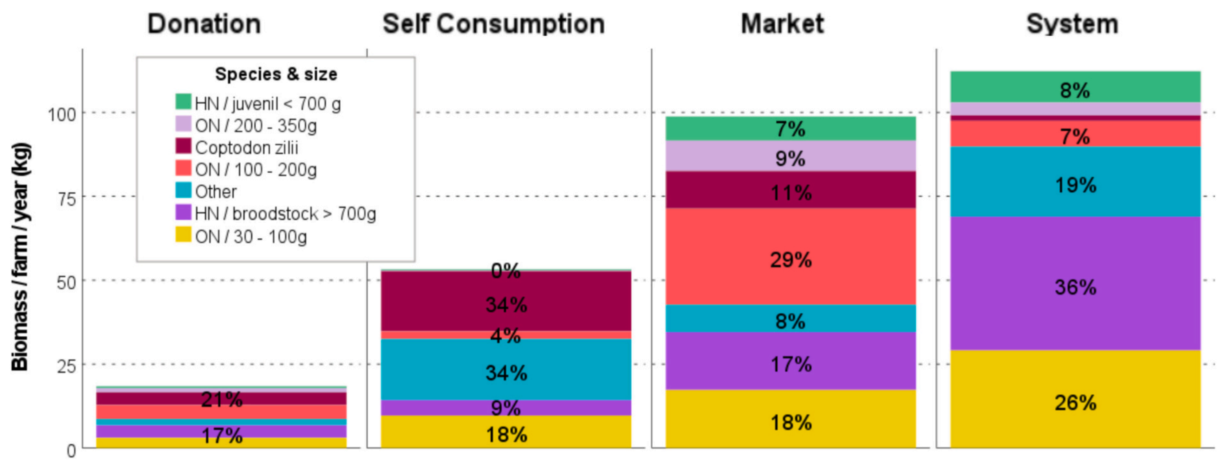


Fig. 7. Volume of fish self-consumed, given away, and sold by species and sizes. Data are from 67 ponds managed by 16 fish farmers in the in-depth cycle monitoring. *ON = Oreochromis niloticus (Tilapia); HN = Heterotis niloticus; CZ = Coptodon zillii.*

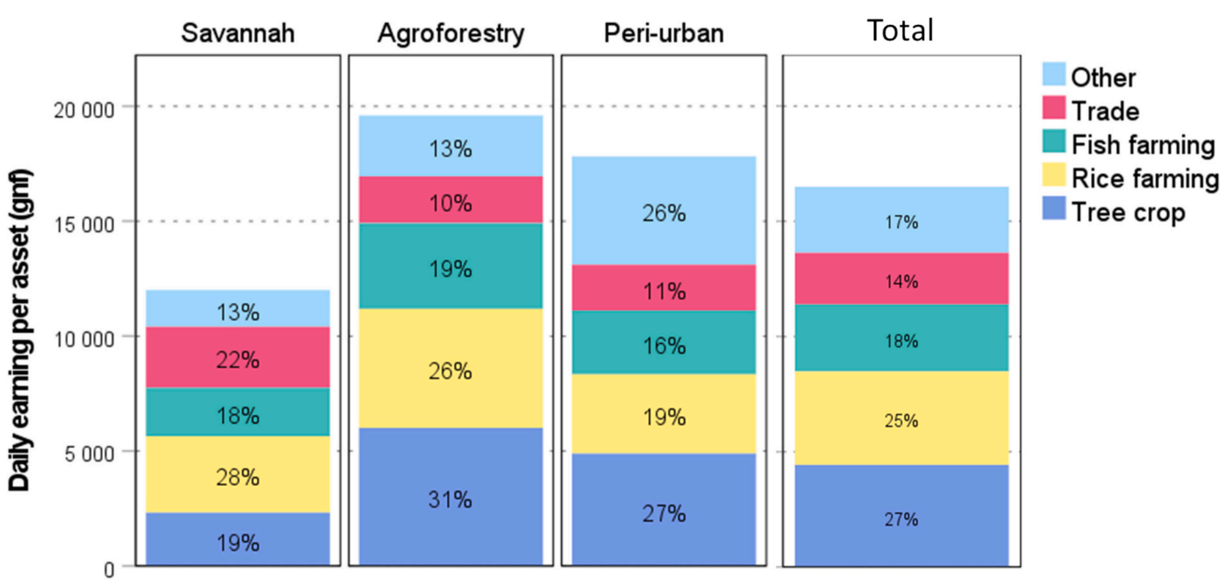


Fig. 8. Contribution of the activities of the 16 fish farmers of the in-depth cycle monitoring to the daily remuneration of their asset. €1 = 9086 GNF. As there is no paid work on the farms studied, this figure shows the monetization of family working time to enable comparison of the economic performance of the activities.

failure. Instead, it reflects the emergence of alternative rice-fish farming models better suited to the specific conditions of these zones. This highlights the adaptability and pragmatism of farmers in designing systems tailored to their unique needs and constraints.

In agroforestry zones, plantations tend to provide the main source of income, while in savannah areas, rice farming plays this role. When farmers work for themselves, their priority is to optimize the profitability of their labour by choosing production systems that offer the best return for the effort put in (Ferraton and Touzard, 2009). It is thus understandable that fish farmers, when given a choice, would prefer to spend their day clearing coffee plots rather than sorting fish, as coffee would generate more income in the current economic context. Similarly, lowland rice cultivation remains a priority to ensure food security for Guinean families (Rey and Rétif, 2017). In this context, fish farming appears to be an agro-ecological lever capable of intensifying plots in hydromorphic systems (lowlands) by integrating this activity with others, such as horticulture and rice farming. Family farms prefer this strategy over specializing in high-yield crops (Dufumier, 2007). In this regard, it might be appropriate to develop agricultural advisory services specifically adapted to these rice-fish farmers, considering them more as lowland farmers who value not only fish farming, but also rice growing and market gardening. In the case of the Savannah zone, high-impact research and development interventions should therefore continue to focus on improving fish yields in line with local market demand, but also on other pond crops such as rice varieties suitable for rice-fish farming, or dry season market garden crops with relevant pest control options). In peri-urban areas, the pursuit of research and development interventions should focus on agro-ecological intensification with a network of farmers wishing to specialize in more intensive fish farming (e.g. improving fish nutrition and pond fertilization with processed fish feed or trials of innovative lowland management to obtain low water renewal and enhance phytoplankton development). (Duodu et al., 2020; Kabir et al., 2020).

Moreover, cette approach, could helps to strengthen the resilience of agricultural systems when faced with various economic and climate risks (Dixon et al., 2021; Pretty, 2018). From this standpoint, the optimization of lowlands, due to their complexity, becomes a subject of study in its own right, falling within the realm of agrarian systems and household economics (Lavigne-Delville et al., 1996). However, assessments of the first attempts to develop rice-fish farming in the forested regions of Guinea have revealed failures, often due to insufficient consideration of farmers' practices and adjacent agricultural activities

(Delarue, 2008). The current goal is to continue studying the lowlands as a complex hydromorphic agro-system that can benefit from various interconnected crop-livestock associations managed through a single agro-ecological technical itinerary. This technical itinerary, which can be adjusted according to the season and the water level in multi-use spaces, requires transdisciplinary support (Lavigne-Delville, 1998; Theisen et al., 2017). Few studies have focused on these complex technical itineraries, although some experiments in Southeast Asia seem to have been documented (Jewel et al., 2023). These findings, combined with our own results, indicate that the optimization of integrated rice-fish farming systems using the Farming System approach remains relevant, although few scientific publications are currently available on this subject (Côte et al., 2018; Dabbadie and Mikolasek, 2015).

3.6. Improving future support methodologies

Co-designing rice-fish farming technical itineraries using mass balance models is a rigorous, participatory method that is accessible to research and development organizations working in the Global South. This original method is positioned at the intersection of Management Advice for Family Farms (Faure et al., 2004) and co-evaluation approaches (Périnelle, 2021). It is based on the individual commitment of each fish farmer to monitor their own technical and economic results in partnership with a technician. In addition to helping to better understand farmers' strategies and the farming systems in which they operate to provide more effective support (Sébillotte, 1977), this method also relies on a quantitative follow-up of flows of inputs, rice, and fish that pass through ponds. We have taken the work initially carried out on mesosome-based aquaculture experimentation systems (Aubin, 2007; Mathonnet et al., 2022) and adapted it for deployment in real farm situations. Further studies could be carried out using this method to accurately measure cause-and-effect relationships between yields and inputs used in family rice-fish farming. These extremely complementary quantitative and qualitative data harvesting methods provide a deeper understanding of rice-fish farming strategies in action. However, to reduce variability in the results, it may be necessary to choose farms that are uniformly affected by the issue being addressed.

4. Conclusion

This study highlights the diversity and complexity of small-scale fish farming practices in Guinea, revealing significant geographical differences. Agroforestry and peri-urban zones benefit from favourable conditions for producing larger fish, primarily destined for more lucrative regional markets. Conversely, savannah regions face environmental constraints and limited market access, prompting a focus on smaller fish production integrated into diversified farming systems, such as rice cultivation and horticulture. These findings emphasize the need for flexible fish farming strategies tailored to the actual circumstances of rural households.

A key takeaway from the study is that farmers have the capacity to assess and adopt practices that align with their priorities. The economic importance of fish farming in savannah and remote areas suggests that the low adoption rate of certain practices in these regions should not be seen as a failure. Instead, it reflects the emergence of alternative rice-fish farming models better suited to the specific conditions of these zones. This highlights the adaptability and pragmatism of farmers in designing systems tailored to their unique needs and constraints.

For policymakers and development stakeholders, these findings suggest the need for tailored approaches. In zones with high commercial potential, promoting specialized fish farming could better meet urban market demand. In contrast, in savannah regions, integrated systems combining fish farming with other agricultural activities would be more appropriate. These multi-purpose lowland agroecosystems could enhance food security and resilience to respond to climatic and economic challenges.

Finally, the study underscores the value of a Farming System approach in analyzing the complex interactions between aquaculture and agriculture. It also highlights the importance of refining methodologies that combine quantitative and qualitative monitoring of input and output flows. This approach could enable more precise technical recommendations and support the sustainable development of family-based rice-fish farming systems.

CRediT authorship contribution statement

Lucas Fertin: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Anne Perinelle:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Teatske Bakker:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Funding

This study received financial support from the Agence Française de Developpement (AFD), as part of the commercial and family fish farming development project (PisCoFam).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Fertin reports financial support was provided by French Development Agency. Fertin reports a relationship with French Development Agency that includes: consulting or advisory. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank Grace Delobel for proofreading the English. We would also like to thank the NGO APDRA pisciculture for making this study possible, in particular Florent Rouland, Barbara Bentz, Jean-Philippe Kolié and Gbamon Théa for the rich interactions that fed these reflections.

Data availability

Data will be made available on request.

References

Amian, A.F., Wandan, E.N., Blé, M.C., Vanga, A.F., Kaudhjis, P.J.A., 2017. Étude des déterminants socioéconomiques et techniques de la pisciculture extensive en Côte d'Ivoire. Eur. Sci. J. 13, 389–409.

ANAG, 2022. In: Guinée, A.N.D.A.D. (Ed.), Recensement 2022-2023 des pisciculteur.rice.s et etangs (rizi)piscicoles à l'echelle de la Guinée Forestière et des préfectures de Kissidougou, Faranah et Kerouane. Projet de développement de la Pisciculture Commerciale et Familiale.

Andrieu, N., Descheemaeker, K., Sanou, T., Chia, E., 2015. Effects of technical interventions on flexibility of farming systems in Burkina Faso: lessons for the design of innovations in West Africa. Agric. Syst. 136, 125–137.

APDRA, 2017. Guide de la pisciculture en Guinée Forestière.

Aubin, J., 2007. Evaluation des rejets de pisciculture par l'utilisation des bilans de masse. Principes et applications en piscicultures de truite et de turbot, 1. Recherche Filière Piscicole, Paris, France, p. 1.

Babatunde, A., Deborah, R.-A., Gan, M., Simon, T., 2021. A quantitative SWOT analyses of key aquaculture players in Africa. Aquac. Int. 29, 1753–1770.

Barthes, V., 2007. Étude de la rentabilité de l'activité piscicole, juin 2006 à avril 2007. Projet Piscicole de Guinée Forestière (PPGF) 29.

Berg, H., Lan, T.H.P., Tam, N.T., Trang, D.H., Van, P.H.T., Duc, H.N., Da, C.T., 2023. An ecological economic comparison between integrated rice-fish farming and rice monocultures with low and high dikes in the Mekong Delta, Vietnam. Ambio 52, 1462–1474.
Boyd, C.E., Tucker, C.S., 2012. Pond Aquaculture Water Quality Management. Springer Science & Business Media.
Copin, Y., Oswald, M., 1993. Orientation des techniques d'élevage de la pisciculture artisanale dans le Centre Ouest de la Côte d'Ivoire. Spec. Publ. Eur. Aquac. Soc. 18, 407–419.
Coquil, X., Dedieu, B., Beguin, P., 2010. 9. European IFSA symposium. Vienna, Austria. July 2010. [online] Available at: https://hal.archives-ouvertes.fr/hal-01195306.
Côte, F.-X., Rapidel, B., Sourisseau, J.-M., Affholder, F., Caron, P., Deguine, J.-P., Faure, G., Hainzelin, E., Malézieux, E., Poirier-Magona, E., Roudier, P., Scopel, E., Tixier, P., Toillier, A., Perret, S., 2018. Transition agro-écologique des agricultures des pays du Sud : retours d'expériences et perspectives. In: Côte François-Xavier, P.-M.E.P.S.R.P.B.R.T.M.-C. (Ed.), La transition agro-écologique des agricultures du, Sud. ed. Quae, Versailles, France, pp. 472–509.
Dabbadie, L., 1996. Etude de la viabilite d'une pisciculture rurale a faible niveau d'intrant dans le centre-ouest de la cote d'ivoire : approche du reseau trophique. In: Thèse de doctorat dirigée par Sevrin-Reyssac, Josette Sciences biologiques et fondamentales appliquées. Psychologie Paris 6 1996, 208 P. NNT:. tel-00321419.
Dabbadie, L., Mikolasek, O., 2015. Aquaculture Systems and Farming Systems: Inside, outside or Side-by-Side? European Society of Agronomy.
Darnhofer, I., Bellon, S., Dedieu, B., Milestad, R., 2010. Adaptiveness to enhance the sustainability of farming systems. A review. Agron. Sustain. Dev. 30, 545–555.
Delarue, J., 2008. Innovations et aménagement de bas-fonds en Guinée forestiere. In: Défis agricoles africains, sous le Direction de JC Deveze, Ed Karthala, pp. 137–151.
Desprez, M., 2023. Description des circuits de commercialisation de la filière poisson de pisciculture en zone rurale et analyse de la contribution à la sécurité alimentaire des ménages. ISTOM & APDRA.
Diédhiou, I., Diadhiou, H.D., Dème, M., 2020. La production et la consommation de poisson d'aquaculture à Saint-Louis du Sénégal. J. Appl. Biosci. 152, 15640–15649.
Dixon, J.M., Weerahewa, J., Hellin, J., Rola-Rubzen, M.F., Huang, J., Kumar, S., Das, A., Qureshi, M.E., Krupnik, T.J., Shideed, K., 2021. Response and resilience of Asian agrifood systems to COVID-19: an assessment across twenty-five countries and four regional farming and food systems. Agric. Syst. 193, 103168.
Dufumier, M., 2007. Agriculture comparée et développement agricole. Revue Tiers Monde 191, 611–626.
Duodu, C.P., Boateng, D.A., Edziyie, R.E., 2020. Effect of pond fertilization on productivity of tilapia pond culture in Ghana. J. Fish. Coastal Manag. 2, 56–64.
El-Sayed, A.F.M., Fitzsimmons, K., 2023. From Africa to the world—the journey of Nile tilapia. Rev. Aquac. 15, 6–21.
FAO, 2001. Integrated agriculture-aquaculture: a primer. Food & Agriculture Org.
FAO, 2024. The State of World Fisheries and Aquaculture 2024. FAO, Rome, Italy.
Faure, G., Dugué, P., Beauval, V., 2004. Conseil à l'exploitation familiale. Expériences en Afrique de l'Ouest et du Centre, GRET-CIRAD, France.
Ferraton, N., Touzard, I., 2009. Comprendre l'agriculture familiale. In: Diagnostic des.
Gazull, L., Camara, A., Jaffrain, G., 2023. Atlas du zonage agro-écologique de la Guinée (et des dynamiques d'occupation des sols).
Glasser, F., Oswald, M., 2001. High stocking densities reduce Oreochromis niloticus yield: model building to aid the optimisation of production. Aquat. Living Resour. 14, 319–326.
Halftermeyer, S., 2009. VERSES.
Hossain, M.A., Mridha, M.A.R., Shah, A.K.M.A., Nahiduzzaman, M., Uddin, M.S., 2015. Performance of mono-sex tilapia (O reochromis niloticus) in rice field with different ditch size. Aquac. Res. 46, 1891–1901.
Hyslop, E., 1987. Aspects of the biology of Hemichromis bimaculatus from a small stream in Nigeria. J. Fish Biol. 31, 745–751.
Jewel, M.A.S., Haque, M.A., Ali, S.W., Pervin, M.E., Ahmed, M.G.U., Islam, M.S., Hossain, M.B., Albeshr, M.F., Arai, T., 2023. Integration of vegetables and fish with Rice in rain-fed farmland: towards sustainable agriculture. Agriculture 13, 755.
Kabir, K.A., Verdegem, M.C., Verreth, J.A., Phillips, M.J., Schrama, J.W., 2020. Effect of dietary carbohydrate to lipid ratio on performance of Nile tilapia and enhancement of natural food in pond aquaculture. Aquac. Res. 51, 1942–1954.
Kouadio, A., Pepey, E., Boussou, C., Brou, S., Fertin, L., Pouil, S., 2024a. Leviers de substitution à l'usage de pesticides dans les systèmes cacaopiscicoles intégrés en Côte d'Ivoire. Cahier d'agriculture 240095, 10.
Kouadio, A.D., N'da, D.S.-E.F., Groga, N., Kouassi, A.K., 2024b. Revue bibliographique sur la pratique de la rizipisciculture en Cote d'Ivoire. Agron. Afr. 36, 73–83.
Lanta, H., 2023. In: Paysanne, I.A.M.A.P. (Ed.), Poursuite de la description des circuits de distribution de poisson de pisciculture dans la ville de N'Zérékoré et sa contribution à la sécurité alimentaire des acteurs en aval de la filière, p. 104.
Lavigne-Delville, P., 1998. Logiques paysannes d'exploitation des bas-fonds en Afrique soudano-sahélienne: quelques repères pour l'intervention. Cirad.
Lavigne-Delville, P., Boucher, L., Vidal, L., 1996. Les bas-fonds en Afrique tropicale humide: stratégies paysannes, contraintes agronomiques et aménagements. In: Fertilité du milieu et stratégies paysannes sous les tropiques humides, actes du séminaire international, CIRAD, pp. 148–161.
Lazard, J., 2012. La pisciculture en Afrique Noire: une Histoire ou que des histoires? GRET.
Lazard, J., Oswald, M., 1995. Association silure africain-tilapia: polyculture ou contrôle de la reproduction? Aquat. Living Resour. 8, 455–463.
Lethimonnier, D., Bentz, B., Mikolasek, O., Oswald, M., 2022. Case study of innovations in commercial west African family fish farming that led to an ecological intensification. Aquat. Living Resour. 35, 6.
Lévêque, C., Paugy, D., Teugels, G., 1990. Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest= The fresh and brackish water fishes of West Africa: Tome 1.
Longley, C., Thilsted, S.H., Beveridge, M., Cole, S., Nyirenda, D.B., Heck, S., Hother, A.-L., 2014. The Role of Fish in the First 1,000 Days in Zambia.
Mathonnet, I., Bouchemousse, S., Aubin, J., Jaeger, C., Le Bris, H., Sadoul, B., Oms, P.-E., Jacquemin, B., Michel, R., Agro, S., 2022. Analyse de méthodes de suivi environnemental en Aquaculture Multitrophique Intégrée en mer: Approche par bilan de masse.
Meynard, J.-M., Cerf, M., Coquil, X., Durant, D., Le Bail, M., Lefèvre, A., Navarrete, M., Pernel, J., Périnelle, A., Perrin, B., 2023. Unravelling the step-by-step process for farming system design to support agroecological transition. Eur. J. Agron. 150, 126948.
Mikolasek, O., Oswald, M., 2017. Engagement de l'APDRA et du CIRAD à mettre en place une démarche commune de recherche d'accompagnement au service de la pisciculture paysanne. Cirad/APDRA 3.
Mischke, C.C., 2012. Aquaculture Pond Fertilization: Impacts of Nutrient Input on Production. John Wiley & Sons.
Morissens, P., Oswald, M., Sanchez, F., Hem, S., 1996. Approche de nouveaux modèles d'exploitation piscicole adaptés au contexte rural ivoirien, Le troisième symposium international sur le tilapia en aquaculture. In: ICLARM/CRO/ORSTOM/CIRAD/CTA/MCAC. ISSN, pp. 015–4435.
Osty, P., Landais, E., 1993. Functioning of Pastoral Farming Systems. Systems studies in agriculture and rural development, INRA, Paris, pp. 201–213.
Oswald, M., 2013. La pisciculture extensive, une diversification complémentaire des économies de plantation. Enjeux économiques et écologiques de la diversification. Quae, Cultures pérennes tropicales, pp. 165–183.
Oswald, M., Chamoine, J., 2000. La réponse à la demande ivoirienne d'aménagement piscicole: un exemple d'outil d'aménagement d'une campagne d'Afrique forestière, Colloque international de l'eau, l'aménagement du territoire et le développement durable, pp. 10–11.
Oswald, M., Mikolasek, O., 2016. Le secteur piscicole en Afrique subsaharienne: des outils de financement adaptés aux enjeux? Techniques financières & développement 81–95.
Oswald, M., Glasser, F., Laubier, F., 2003. Techniques de pisciculture: gestion technico-économique des étangs. In: Collectif. Mémento de l'agronome, Quae, GRET, MAE, CIRAD & CTA.
Pallière, A., Rangé, C., 2018. Quelle place pour les approches systémiques dans les dispositifs d'appui à l'innovation agricole?.
Périnelle, A., 2021. Co-conception de systèmes de culture innovants avec deux communautés villageoises du Burkina Faso: Articulation entre traque aux innovations, prototypage participatif et expérimentations paysannes. Université Paris-Saclay.
Pretty, J., 2018. Intensification for redesigned and sustainable agricultural systems. Science 362, eaav0294.
Qiuming, L., Yi, Y., 2004. Tilapia culture in mainland China, 6th International Symposium on Tilapia in Aquaculture, ISTA.
Ragasa, C., Charo-Karisa, H., Rurangwa, E., Tran, N., Shikuku, K.M., 2022. Sustainable aquaculture development in sub-Saharan Africa. Nat. Food 3, 92–94.
Rangé, C., Pallière, A., 2017. Intégration et contribution de la pisciculture au développement agricole du sud de la Guinée Forestière. APDRA Pisiculture Paysanne.
Rey, P., Rétif, M., 2017. Le mythe de l'autosuffisance en riz en Guinée. Le paradoxe des politiques face aux stratégies locales. Les Cahiers d'Outre-Mer 275, 93–114.
Salembier, C., Meynard, J.M., 2013. Evaluation de systèmes de culture innovants conçus par des agriculteurs: un exemple dans la Pampa Argentine. Innov. agronomiques 31, 27–44.
Sébillotte, M., 1977. Jachère, système de culture, système de production, méthodologie d'étude. Journal d'agriculture traditionnelle et de botanique appliquée 24, 241–264.
Shiferaw, B.A., Okello, J., Reddy, R.V., 2009. Adoption and adaptation of natural resource management innovations in smallholder agriculture: reflections on key lessons and best practices. Environ. Dev. Sustain. 11, 601–619.
Simon, D., Benhamou, J., 2009. Rice-fish farming in Guinée Forestière–outcome of a rural development project. In: Field Actions Science Reports. The journal of field actions, p. 2.
Theisen, G., Silva, J., Silva, J., Andres, A., Anten, N.P., Bastiaans, L., 2017. The birth of a new cropping system: towards sustainability in the sub-tropical lowland agriculture. Field Crop Res. 212, 82–94.
Thilsted, S.H., 2012. The Potential of Nutrient-Rich Small Fish Species in Aquaculture to Improve Human Nutrition and Health.
Thomas, M., Pasquet, A., Aubin, J., Nahon, S., Lecocq, T., 2021. When more is more: taking advantage of species diversity to move towards sustainable aquaculture. Biol. Rev. 96, 767–784.
Tsuruta, T., Yamaguchi, M., Abe, S.-I., Iguchi, K.I., 2011. Effect of fish in rice-fish culture on the rice yield. Fish. Sci. 77, 95–106.
WorldBank, 2020. Poverty & equity brief for Guinea. Poverty & Equity Brief 2.