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Fish farming: A driver of diversification and resilience in rural livelihoods in Madagascar

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Abstract

In developing countries, diversifying rural livelihoods is a key strategy to enhance food security and strengthen household resilience to economic and climatic shocks. Within this dynamic, fish farming stands out as a promising activity, offering both nutritional benefits and additional income opportunities. Nevertheless, its concrete contribution to income structuring and vulnerability reduction at the local level remains insufficiently documented. This raises the following research question: to what extent does fish farming income contribute to the diversification and resilience of rural households according to the profiles of fish farmers? The underlying hypothesis is that this contribution varies significantly with the degree of integration of fish farming, becoming more decisive in highly specialized systems. This study analyzes the socioeconomic effects of fish farming on rural households in the Vakinankaratra region of Madagascar, with particular attention to its contribution to total income and its allocation. The methodology relies on a survey of 180 fish farmers and combines multivariate statistical analyses with strategic tools, including the strategic rectangle, benchmarking, and a prospective approach. The findings reveal three categories of fish farmers: emerging (61%), intermediate (22%), and advanced (17%), each displaying distinct levels of diversification and intensification. While agricultural income remains predominant, fish farming income is progressively evolving from a supplementary role to a more structuring one. Overall, fish farming appears as a lever for diversification whose impact depends on the level of integration, highlighting the need for differentiated policy interventions.

Keywords: Typology; Influential and Dominant Variables; Fish Farming Income; Vakinankaratra; Madagascar

1 Introduction

In rural areas of developing countries, the diversification of agricultural activities is a key strategy for securing livelihoods in the face of climatic and economic uncertainties [1, 2]. Among these strategies, pond and paddy field fish farming stands out as a promising option, combining improved animal protein intake with the generation of supplementary income [3, 4]. Globally, aquaculture now supplies more than half of the fish intended for human consumption, underscoring its strategic role in food security and poverty reduction [5, 6].

In Madagascar, fish farming, introduced in the early 20th century, has developed primarily as rice-fish farming in the Highlands, addressing both nutritional and economic needs [7]. However, national production remains insufficient, with annual consumption estimated at 7.1 kg per capita, which is below both the African and global averages [8, 9]. In these

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areas, family-based fish farming remains constrained by technical limitations, restricted access to inputs, and structural vulnerabilities such as isolation and low incomes [10, 11].

The Vakinankaratra region, characterized by high rural density and specialization in rice, cereals, and vegetable crops, provides a relevant setting for studying the socioeconomic impacts of fish farming. Existing research has focused primarily on technical and production aspects, at the expense of analyzing the relative contribution of fish farming income within farming systems [13, 14]. Despite outreach efforts [12], the actual role of fish farming in shaping rural incomes and reducing vulnerabilities remains poorly documented at the local level. Given this challenge, to what extent does fish farming income contribute to the diversification and resilience of rural households, depending on the profiles of fish farmers? This research question frames the overall objective, which is to evaluate the socioeconomic impacts of fish farming on rural households in Vakinankaratra; The aim is to characterize the role of fish farming income within the overall income structure and to analyze how it is used (consumption, investment, social spending). The hypothesis posits that the contribution of fish farming varies significantly depending on the degree of specialization in fish farming, becoming a key component in the most specialized operations.

2 Methods

2.1 Study Area and Sampling

The study was conducted in the Vakinankaratra region, in the Central Highlands of Madagascar, specifically at six sites spread across two districts: Ambohibary, Ambano, and Andranomanelatra (Antsirabe II District, 47°04'00“E, 19°52'00”S) and Betafo, Antohobe, and Antsoso (Betafo District, 46°52'00“E, 19°50'00”S). These sites were selected for the diversity of their ecological and socioeconomic conditions, as well as for their high representativeness of fish farming [11, 12]. A stratified random sampling design was adopted for six sites, with each site constituting a stratum. The number of surveys was determined based on the central limit theorem: a sample of at least 30 individuals per group ensures reliable estimates for parametric analyses [19, 20]. Thus, 180 fish farmers were surveyed (30 per site) through household surveys and focus groups, ensuring representativeness and multivariate validity.

2.2 Approaches

The analysis combined various statistical tools and analytical frameworks to characterize incomes, assess their influence, and identify the economic impacts of fish farming. MCA (Multiple Correspondence Analysis) and DFA (Discriminant Factor Analysis) were used to classify fish farmers’ profiles into distinct groups; an analysis of dominant and influential variables ranked the sources of income; benchmarking compared the identified classes; prospective analysis modelled their medium-term evolution; finally, the sustainable livelihoods framework examined the allocation of fish farming income among current needs, productive investments, and social expenditures, in relation to household subsistence strategies [15, 16].

2.3 Typology of fish farmers according to their sources of income

Table 1 Distribution of the 30 active variables in the typology (RV1–RV30)

Category	Variables
Crops	Potatoes (RV1), Other grains (RV2), Cattle (RV3), Tropical fruits (RV4), Légumes (RV5), Leafy vegetables (RV6), Rice (RV7), Fruit vegetables (RV8), Temperate fruits (RV11), Root vegetables (RV13), Other tubers (RV30), Citrus fruits (RV19), Herbs (RV20)
Fish farming	Fry (RV14), Large fish (RV15)
Livestock	Poultry (RV16), Small ruminants (RV17), Rabbits (RV18), Pigs (RV12), Honey (RV24)
Non-agricultural activities	Day labor (RV9), Fuels (RV10), Textiles & Fibbers (RV21), Wood Construction (RV22), Metallurgy (RV23), Trade (RV25), Transportation (RV26), Rural Tourism (RV27), Miscellaneous Services (RV28), Wages (RV29)

Income levels were classified into three categories: A: no income; B: income less than 500,000 Ar/year; C: income higher than or equal to 500,000 Ar/year.

The typology aims to identify homogeneous groups of households based on their income-generating activities. Cluster analysis was used to group observations according to their similarities, and the results were validated using a factor analysis to improve the differentiation of groups and identify explanatory variables [17, 18].

Thirty active variables (coded RV1 to RV30), representing different sources of income, were included in the analysis. They cover agricultural, fishing, livestock, and non-agricultural activities (Table 1).

This classification made it possible to identify different profiles of fish farmers, represented on the factor plot (F1–F2).

2.4 Dominant and influential variables affecting income sources

The development of the strategic rectangle made it possible to assess the dominant and influential variables related to household income sources, based on the matrix of significant correlations between variables. The variables considered are those selected for the classification of fish farmers.

The significance of the correlations was tested using the critical threshold $|\rho| = \frac{t_\alpha}{\sqrt{n-2+{t_\alpha}^2}}$ where n represents the number of observations and t_α the quantile of the Student's t-distribution with n−2 degrees of freedom, for a significance level of α=0.05. Correlations below this threshold were set to zero, and only the upper triangular part of the matrix was retained to eliminate symmetric redundancies.

Two indicators were derived for each variable: the ratio of outgoing to incoming correlations (X=measure of influence) and their product (Y=overall strength). These metrics were used to classify the sources within the strategic matrix, distinguishing between influential (X>average), dominant (Y>average), and sources that are both.

The calculations were performed using Excel (organization and indicators) and XLSTAT (correlation matrix), retaining only the significant variables related to the economic dynamics of the fishing industry.

2.5 Benchmarking of Revenue Profiles

Based on the classes derived from MCA and DFA, a correlation analysis using p-values allowed us to exclude non-significant variables (p>0.05). Only the variables identified as dominant or influential in the strategic matrix were selected for further analysis.

The average values per class, obtained from the DFA, were then used to construct stochastic matrices. These matrices enabled the creation of comparative income profiles, which were represented as radar charts, in accordance with the approach proposed by Randimbimahenina [18].

2.6 Modelling Income Trends

The prospective analysis projected the 10-year probabilistic trend of dominant and influential incomes derived from the strategic rectangle, according to fish farmers' profiles. Using stochastic matrices (averages by DFA class with correlations removed), the initial value was iteratively multiplied by the matrix for each year (t+1 to t+10). These trajectories were visualized as sparklines for each income source and identified profile.

3 Results

3.1 Classification of fish farmers by income source

Multiple Correspondence Analysis (MCA) reveals a distinct structure comprising three classes of fish farmers, with each class forming angles greater than 90°.

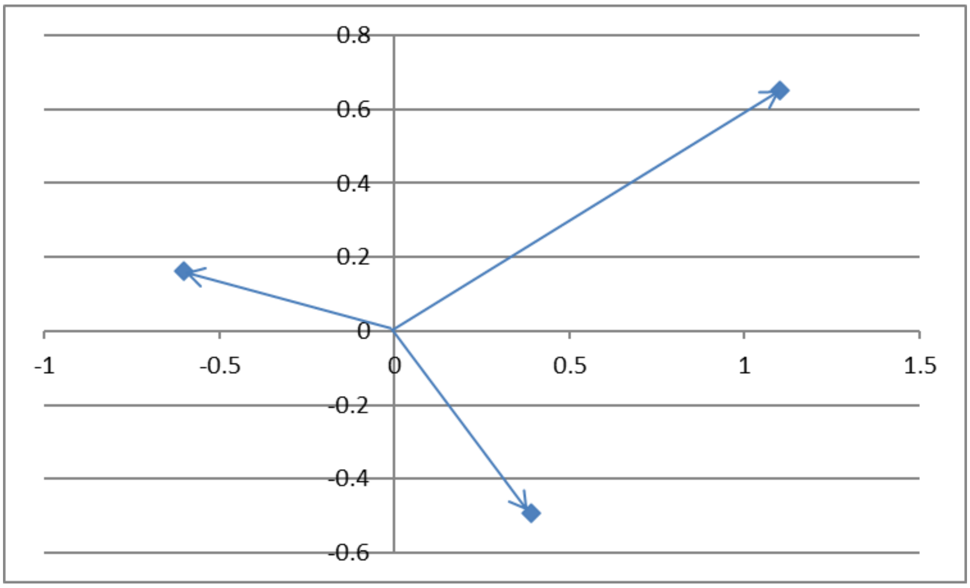


Figure 1 Income classes of fish farmers according to the MCA

The MCA reveals a gradient of professionalization, ranging from loosely structured operations to specialized, high-performing systems, confirming the validity of the three-class typology (Figure 1).

- Emerging fish farmers are predominantly found in the low and negative values of F1 (-0.93 to 0.30) with a wide dispersion on F2 (-1.30 to 0.40), reflecting diversified and loosely organized strategies.
- Intermediates occupy an intermediate position (F1 between 0.30 and 1.00; F2 between -0.80 and 0.20), characterized by a gradual structuring of activities.
- -Advanced are concentrated in the high F1 values (1.00 to 1.67) and positive F2 values (0.10 to 1.35), indicating increased specialization and a focus on activities with higher economic value.

3.2 Dominant and Influential Income Variables

Analysis of the influence and dominance matrix allowed us to rank the selected variables based on their relative values of X (influence ratio) and Y (combined strength). The mean values of the indicators (X=4.91; Y=64.04) were used as thresholds to distinguish the different variable profiles (Table 2).

Fourteen of the thirty variables have X values greater than 1, eight of which have Y values above the mean. They occupy a position that is both influential and dominant: rice (RV7-C, Y=136.07), fruit vegetables (RV8-C, Y=125.17), root vegetables (RV13-C, Y=119.31), temperate fruits (RV11-A, Y=118.68), other grains (RV2-C, Y=90.93), day labor (RV9-C, Y=65.14), and leafy vegetables (RV6-A, Y=60.41), Cattle (RV3-C, Y=50.65)

Some variables exceed the mean for X but remain below the mean for Y. This is the case for pork (RV12-C, Y=20.78), large fish (RV15-A, Y=16.14), and poultry (RV16-C, Y=13.09)

Leftovers, Fuels (RV10, Y=48.18), and tropical fruits (RV4-B, Y=5.12) have values below the average for both X and Y.

Table 2 Strategic Rectangle: Dominance/Influence effects of fish farmers' incomes

Variables	X (influence score) (Mean: 4.91)	Y (combined strength: Dominance and influence) (Mean: 64.04)	Status
RV7-C	1,19	136,07	Dominant and Influential
RV8-C	1,84	125,17	
RV13-C	2,24	119,31	

RV11-A	1,45	118,68	
RV2-C	3,44	90,93	
RV9-C	1,38	65,14	
RV6-A	2,23	60,41	
RV3-C	7,82	50,65	
RV10-A	2,92	48,18	Influential
RV5-C	4,65	26,89	
RV12-C	7,90	20,78	
RV15-C	16,14	16,14	
RV16-C	13,09	13,09	
RV4-B	2,45	5,12	

Legend A: no income, B: income<500,000Ar, C: income≥500,000Ar, RV4=tropical fruits, RV10= Fuels, RV5=legumes, RV11= temperate fruits, RV6=leafy vegetables, RV12=Pork, RV7=Rice, RV13=Root vegetables, RV2=Other grains, RV8=Fruit vegetables, RV15=Large fish, RV3=Cattle, RV9=Daily wage, RV16=Poultry

3.3 Benchmarking of fish farmers by income

Benchmarking, derived from discriminant analysis (Wilks' lambda=0.0000, $p < 0.0001$ at $\alpha=0.05$ threshold), underpins the radar plot representation of the three groups of fish farmers as well as the maximum values for each variable.

- *Class 1: Emerging fish farmers*

Class 1 exhibits the greatest diversification but the lowest income levels. Income from tropical fruits (RV4-B), daily wages (RV9-C), and leafy vegetables (RV6-A) reaches its highest levels. Members of this group also rely on fruit vegetables (RV8-C) and legumes (RV5-C) for their moderate incomes, which partially offset the lack of significant fish farming income (Figure 2).

- *Class 2: Intermediate Fish Farmers*

Intermediate fish farmers are characterized by peak incomes from grains other than rice (RV2-C), root vegetables (RV13-C), poultry (RV16-C), pork (RV12-C), and legumes (RV5-C). Furthermore, they occupy an intermediate position between novices and advanced in terms of income from leafy vegetables (RV6-A), cattle (RV3-C), and fuel (RV10-A) (Figure 3).

- *Class 3: Advanced Fish Farmers*

For advanced fish farmers, the most significant sources of income are rice (RV7-C) and large fish (RV15-C). Income from dairy cows (RV3-C), fruit vegetables (RV8-C), and pigs (RV12-C) also reaches its maximum, but to a lesser extent. Finally, poultry (RV16-C) occupies an intermediate position between the other two classes (Figure 4).

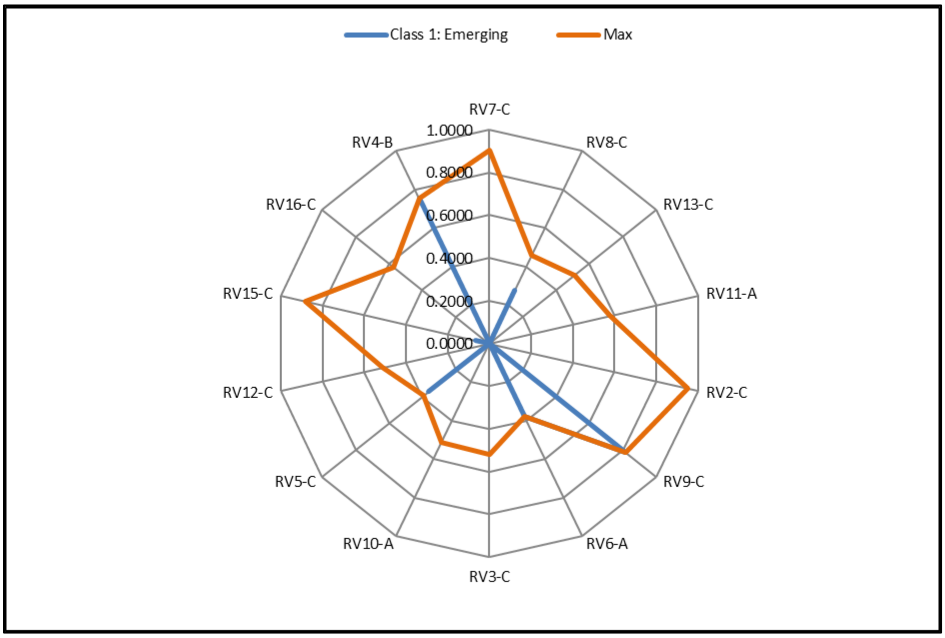


Figure 2 Income Benchmarking. Class 1: Emerging Fish Farmers

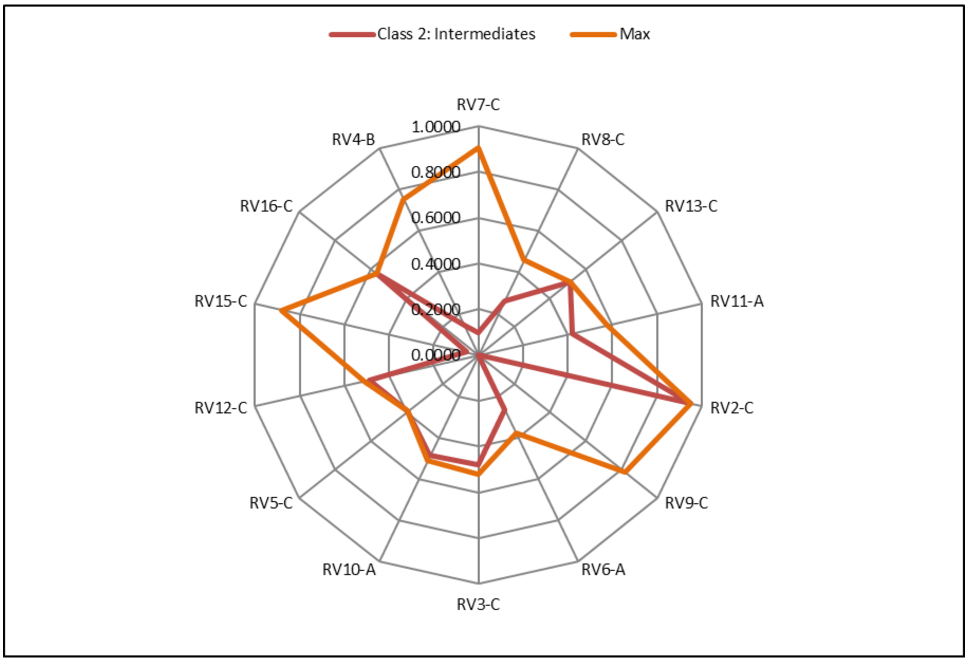
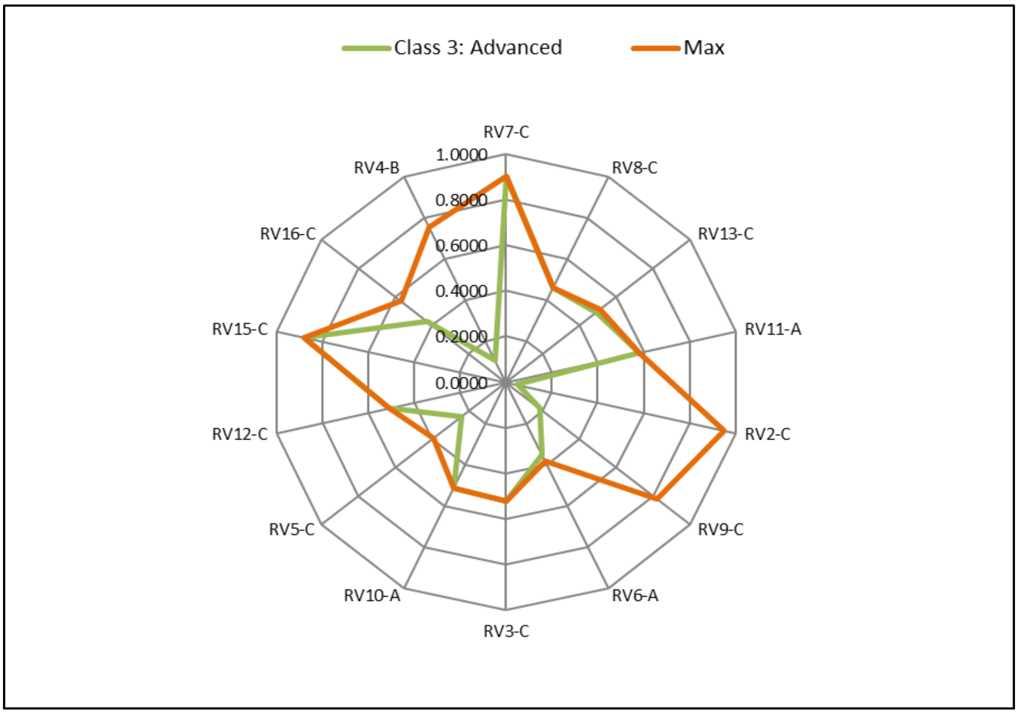


Figure 3 Income Benchmarking. Class 2: Intermediate Fish Farmers



Legend A: no income, B: income<500,000Ar, C: income≥500,000Ar, RV4=tropical fruits, RV10= Fuels, RV5=legumes, RV11= temperate fruits, RV6=leafy vegetables, RV12=Pork, RV7=Rice, RV13=Root vegetables, RV2=Other grains, RV8=Fruit vegetables, RV15=Large fish, RV3=Cattle, RV9=Daily wage, RV16=Poultry

Figure 4 Income Benchmarking. Class 3: Advanced Fish Farmers

3.4 Income Projections

The prospective analysis reveals a lack of consensus on future trends among the groups of fish farmers: no single income source follows a trajectory common to all profiles (Figure 4).

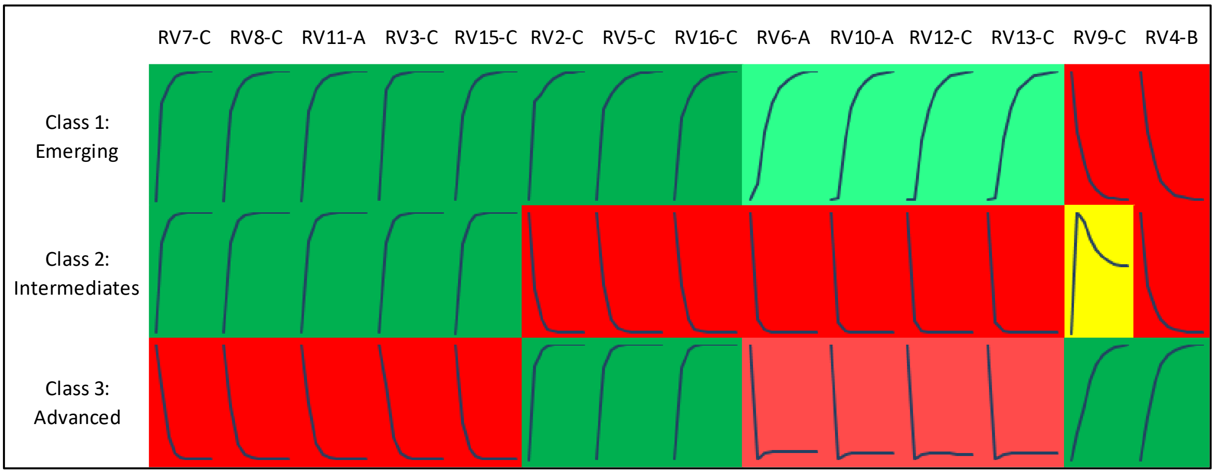
Emerging and Intermediate fish farmers converge toward simultaneous growth in income from rice (RV7-C), vegetables and fruits (RV8-C), temperate fruits (RV11-A), cattle (RV3-C), and large fish (RV15-C). Paradoxically, these same sources show a declining trend among the advanced.

Conversely, both Emerging observers and advanced observers agree on the trend in income for other grains (RV2-C), legumes (RV5-C), and poultry (RV16-C).

The trajectories diverge sharply for leafy vegetables (RV6-A), and fuel crops.

(RV10-C), pork (RV12-C), and root vegetables (RV13-C), which are increasing among the Emerging but declining among enthusiasts and advanced.

Finally, tropical fruits (RV4-B) follow the opposite trend: declining among the Emerging and Intermediates, growing among the advanced. Income from day labor (RV9-C) shows particularly divergent trajectories across the classes.



Legend A: no income, B: income<500,000Ar, C: income≥500,000Ar, RV4=tropical fruits, RV10= Fuels, RV5=legumes, RV11= temperate fruits, RV6=leafy vegetables, RV12=Pork, RV7=Rice, RV13=Root vegetables, RV2=Other grains, RV8=Fruit vegetables, RV15=Large fish, RV3=Cattle, RV9=Daily wage, RV16=Poultry

Figure 5 Projected Income Trends for Fish Farmers

4 Discussion

4.1 Role and importance of fish farming income in household economies

4.1.1 Specific characteristics of activity portfolios by type of fish farmer

The results from the MCA and DFA (Figure 1) highlight three distinct profiles of fish farmers, reflecting different strategies for diversifying and intensifying livelihoods. This heterogeneity fits within the analytical frameworks of rural livelihoods, where the combination of activities reflects trade-offs between security, accumulation, and risk management [1, 2, 16, 21, 22].

Among "Emerging" fish farmers, the predominance of food crops and supplementary activities reflects a survival strategy characterized by a strong aversion to risk and limited capacity for investment. Fish farming remains marginal in these cases, which aligns with observations made in several African contexts where constraints on access to inputs, land, and capital limit the adoption of aquaculture innovations [3, 23, 24].

"Intermediates" represent an intermediate phase of transition toward more integrated systems. The rise of fish farming can be explained by better market integration and increased access to information and support services, confirming the role of integrated agriculture–livestock–aquaculture systems in income stabilization and sustainable intensification [4,13, 14, 25].

Among "advanced," fish farming is viewed as part of a process of accumulation and gradual specialization. Functional integration between rice farming, livestock raising, and fish farming optimizes nutrient and income flows, in line with ecological intensification models [24, 26]. This differentiation confirms that the share of income from fish farming depends heavily on households' productive, organizational, and institutional capacities [15, 21].

4.1.2 Dominant and influential income sources and the specific role of fish farming income

Analysis of the strategic matrix (Table 2) confirms the central role of food and vegetable crops in the farming systems of the Highlands, consistent with the literature on African rural economies dominated by rain-fed agriculture [1, 2, 11].

In this context, fish farming occupies an intermediate position: it is not a dominant activity, but plays a key role as a source of diversification and a safeguard against shocks. This function as an "economic buffer" is well documented in family-based aquaculture systems, where fish farming income helps smooth out seasonal fluctuations and reduce vulnerability [2, 6, 27, 28].

Furthermore, integrated rice-fish farming offers significant productivity gains, both in terms of rice yields and fish production, reinforcing its potential as an agroecological innovation [4, 7, 29]. On the most productive farms, fish farming can thus evolve into a structuring role, particularly when coupled with secure market access [26].

4.1.3 Future income trends and development scenarios

Prospective analyses (Figure 5) confirm the robustness of mixed systems as an adaptation strategy in the face of uncertainty, consistent with research on the resilience of agricultural systems [16, 30]. However, the divergent trajectories observed across profiles reflect dynamics of structural inequality, where only certain households manage to capitalize on the opportunities offered by fish farming.

The move upmarket observed among advanced fish farmers is part of a process of structural transformation of farms, supported by intensification and commercialization [27, 31]. Conversely, the more vulnerable profiles remain trapped in trajectories of low accumulation, reinforcing rural dualism.

In this context, fish farming emerges as a differentiated lever: a subsistence activity for some, a driver of accumulation for others. This finding underscores the importance of targeted support policies to prevent the widening of inequalities [5, 22].

4.2 Fish farming as a lever for recovery and sustainability of the farming system

4.2.1 The relationship between vulnerability, resilience, and fish farming performance

The correlation between fish farming performance and the level of resilience confirms that fish farming can serve as both an indicator and a driver of resilience for rural households. By diversifying income sources and offering flexible production, it strengthens the capacity to adapt to climatic and economic shocks [16, 26, 31].

4.2.2 Conditions for economic, social, and environmental sustainability

The sustainability of fish farming rests on a balance between economic viability, social inclusion, and environmental sustainability. Integrated systems, particularly rice-fish systems, offer advantages in terms of resource efficiency and nutrient recycling [4, 29]. However, their sustainability depends on adequate access to inputs, water, and markets, as well as appropriate management practices [5, 26].

4.2.3 Prospective Analysis and Outlook

The prospective analysis highlights differing trajectories depending on the profiles of fish farmers. Emerging fish farmers show limited growth potential due to structural constraints (access to inputs, limited capital), while hobbyists constitute a pivotal group likely to move toward gradual intensification. Advanced fish farmers are already following a path of specialization and economic consolidation. These results confirm that the level of integration in fish farming strongly determines its economic impact [11, 31].

Furthermore, these trajectories reveal a risk of widening inequalities among farms, but also a potential for transforming the sector if targeted support is implemented. The integration of fish farming as a complementary and then a core activity is part of a strategy to diversify livelihoods and strengthen resilience [5].

From this perspective, differentiated policies appear necessary: basic support for those with an interest in the field, technical and financial reinforcement for enthusiasts, and improved access to markets and innovation for advanced. Thus, fish farming offers significant potential for growth, the impact of which will depend on the conditions of support and the institutional environment [31].

4.2.4 Limitations and Strategic Repositioning of Fish Farming

Despite its potential, fish farming remains a supplementary activity on most farms due to persistent structural constraints. Its development on a larger scale requires strategic repositioning, incorporating technical support, sector structuring, and access to financing [3, 5].

Differentiated policies, tailored to the profiles of fish farmers, appear essential to transform this activity into a true driver of inclusive and sustainable rural development [22, 31].

5 Conclusion

This study highlights the distinct yet strategic role of fish farming in the farming systems of rural households in Vakinankaratra. Using an approach that combines multivariate analyses (CMA, AFD), strategic quadrants, benchmarking, and prospective modelling, three distinct profiles of fish farmers were clearly identified: curious, amateur, and expert. This typology reveals contrasting levels of diversification, intensification, and integration of fish farming within activity portfolios.

The results confirm that traditional agricultural incomes, particularly from rice, vegetable crops, and livestock, remain dominant in the economic structure of households. However, fish farming occupies a cross-cutting and evolving role: marginal and irregular among curious fish farmers, it becomes more visible among amateurs, and then a structural component among experts, where it contributes significantly to monetary income and productive investments. Thus, far from supplanting other activities, income from fish farming acts primarily as a lever for diversification and resilience in the face of economic and climatic uncertainties.

The prospective analysis highlights divergent development trajectories across different profiles, reflecting patterns of inequality as well as opportunities for upward mobility for the well-structured farms. Furthermore, the uses of income from fish farming vary significantly: ensuring food security for the most vulnerable and capital accumulation and productive processing for the most advanced. These results confirm the relevance of the sustainable livelihoods framework for understanding the differentiated strategies of households.

Ultimately, this study makes an important empirical contribution by quantifying and contextualizing the socioeconomic impacts of fish farming in Madagascar. It highlights the need for targeted policies, tailored to the profiles of fish farmers, to strengthen access to inputs, markets, and technical support mechanisms. Fish farming thus emerges as a relevant lever for sustainably improving rural livelihoods, provided it is integrated into a systemic and differentiated approach to agricultural development.

Compliance with ethical standards

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Disclosure of conflict of interest

We, authors of this manuscript, declare that we have no conflict of interest concerning the present research.

Statement of ethical approval

Participation was voluntary. The purpose of the study was explained to each participant before the interview.

Statement of informed consent

Informed consent was obtained before questionnaire administration.

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