World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

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Fish farmers of Malagasy highland adopt differential resilience strategies against multiple risks

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World Journal of Advanced Research and Reviews, 2026, 30(01), 1309-1320

Publication history: Received on 03 March 2026; revised on 08 April 2026; accepted on 11 April 2026

Article DOI: https://doi.org/10.30574/wjarr.2026.30.1.0934

Abstract

This study analyses the resilience strategies adopted by fish farmers in the Malagasy Highlands in the face of numerous socio-economic, technical and climatic risks. The aim is to identify the main risks faced and to evaluate adaptation strategies according to farmers' profiles. The study was conducted in the Vakinankaratra region among 180 fish farmers spread across six sites. It employs a mixed-methods approach combining household surveys and focus groups, as well as statistical tools such as Multiple Correspondence Analysis (MCA), Discriminant Factor Analysis (DFA), dominance/influence analysis, benchmarking, prospective modelling and strategy analysis within the framework of sustainable livelihoods. The results reveal three profiles of fish farmers: emerging (n=95), intermediates (n=55) and advanced (n=30), with very high discriminant power (λ=0.006; p<0.0001). The main risks identified as dominant and influential are lack of funding (Y=18.49), low educational attainment (Y=10.76) and lack of water management skills (Y=10.54). Emerging fish farmers are the most vulnerable, whilst advanced demonstrate greater technical proficiency. Prospective analyses indicate a worsening of certain risks, notably insufficient land area and water constraints. Adaptation strategies vary according to profiles, ranging from passive responses (mutual aid, self-consumption) to proactive strategies (technical innovation, market access, and mechanisation). The resilience of fish farming systems relies on a combination of endogenous strategies and strengthened institutional support. The sustainable development of the sector requires better integration of technical, financial and organisational support.

Keywords: Fish farming; Resilience; Risks; Madagascar; Adaptation strategies; Typology

1. Introduction

Aquaculture is now one of the fastest-growing food production sectors in the world. It supplies more than half of the fish intended for human consumption, compared with less than a quarter in the 1990s [1–3]. This growth can be attributed to the overexploitation of natural fishery resources and the need to meet a growing demand for animal protein. It is therefore seen as a strategic lever for achieving the Sustainable Development Goals, particularly the fight against hunger and the reduction of poverty [4-6]. However, in developing countries, it remains fragile as it is subject to multiple technical, economic and environmental constraints [7-9].

In Madagascar, fish farming was introduced at the beginning of the 20th century, mainly in the form of rice-fish farming, particularly in the Highlands [10]. It serves a dual purpose: to improve the supply of animal protein and to diversify household incomes. However, despite this potential, national production remains insufficient to meet food

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requirements. Annual fish consumption is estimated at just 7.1 kg per capita, well below the African average of 10.5 kg and the global average of 20.5 kg [11, 12]. In the Highlands, where small-scale family fish farming is most widespread, this activity remains severely constrained by climatic uncertainties, inadequate water infrastructure, a lack of inputs and equipment, as well as socio-economic constraints such as isolation, low incomes and limited access to credit [13, 14].

In light of these challenges, the aim of this research is to understand how fish farmers in the Malagasy Highlands manage the risks they face. More specifically, the object is not only to classify the main socio-economic, technical and climatic risks faced by fish farmers but also to analyse the adaptation strategies they implement in order to assess their contribution to strengthening their resilience [15, 16]. With this in mind, the research centres on two key questions: what are the main risks faced by fish farmers in the Malagasy Highlands, and what adaptation strategies do they develop to cope with them? It is based on two main hypotheses: firstly, fish farmers, exposed to a variety of risks, mobilise different forms of capital—human, social, financial and technical—to develop their adaptive responses; secondly, the effectiveness of these strategies varies and depends on the farmers' profiles as well as the resources at their disposal [17–19].

2. Materials and 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 chosen for the diversity of their ecological and socio-economic conditions, as well as for the high representativeness of fish farming in the area [20].

A stratified random sampling method was adopted, with each site constituting a stratum. The number of respondents was determined by reference to the central limit theorem, according to which a sample of at least 30 individuals per group allows for reliable estimates and robust parametric statistical analyses [21, 22].

Thus, 180 fish farmers were surveyed—30 individuals per site—through household surveys and focus groups.

2.2. Methodological approaches

The analysis utilised several complementary tools to classify fish farmers, characterise the risks they face, assess their influence and identify their adaptive responses. Multiple Correspondence Analysis (MCA) and Discriminant Factor Analysis (DFA) enabled classes to be distinguished according to risks; ranking and influence/dominance analysis prioritised the main risks, whilst benchmarking, based on the correlation matrix of dominant risks, compared vulnerability profiles. The prospective analysis modelled their medium-term evolution, and the sustainable livelihoods framework informed the adaptation strategies and assets underpinning the resilience of fish farming operations.

2.3. Typology of fish farmers according to the risks incurred

Table 1 Distribution of the 30 active variables used in the typology (AL1–AL30)

Catégorie	Variables
Human	AL1 (labour force), AL2 (education level), AL3 (insecurity), AL16 (information system), AL24 (membership of associations), AL29 (experience), AL9 (mixed farming)
Technical	AL17 (lack of water management), AL18 (use of fertiliser), AL19 (fish species), AL20 (access to fry), AL23 (feeding), AL26 (fry production), AL27 (adult fish production), AL12 (equipment), AL15 (fish mortality), AL30 (decline in production)
Economic	AL8 (selling price), AL14 (financing), AL13 (transport), AL28 (marketing), AL11 (remoteness)
Environmental	AL6 (late rain), AL21 (cold), AL22 (heat)
Structural	AL4 (rice field area), AL5 (inadequate rice field), AL7 (no pond), AL10 (hydraulic infrastructure), AL25 (access to land)

A Multiple Correspondence Analysis (MCA) was carried out to identify the most distinct clusters, followed by a Discriminant Factor Analysis (DFA) to determine the variables explaining membership of each class [23, 24]. Thirty active variables (AL1–AL30), divided into five categories (human, technical, economic, environmental, structural), were used and transformed into binary categories, A/B (Table 1). This approach led to a typology based on the risks incurred, illustrated in the F1-F2 factor plot.

2.4. Dominance and influence of risks

The analysis of risk dominance/influence was carried out using the matrix of significant correlations between variables, which served as the analytical basis. The variables considered correspond to the same risks as those identified in the typology of fish farmers. The significance of a correlation was assessed using the critical threshold $|\rho|$, defined by the relationship:

$$|\rho| = \frac{t_\alpha}{\sqrt{n - 2 + {t_\alpha}^2}}$$

where n represents the number of observations and $t\alpha$ is the quantile of the Student's t distribution with n−2 degrees of freedom, for a risk α=0.05. Values below the critical threshold were discarded, and only the upper part of the matrix was retained to avoid redundancies due to symmetry.

Two indicators were calculated for each variable: the ratio of sent to received correlations (X) and the product of these correlations (Y). For each variable, X represents the influence ratio and Y the combined strength. These two indicators were used to position the variables within the strategic rectangle, distinguishing:

- Influential factors, whose X values are above average;
- Dominant factors, whose Y values are above average;
- And variables that combine both statuses.

All data processing was carried out in Excel for data organisation and the calculation of indicators, and in XLSTAT for the construction of the correlation matrix. Only the significant variables among the determining factors were included in the correlation matrix. This selection ensures that the strategic quadrant analysis focuses on the factors actually associated with the adoption of agricultural innovations.

2.5. Benchmarking of fish farmers according to risks

Based on the MCA/DFA classes, correlations and p-values were calculated, and non-significant variables ($p > 0.05$) were eliminated. Only the dominant/influential variables from the strategic rectangle were retained. The DFA ranking functions provided the mean values per class, which were transformed into stochastic matrices to compare vulnerability profiles (benchmarking).

2.6. Modelling of risk trends

The prospective analysis enabled the probabilistic evolution over 10 years of the dominant/influential risks derived from the strategic rectangle to be projected by class of fish farmers. Based on the stochastic matrices (DFA means/classes + refined correlation), the initial value is iteratively multiplied by the matrix for each year (t+1 to t+10). The evolution is visualised using sparkline charts by risk and by category.

2.7. Analysis of adaptation strategies

The synthesis of surveys and focus groups identified adaptation strategies to dominant/influential risks at the strategic rectangle, analysed according to the capital mobilised (human, social, financial, technical) within the framework of sustainable livelihoods [15, 25].

This cross-tabulation of fish farmers' types/risks/adaptive responses revealed the differential forms of resilience in regional fish farming systems.

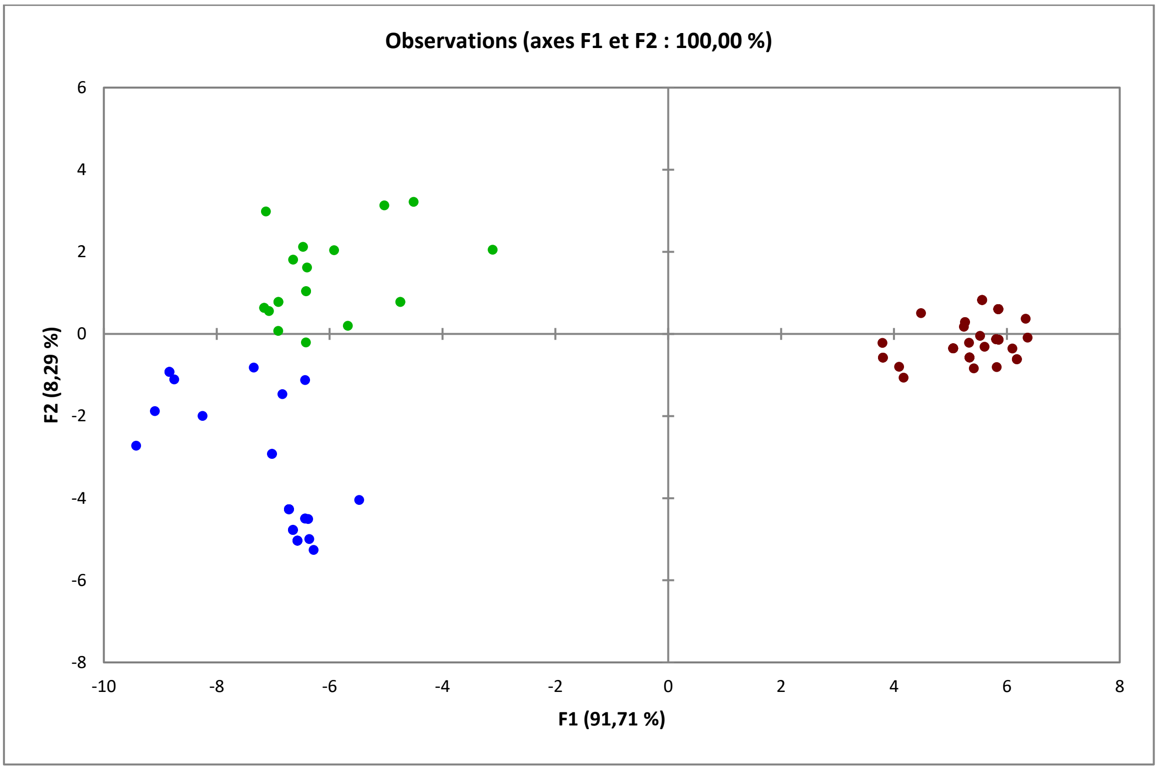
3. Results

3.1. Typology of fish farmers based on risks

The AFD generates two discriminant factors: F1 (λ=37.11, 91.7%) and F2 (λ=3.35, 8.3%), accounting for 100% of the variance (Wilks' lambda=0.006, p<0.0001). The F1-F2 plot reveals three natural groups of fish farmers (Figure 1):

- Class 1: Emerging fish farmers (red, n=95, F1 > 0 up to +6): spread across the right-hand quadrant
- Class 2: Intermediate fish farmers (green, n=55, F1 ≈ -5 to -1): intermediate positions on the left
- Class 3: Advanced fish farmers (blue, n=30, F1 ≈ -7 to -5): compact profile in the lower left quadrant

F1 contrasts those with strong logistical and operational constraints with those with advanced and low structural constraints. The a posteriori classification is over 99%.



Legend C1: Group of Emerging farmers, C2: Group of intermediates, C3: Group of advanced

Figure 1 F1-F2 factor plot of fish farmers

3.2. Dominance/influence of risks

The analysis of the dominance and influence matrix enabled the selected variables to be positioned according to their relative values of X (influence score) and Y (combined strength). The mean values of the indicators (X = 2.55; Y = 8.09) were used as thresholds to distinguish between the different variable profiles (Table 2).

Seven variables have X values greater than 1, three of them have Y values above the mean. They occupy a position that is both influential and dominant: funding issues (AL14-A), low education level (AL2-B) and lack of water management (AL17-A).

Some variables exceed the average for X but remain below the average for Y. This is the case for Insufficient area for fish stocking (AL4-B) and the problem of Insufficient labour (AL1A). The two remaining risks (Insecurity (AL3) and Price problem (AL8)) have values below the average for both X and Y.

Table 2 Strategic Rectangle: Dominance/influence effects of the risks faced by fish farmers

Variables	X (influence rate)	Y (combined strength)	Status
AL14-B	1,26	18,49	Influential and Dominant
AL2-B	3,03	10,76	
AL17-B	1,25	10,54	
AL4-B	2,24	6,71	
AL3-B	1,37	4,17	Influential
AL8-B	1,40	4,16	
AL1-A	2,65	2,65	

Legend AL1-A = no labour issues, AL2-B = low level of education, AL3-B = insecurity, AL4-B = insufficient stocking area, AL8-B = unsatisfactory selling price, AL14-B = financing issues, AL17-B = lack of water management

3.3. Benchmarking of fish farmers according to risks

The Wilks's lambda from the discriminant analysis indicates a clear distinction between the groups (Lambda=0.0060), with $p < 0.0001$ at $\alpha = 0.05$ threshold. The benchmarking derived from this discriminant analysis underpins the radar plot of the three groups of fish farmers as well as the maximum values for each variable.

The class of 'Emerging' fish farmers is the most affected by financial, technical, economic and institutional problems (Figure 2). The financial problem (AL14-B) reaches the highest level of 0.86. Members of this group also suffer from problems relating to a lack of water control (AL17-B), which results in the flooding and/or drying out of fish ponds. This risk affects hydraulic infrastructure, water flow control, and the technical management of irrigation systems. Furthermore, the group faces a shortage of rice fields suitable for fish farming (AL4-B). Finally, almost half suffer from a lack of education (AL2-B).

The class of intermediate fish farmers (Figure 3) is characterised by issues relating to education (AL2-B) and market access (AL8-B). Furthermore, it occupies an intermediate position between the novices and the advanced in terms of labour (AL1-A), water management (AL17-B) and insecurity (AL3-B)

For the class of advanced fish farmers (Figure 4), the most problematic risks are insecurity, which manifests as fish theft (AL-B), and insufficient area for stocking (AL4-B). However, this group does not report any issues regarding labour (AL1-A), education (AL2-B), water management (AL-17-B), or product marketing (AL8-B).

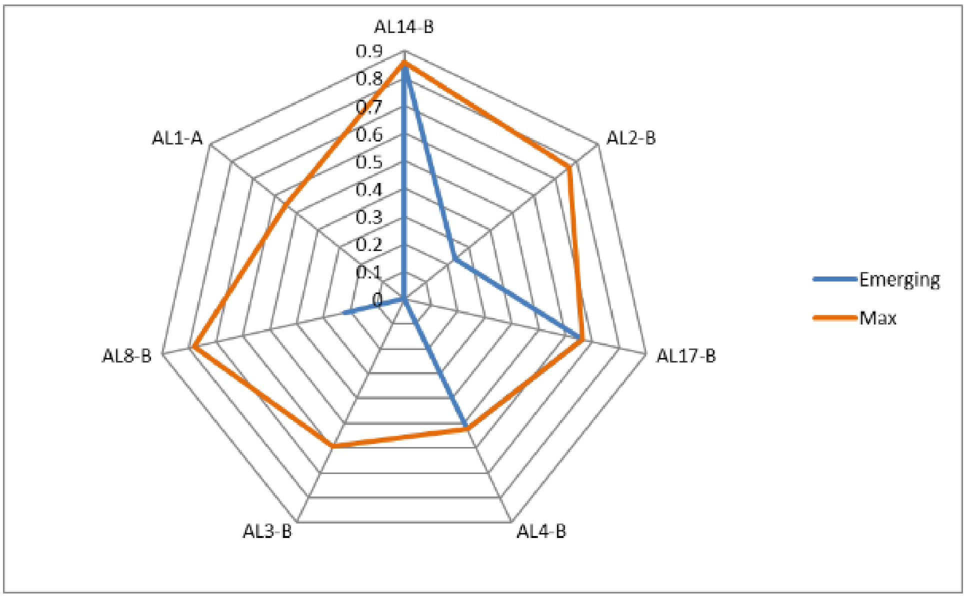


Figure 2 Benchmarking of risks faced by Emerging Fish Farmers

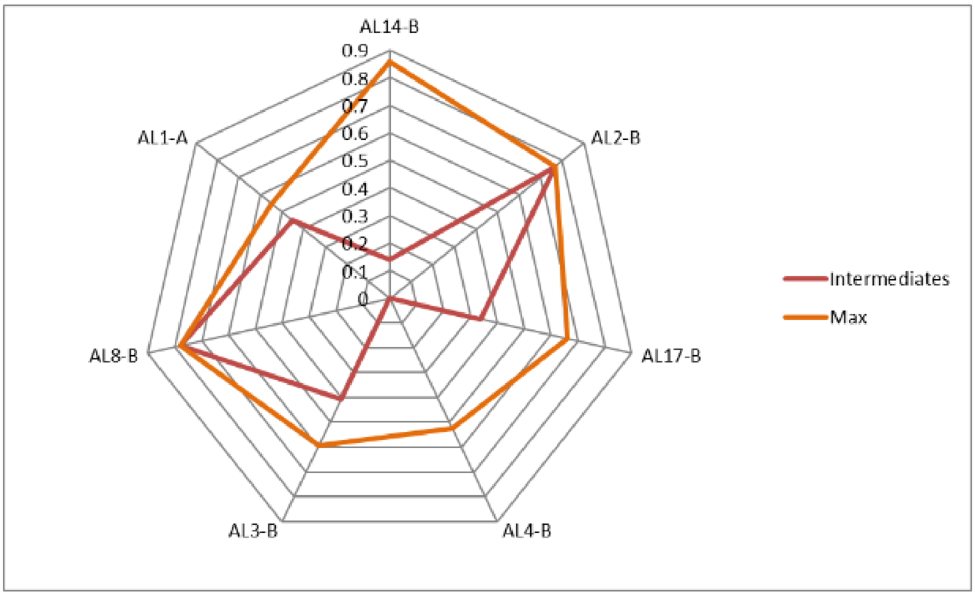
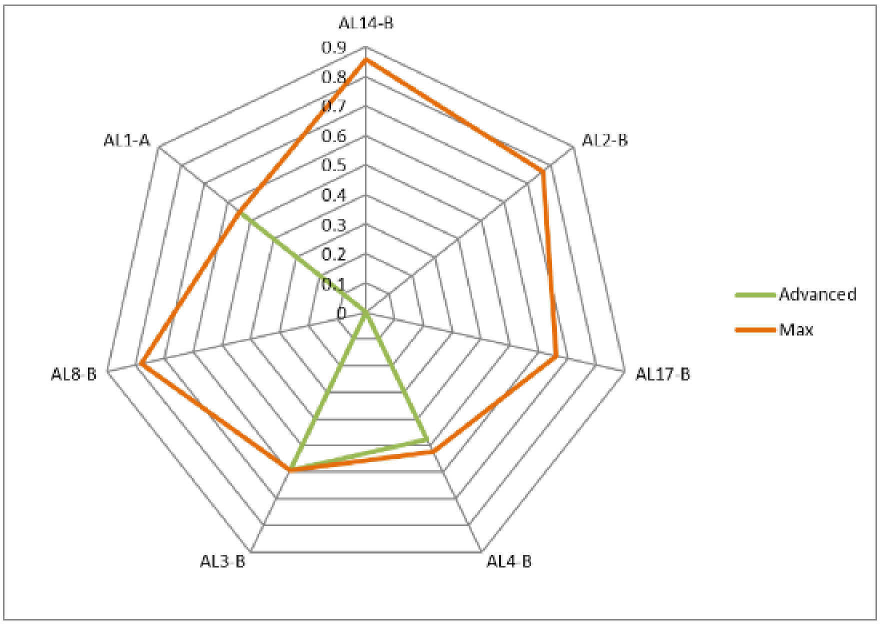


Figure 3 Benchmarking of risks faced by Intermediate Fish farmers

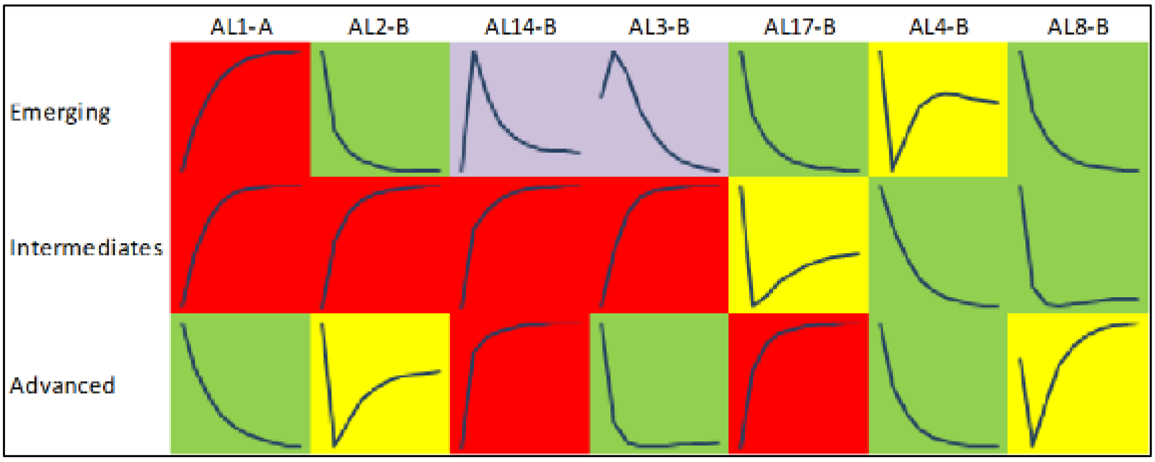


Legend AL1-A = no labour issues, AL2-B = low level of education, AL3-B = insecurity, AL4-B = insufficient rice field area, AL8-B = unsatisfactory selling price, AL14-B = financing issues, AL17-B = lack of water management

Figure 4 Benchmarking of risks faced by Advanced Fish Farmers

3.4. Risk outlook

All three groups of fish farmers show an increasing trend in the shortage of areas suitable for stocking (AL4-B). For the remaining risks, the trend varies according to the group of fish farmers (Figure 5). The labour shortage (AL1-A) will become more acute for advances, whilst it will ease for those with a casual interest and intermediates. The issue of water management (AL17-A) is on the rise for emerging and intermediate fish farmers, whilst it is on the decline for advanced class. The issue of education level (AL2-B) will worsen among the Emerging, whilst it will ease for the other two groups. The problem of funding (AL14-A) will intensify only among the Emerging. The problem of market conditions (AL8-A) and insecurity (AL3-A) will affect advanced and intermediates more, whilst it will be less pronounced among the Emerging.



Legend AL1-A = no labour issues, AL2-B = low level of education, AL3-B = insecurity, AL4-B = insufficient rice field area, AL8-B = unsatisfactory selling price, AL14-B = financing issues, AL17-B = lack of water management

Figure 5 Forecast of risks faced by fish farming

3.5. Fish farmers' adaptation strategies in response to various risks

The strategies adopted by fish farmers are shifting from passive/social to proactive/professional, optimising local resources for resilience (Table 3).

Intermediate fish farmers generally rely on community and family support to address labour shortages; they are little affected by insecurity and opt to temporarily abandon fish farming due to water-related problems. They are heavily dependent on social assistance to fund their activities. Faced with market issues and low local prices, they generally produce only for their own consumption.

Intermediate fish farmers, on the other hand, are moving towards collective solutions: family-based distribution to address security concerns and labour shortages. They are strengthening surveillance through a collective community agreement known as 'DINA'. To gain greater access to the market, they are beginning to join cooperatives and sell their produce in local market squares. They adapt locally to water constraints and modestly combine human, social and financial capital.

Advanced fish farmers incorporate advanced technical and financial resources. To address labour shortages, they streamline operations through partial mechanisation and the recruitment of employees. Furthermore, they undertake structured training and adopt technical innovations (ponds, flood defences) to bridge the skills gap compared to rural areas. To address price constraints, they seek to secure contracts and access urban or external markets with higher demand.

Table 3 Adaptation strategies of each type of fish farmer in response to the main risks

Risks Incurred	**Capital Employed**	**Class of fish farmers**		
		Emerging	**Intermediates**	**Advanced**
Labour	Human, social, financial	Community or family support	Family division of labour, village mutual aid	Streamlined organisation, mechanisation, wage labour
Level of education	Human, social	Low participation, passive observation	Learning by imitation and local exchanges	Structured training, community involvement, use of extension services
Insecurity	Social, human, financial	Little concern due to low production volume	Collective surveillance, preventive harvesting, *'DINA'* community collective agreement	Recruitment of guards, fencing, coordination with local authorities, Community collective agreement

Fish pond	Technical, financial, social	Rice-fish farming without infrastructure	Small-scale artisanal developments, collective maintenance	Technical innovations, infrastructure development
Market	Social, financial	Self-consumption, sale on-site or in the immediate neighbourhood	Local cooperatives; motorbike transport; improved storage; pre-arranged buyer contracts	Buyer contracts; processing (smoked/dried); access to urban markets; product diversification
Financing	Financial, social	Heavy reliance on family support and occasional income	Financial mutual aid, complementary activities	Access to credit, savings, structured diversification
Water	Technical, human, social, financial	Reduction, temporary cessation or monitoring	Local adaptation and timing of stocking, village solidarity, water drainage	Planning, hydraulic infrastructure, suitable species Structured flood control measures

4. Discussions

4.1. Diversity of risks and differentiated responses

The results in Table 2 and Figures 2–5 reveal a wide range of risks faced by fish farmers, the most significant of which are land-related, water-related, economic and technical constraints. The distinction between advanced, intermediates and those with a general interest confirms that the perception and prioritisation of risks are not uniform. For example, advanced fish farmers are more concerned about water regulation infrastructure and financial problems, whilst intermediates and emerging individuals primarily mention difficulties relating to training, labour and selling prices. This diversity reflects differing access to resources and varying adaptive capacity [18, 26]. It also aligns with the observations of Ellis [27], according to whom farming households adjust their strategies according to their capital endowment and subsistence priorities. In Madagascar, [10] highlights that this heterogeneity is reinforced by the fact that fish farming is often a secondary activity for rice farmers, which explains the differing levels of involvement and responses depending on profiles.

Socio-economic vulnerability emerges as a defining factor: These results confirm the assertions of [28] that low levels of education hinder innovation. Furthermore, limited access to credit perpetuates a subsistence-oriented approach among fish farmers [14], and price instability complicates planning.

4.2. Socio-economic vulnerability

Socio-economic vulnerability emerges as a structuring factor in fish farming profiles (Figure 2, Table 2). Among the ‘Emerging’ group, predominantly affected by low levels of education among heads of household (AL2-B dominant, Y=10.76), this shortcoming hinders innovation and the adoption of advanced techniques, confirming the key role of human capital in Malagasy agricultural productivity [28, 29].

Limited access to credit (AL14-B, influential/dominant with Y=18.49) perpetuates a subsistence mindset, blocking the investments needed for intensification [14, 13]. The labour shortage (AL1-A), which advanced fish farmers consider critical, is worsening due to young people migrating to cities for education or employment, and the priority given to rice farming [10].

Finally, income insecurity and price volatility (AL8-B, Figure 2), particularly acute among the Emerging, undermine any long-term planning [12, 30, 31]. These dimensions reflect multidimensional poverty, in line with Allison and Ellis [7] for rural micro-aquaculture and Bebbington [17] regarding the limiting role of human and social capital in disadvantaged areas.

4.3. Vulnerability to climate hazards

Climate hazards (lack of water management AL17-B, dominant/influential Y=10.54, Table 2; Figure 5) reflect fish farmers’ heavy dependence on natural conditions, particularly late rains and floods listed in Table 3.

These results confirm the findings of the IPCC [16, 32], which identify Madagascar as a hotspot for rainfall variability and increasing droughts. In the Highlands, rice-fish farming follows the rice-growing calendar. Consequently, delayed rains delay stocking and dry out the ponds, whilst floods cause leaks and mass fish mortality [13]. This water-related vulnerability, common to both small-scale and hobbyist farmers (Figures 2–3), undermines the rice-fish farming balance and erodes household incomes [10].

Unlike the intensive Asian systems regulated by pumps and enclosed ponds reported by the FAO [12], Malagasy farmers remain dependent on the climate, amplifying their vulnerability in the face of accelerating climate change [20].

4.4. Improving risk management in fish farming

Table 3 reveals strategies that differ according to profile: advanced primarily draw on technical and financial capital, such as the partial mechanisation of rice fields and fish ponds, innovations in flood-control basins, and the pursuit of contracts with buyers. Intermediates, on the other hand, rely on social and human capital, such as strengthening collective community agreements known locally as ‘dina’, setting up and joining local cooperatives, and improving product processing, packaging and transport. For their part, the Emerging favour village mutual aid and simple practices for self-consumption, and temporarily abandon fish farming in ponds where water management is difficult.

This gradation—passive among the Emerging, collective among the enthusiasts and proactive among the advanced—confirms that adaptive capacities depend on available capital and accumulated experience [18, 33]. Figures 2–4 illustrate this profile-resource correlation: advanced are only marginally affected by the issue of educational attainment.

Two forms of resilience emerge: individual resilience manifests itself through multiple income streams, savings and local innovation, whilst collective resilience prioritises solidarity and cooperatives, as in the work of Allison and Ellis [7]. These autonomous responses, whilst relevant, remain limited without sustainable institutional support [12, 15, 25].

4.5. Strategies to reduce the vulnerability of fish farmers

In response to the dominant/influential risks in Table 2, Table 3 documents a range of responses such as renting rice fields, mutual labour assistance, multiple income streams and saving, emulating peers, adopting flexible schedules, and sales via cooperatives. Among the ‘Emerging’, production for self-consumption dominates, whilst the ‘enthusiasts’ opt for the ‘dina’ and cooperatives. The ‘advanced’ favour contracts with buyers and the processing of fish products.

These trade-offs illustrate Ellis’s concept of livelihood diversification [27], whereby rural households expand their agricultural or non-agricultural activities in response to shocks. This behaviour has been confirmed in Madagascar by Rakotonarivo et al. [14] as a recurring response to climatic and economic uncertainty.

Collective practices underpin resilience: village solidarity, such as dina and neighbourhood watch schemes, and cooperatives that facilitate market access, enhance social capital, which is the cornerstone of community sustainability according to Bebbington and the DFID framework [17, 15].

4.6. Resilience to key risks through developed strategies

Summarised in Table 3 using the DFID framework [15], resilience brings together four forms of capital intersecting with fish farming profiles:

Human capital mobilises the family and the transmission of practical knowledge, such as structured training among advanced or imitation by the Emerging and intermediatess; social capital activates village mutual aid, the dina and cooperatives for monitoring and market access. Financial capital encourages the use of savings and microcredit (especially by advanced) and multiple income streams; technical capital deploys artisanal innovations such as small dams and flood-control ponds. Among the Emerging: social capital is the most dominant; among the advanced: technical and financial capital are predominant (Figures 2–4).

This synergy validates Scoones’ [18] assertion regarding cross-cutting assets for rural sustainability, and the FAO’s [34, 12] recommendations integrating endogenous resources such as solidarity and exogenous resources such as extension services and inputs for sustainable resilience in the face of multiple shocks (Table 3).

4.7. Assisted resilience in the face of the effects of climate hazards

Despite the notable autonomous resilience shown in Table 3 (flexible timetables and dina), it proves insufficient in the face of the intensifying water-related hazards affecting emerging and intermediate fish farmers (Figure 5).

External support, or assisted resilience, is essential for strengthening water infrastructure (flood defenses), the introduction of resilient species (tilapia vs. sensitive carp), access to inputs and fingerlings, technical extension and innovative financial tools (microcredit, crop insurance). GIZ [20] recommends these measures for Madagascar's vulnerable fish farming sector.

The FAO [12] emphasises that only sectoral integration within national agri-food policies can ensure their sustainability. In Madagascar, combining endogenous resilience—such as solidarity—with assisted resilience—such as infrastructure and finance—will safeguard rice fish farming in the face of climate change [16].

5. Conclusion

This study has highlighted the wide range of risks faced by fish farmers in the Malagasy Highlands. The most significant constraints relate to inadequate water regulation infrastructure, a lack of agricultural equipment, financial difficulties, limited access to inputs, labour shortages and vulnerability to climatic hazards such as drought, late rains and floods. These risks undermine family-run fish farming and jeopardise its sustainability.

Faced with these constraints, fish farmers employ various adaptation strategies based on the mobilisation of human, social, financial and technical capital. These include the diversification of agricultural and non-agricultural activities, local innovation, community solidarity, precautionary savings, collective monitoring and the artisanal construction of ponds or small dams. These mechanisms demonstrate a notable capacity for resilience, but often remain limited, as they respond more to short-term emergencies than to a logic of structural transformation.

The analysis shows that fish farming resilience rests on a dual dynamic: on the one hand, endogenous strategies based on experience, mutual aid and the utilisation of local resources; on the other hand, the need for assisted resilience, through institutional and technical support, which is essential to cope with the intensification of climate hazards and structural constraints.

Ultimately, fish farming in the Malagasy Highlands has definite potential to contribute to food security and the diversification of rural incomes. However, its sustainability depends on fish farmers' ability to strengthen their adaptation mechanisms and on external support to transform these local strategies into levers for long-term development.

Beyond typology, these findings guide support policies to combine self-reliance with assistance, boosting rural food security and incomes in the face of increasing climate shocks. Spatial modelling of these strategies remains to be undertaken.

Compliance with ethical standards

Acknowledgments

We acknowledge the Doctoral School of Natural Resource Management and Development (ED-GRND) and the host team Agro-Management and Sustainable Development of Territories (AM2DT) at the University of Antananarivo for their academic support during this study. We are also grateful to fish farmers and resource persons for their participation.

Disclosure of conflict of interest

We, authors of the present 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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