Revista de Ciências Agroveterinárias
Universidade do Estado de Santa Catarina (UDESC)

Research Article

Socioeconomic profile, water quality and sanitary characterization of small fish farming in microregions in the interior of Rondônia State, Brazil

Perfil socioeconômico, qualidade da água e caracterização sanitária da piscicultura de pequeno porte em microrregiões do interior do estado de Rondônia, Brasil

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Submission: June 26th, 2025 | Acceptance: September 05th, 2025

ABSTRACT

This study aimed to gather socioeconomic information and characterize the sanitary conditions of family fish farms in the interior of the state of Rondônia, Brazil. Visits were conducted to 126 fish farms, and interviews were carried out between November 2021 and May 2023. The fish farms adopted a semi-intensive production system, with fish cultivated in fishponds. Most ponds were built on riverbeds, located in lowland areas. The Vale do Jamari and Centro-Leste microregions were identified as the main fish-producing areas in Rondônia. All farms demonstrated adequate water quality for tropical fish production. Almost all were commercially active; however, over half operated below 50% of their production capacity. Two-thirds of these farms supplied only the domestic market, with their main products being whole fish (*in natura*) and frozen gutted fish (commercial cuts). In addition to tambaqui (*Colossoma macropomum*), species cultivated included pirarucu (*Arapaima gigas*), matrinxã (*Brycon amazonicus*), pintado (*Pseudoplatystoma corruscans*), tambatinga (female, *C. macropomum* X *Piaractus brachypomus*, male), pirapitinga (*Piaractus brachypomus*), and jaturarana (*Brycon* sp). Fish farming served as a supplementary source of income alongside dairy and beef cattle production and crops such as corn, coffee, and cocoa. Overall, family fish farming in Rondônia remains traditional and low in productivity, especially in the Vale do Guaporé and Vale do Mamoré microregions.

KEYWORDS: Sanitary management. Small fish farmers. Socioeconomic information. Sustainable management. Water quality.

RESUMO

Este estudo teve como objetivo reunir informações socioeconômicas e caracterizar as condições sanitárias de pisciculturas familiares no interior do estado de Rondônia, Brasil. Foram realizadas visitas a 126 propriedades, com entrevistas conduzidas entre novembro de 2021 e maio de 2023. As pisciculturas adotavam um sistema de produção semi-intensivo, com peixes cultivados em viveiros escavados. A maioria dos viveiros foi construída em leitos de rios, localizados em áreas de várzea. As microrregiões do Vale do Jamari e Centro-Leste foram identificadas como os principais polos de produção de peixes em Rondônia. Todas as propriedades apresentaram qualidade de água adequada para a produção de peixes tropicais. Quase todas estavam ativas comercialmente; entretanto, mais da metade operava com menos de 50% de sua capacidade produtiva. Dois terços dessas propriedades atendiam apenas ao mercado interno, tendo como principais produtos o peixe inteiro (*in natura*) e o peixe eviscerado congelado (cortes comerciais). Além do tambaqui (*Colossoma macropomum*), eram cultivadas espécies como pirarucu (*Arapaima gigas*), matrinxã (*Brycon amazonicus*), pintado (*Pseudoplatystoma corruscans*), tambatinga (female, *C.*

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macropomum X *Piaractus brachypomus*, male), pirapitinga (*Piaractus brachypomus*) e jaturarana (*Brycon* sp). A piscicultura servia como fonte complementar de renda, associada à produção de leite, gado de corte e culturas como milho, café e cacau. De forma geral, a piscicultura familiar em Rondônia permanece tradicional e com baixa produtividade, especialmente nas microrregiões do Vale do Guaporé e Vale do Mamoré.

PALAVRAS-CHAVE: Manejo sanitário, Piscicultores familiares; Informações socioeconômicas, Manejo sustentável, Qualidade da água.

INTRODUCTION

The global fishing and aquaculture industry continues to expand, reaching a historical production volume of 214 million tons in 2020. Aquaculture production has steadily increased each year, with a 5.7% increase in 2024, whereas capture fisheries are declining due to the reduction of natural fish stocks. This trend reinforces aquaculture as a sustainable alternative source of animal protein (AQUACULTURE BRASIL 2022).

In Brazil, aquaculture has grown significantly, with a 48.6% increase in production between 2014 and 2022. According to the Brazilian Fish Farming Association (PEIXE BR 2025), in 2022, national aquaculture production reached 860.35 thousand tons. Native fish farming, led by tambaqui (*Colossoma macropomum*), accounted for 31% of production, while other species represented 5% (CAVALI & DANTAS FILHO 2024). Rondônia is the largest producer of tambaqui in Brazil, reaching 56.9 thousand tons in 2024 (PEIXE BR 2025).

Approximately nine years ago, Rondônia's production volume was 57% higher than current levels. Since then, the state has experienced successive annual declines of 6.3% in production. These reductions have been attributed to multiple factors, including productivity issues caused by a poorly organized production chain, market saturation, and rising input costs, which increased production expenses by over 81% (MARTINS et al. 2020). Additional limiting factors include insufficient marketing strategies and parasitic infestations, which compromise the final product quality (MEANTE & DÓRIA 2017).

Family farming, as defined by Brazilian Law No. 11.326 of July 24, 2006, includes farmers and rural family entrepreneurs who operate on land areas not exceeding four fiscal modules and whose management and labor are primarily provided by family members (BRASIL 2006). In fish farming, this refers to small-scale enterprises managed within a family production system (CAVALI & LOPES 2017, CARDOSO et al. 2023).

Rondônia's State Law on Aquaculture No. 5.280/2022 establishes guidelines for the environmental licensing of aquaculture operations (SEDAM/RO 2022). Its purpose is to modernize and simplify licensing procedures while promoting aquaculture as a sustainable source of food, employment, income, and recreation, harmonizing production with environmental preservation and biodiversity conservation. The law clearly defines which aquaculture activities require environmental licensing, classifying them according to scale and environmental risk. Small-scale family fish farms are defined as those with up to 5 hectares of water surface in excavated fishponds or reservoirs, or up to 5,000 m³ of water in cage, lined, or suspended tanks (SEDAM/RO 2022).

Fish raised under poor water quality, inadequate feeding, or high-density stocking without proper planning are prone to stunted growth and increased susceptibility to pathogens due to stress factors (MACIEL-HONDA et al. 2023). Fish diseases lead to significant direct and indirect economic losses (LOPES et al. 2020), with parasitic infections alone estimated to cause annual losses of approximately US$ 84 million in the Brazilian aquaculture sector (CASTRO et al. 2020). Intensive farming without proper management disrupts the host-pathogen balance, increasing vulnerability to outbreaks (SOUSA et al. 2020, SILVA et al. 2021).

Currently, there is no scientific data describing the panorama of family fish farming across Rondônia's microregions. Therefore, this study aims to provide a simplified state-level diagnosis of fish farming, contributing to the characterization and spatial distribution of the activity. Such information is essential for guiding sustainable management decisions while respecting the social, environmental, and economic dimensions of production (CARDOSO et al. 2022, ALBUQUERQUE et al. 2023).

The objectives of this study were to collect socioeconomic data, evaluate water physicochemical parameters, compare seasonal and regional differences, and characterize the sanitary conditions of family fish farms in Rondônia, ultimately providing a diagnostic and prognostic tool to support sustainable management strategies.

MATERIALS AND METHODS

Ethical considerations

This study was approved by the Research Ethics Committee (CEP/CONEP) of the Universidade Federal de Rondônia (UNIR). Plataforma Brasil assigned CAAE protocol No. 60744322.5.0000.5300 and receipt No. 077412/2022. The approved project title was Health Characterization of Fish Farming in Rondônia.

Study area

The state of Rondônia has a territorial extension of 237,765.240 km² and is in the Amazon biome. Rondônia is divided into seven immediate geographic divisions, called microregions. These are Centro-Leste, Vale do Jamari, Vale do Guaporé, Rio Mamoré, Zona da Mata, Rio Madeira, and Cone Sul. According to IBGE (2010), the Human Development Index (HDI) of the state of Rondônia is 0.756, considered medium HDI.

The number of fish farms in Rondônia state, according to the State Department of Environmental Development (SEDAM/RO 2021), is 4,308 registered and licensed fish farms. Approximately 70.2% of these fish farms are family-owned, with less than five hectares of water surface area. Fish farms in Rondônia occupy a flooded area of 15,801.28 hectares (SEDAM/RO 2021). However, official data do not identify fish farms in productive activity

This study was conducted in five microregions of the state of Rondônia. A total of 126 family-owned fish farms from different microregions were visited, which were Centro-Leste, Vale do Jamari, Vale do Guaporé, Rio Mamoré, and Zona da Mata. Data were collected from 28 family-owned fish farms in the Centro-Leste microregion, and visits were made to fish farmers in the municipalities of Ji-Paraná, Ouro Preto do Oeste, Presidente Médici, Urupá, Teixeirópolis, Nova União, and Mirante da Serra. Data from 24 family-owned fish farms in the Vale do Jamari microregion were collected,

visiting fish farmers in the municipalities of Ariquemes, Machadinho do Oeste, Cujubim, Rio Crespo, Buritis, Cacaulândia, and Monte Negro.

Data from 12 family-owned fish farms in the Vale do Guaporé microregion were collected, visiting fish farmers in the municipalities of Costa Marques and São Francisco do Guaporé. Data from 8 family-owned fish farms in the Rio Mamoré microregion were collected, visiting fish farmers in the municipalities of Nova Mamoré and Guajará-Mirim. Finally, data from 54 family-owned fish farms in the Zona da Mata microregion were collected, visiting fish farmers in the municipalities of Rolim de Moura, Cacoal, Alta Floresta d'Oeste, Santa Luzia d'Oeste, Novo Horizonte do Oeste, and Alto Alegre dos Parecis (Figure 1).

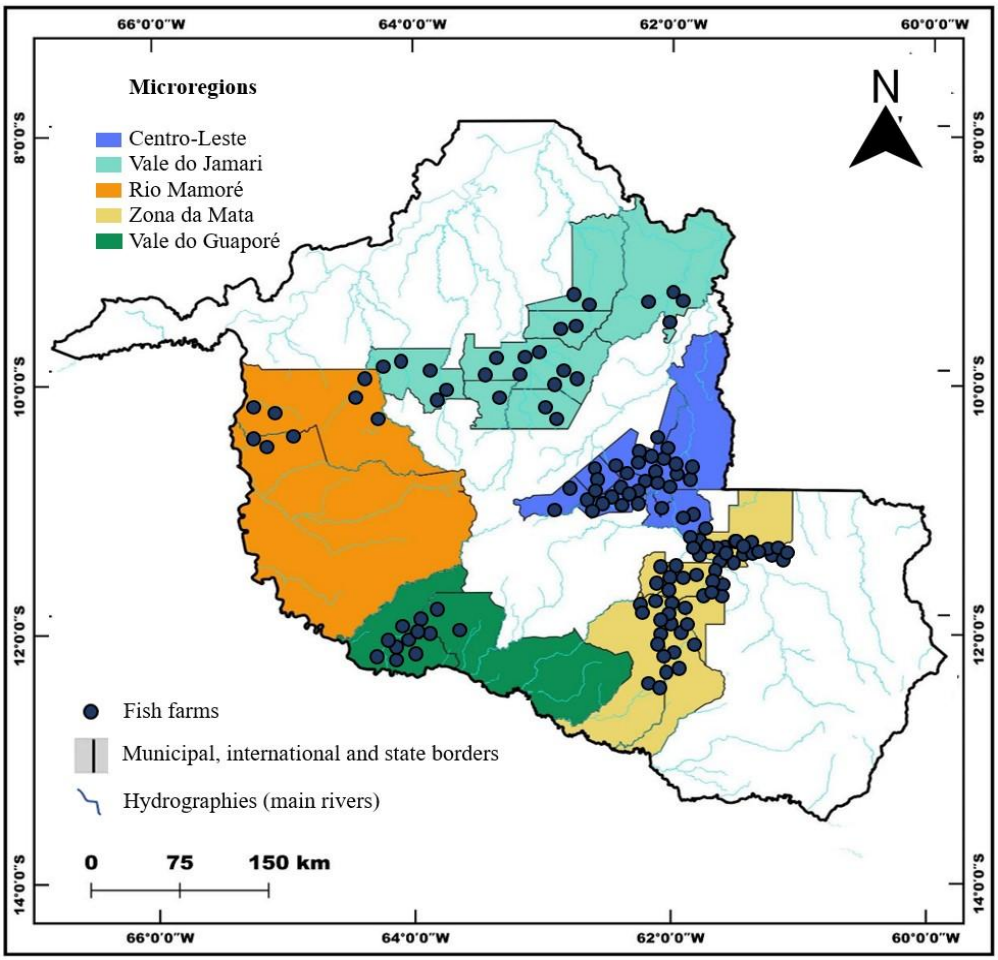


Figure 1. Location of the fish farms visited and their respective microregions in the Rondônia state, Brazil.

Data collection

The study was conducted between November 2021 and May 2023, with technical support and database assistance from the Empresa de Assistência Técnica e Extensão Rural do Estado de Rondônia (EMATER/RO) for defining sampling points and conducting visits to fish farms. Additionally, support was provided by the Regional Environmental Delegation (ERGA) of the State Department of Environmental Development (SEDAM/RO).

This study considered only small-scale commercial fish farms, namely family enterprises. The size of the fish farms was classified according to Annex I of Table 1

of Ordinance No. 413/2009 of the National Environmental Council (CONAMA), which addresses fish farm licensing and defines enterprises based on the following sizes: I – Small size: an area less than 5 hectares (ha), as established by State Law No. 5,280/2022 (SEDAM/RO).

Field data were obtained through visits to rural properties wherea semi-structured questionnaire was conducted, interwieving managers and/or owners of the fish farms to gather information related to the sector (fish farming) and other relevant study topics. The questions were framed within the context of socioeconomic factors including marketing and sanitary conditions (management, mortality rate, veterinary medication treatments, quarantine and sanitary gap, acquisition and acclimatization of post-larvae, water quality monitoring, pond disinfection, prophylaxis, weed and macrophyte control, reports, and preventive measures, parasitosis control among others).

Physicochemical analyzes of water

The physical and chemical analyzes of the water were carried out during visits to properties with fish farming activities, considering two Amazonian hydrological seasons, from November 2021 to April 2022 (rainy) and from May to October 2022 (dry). Pond water was analyzed up to 40 cm deep and measured *in situ*. with a multiparametric probe (model AT155), including pH, dissolved oxygen (mg L^{-1}) and temperature (ºC). The transparency of the water (cm) was measured with a Secchi disk. In the laboratory, total ammonia (N-NH_4), nitrate (NO_3^{1-}), nitrite (NO_2^{1-}), phosphate (PO_4^{3-}), phosphorus (P), alkalinity (mg L^{-1} $CaCO_3$) and hardness (mg L^{-1} $CaCO_3$). The analyzed parameters were framed within CONAMA Resolution No. 357/2005 (BRASIL 2005) which considers water quality intended for fish farming (Class 2).

Database and statistical analysis

The data obtained were stored and organized in Epi Info™ software, version 3.5.3 - 2011 (OS: MS-Windows, programming language C Sharp). Once organized, the data underwent descriptive statistical analysisfollowing the methodological suggestions of SOUSA et al. (2020) which includes frequency analyses (%), arithmetic mean (μ), standard deviation (σ), and total range. Subsequently, the data were subjected to the Shapiro-Wilk test (α = 0.05) to verify if the samples came from a population with a normal distribution (H_0).

After confirming the normality and homoscedasticity of the data, mean tests were applied for water quality and socioeconomic data. A Student's t-test was applied at 5% significance level to compare the physicochemical means of water at different hydrological stations. Additionally, Tukey's test was applied at 5% significance level to compare the physicochemical means of water across different microregions and for socioeconomic information.

All results were considered statistically significant with p <0.05. Statistical analyses were performed using RStudio Development Core Team, version 3.5.3.

RESULTS

Socioeconomic profile

On average, the visited fish farms adopted a semi-intensive production system (maximum 0.6 kg m^{-2} per year with an annual cycle), covering up to 4.9 hectares of

water surface, distributed in semi-excavated fishponds, with individual areas not exceeding 0.5 hectares, with an average depth of 1.64 m. Most of the

fish farms (90%) had their fishponds built in the lower parts of the riverbeds, i.e., in them, taking advantage of water in these regions to dam and supply the fish farms by gravity. At the same time, it was observed that 92% of the visited fish farms cultivate some species of fish for the domestic market and/or property consumption, and of these, 34% were reactivated after a period of inactivity (less than 10 years).

The Secretaria de Estado do Desenvolvimento Ambiental de Rondônia (SEDAM/RO) only has information on the number of registered properties licensed for fish production, however, there is no information about the status of the activity. Thus, it was observed that in the Rio Mamoré microregion, half of the visited properties showed active economic activity, i.e., they sell fish in the domestic or external market to the region. The other half of the properties produce for their own consumption. In the Centro-Leste microregion, 90% are commercially active and 10% are for subsistence. Similar numbers were observed in the Zona da Mata and Vale do Guaporé microregions, which showed 95 and 84% commercially active and 5 and 16% for subsistence, respectively. In the Vale do Jamari, 100% were commercially active, and no subsistence activity was observed. Figure 2 shows the destination of production from commercially active properties, divided by regions.

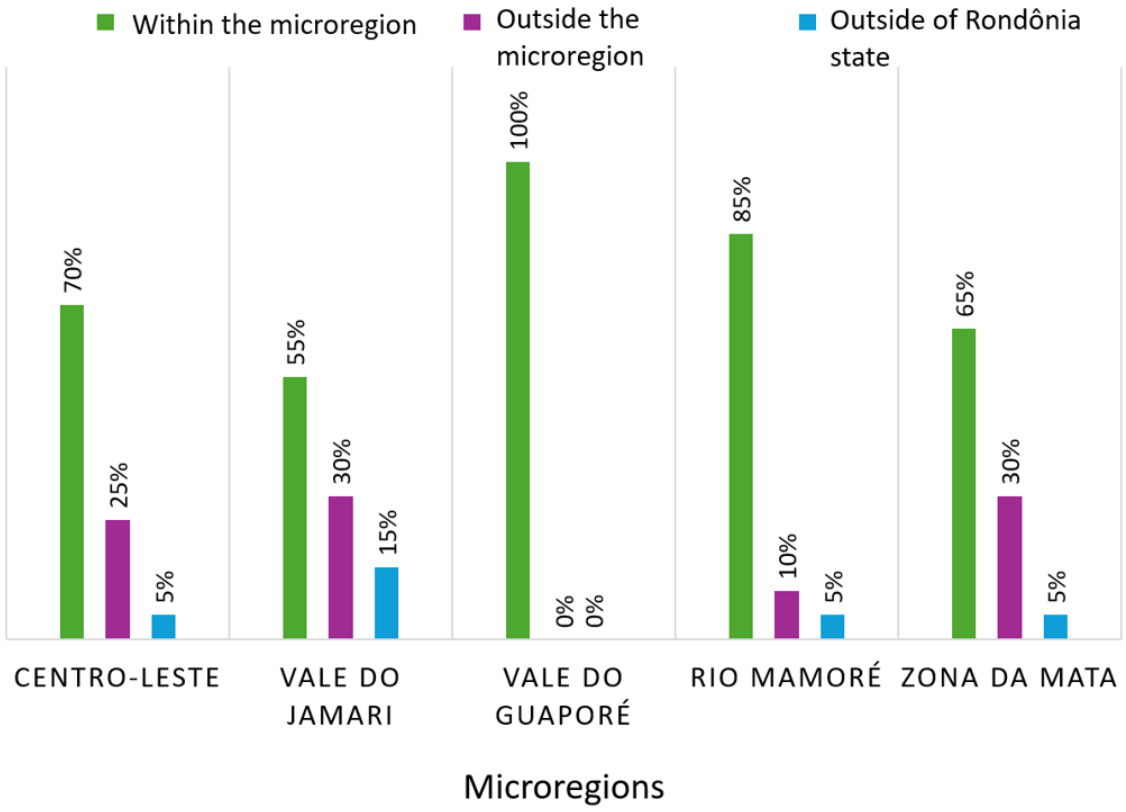


Figure 2. Destination of fish commercialized by family fish farms in the microregions of Rondônia state, Brazil.

Regarding the distribution of production, the fish were marketed within the same microregion (78%), to other states (21%), and outside Brazil (1%). Among the federative units, the production is marketed to Amazonas (55%), Goiás (15%), Pará (13%), Acre (5%), and others (12%). Fish farmers responded about the mode of commercialization, with 95.5% selling whole fish (*in natura*) and 5.5% selling chilled

fish (eviscerated, whole, or cut into pieces). In the overall context of cost management, expenses were mainly concentrated on production costs, facilities, and maintenance, with 76% using own financing, while 69% of fish farmers admitted to not having detailed control over expenses.

In all microregions, the main species cultivated is tambaqui (*Colossoma macropomum*), however, cultivation of pirarucu (*Arapaima gigas*), pintado (*Pseudoplatystoma corruscans*), tambatinga (female, *Colossoma macropomum* X *Piaractus brachypomus,* male), pirapitinga (*Piaractus brachypomus*), jatuarana (*Brycon sp*.), matrinxã (*Brycon amazonicus*), and others was also observed. The distribution of cultivated species, besides tambaqui, by microregions is described in Figure 3.

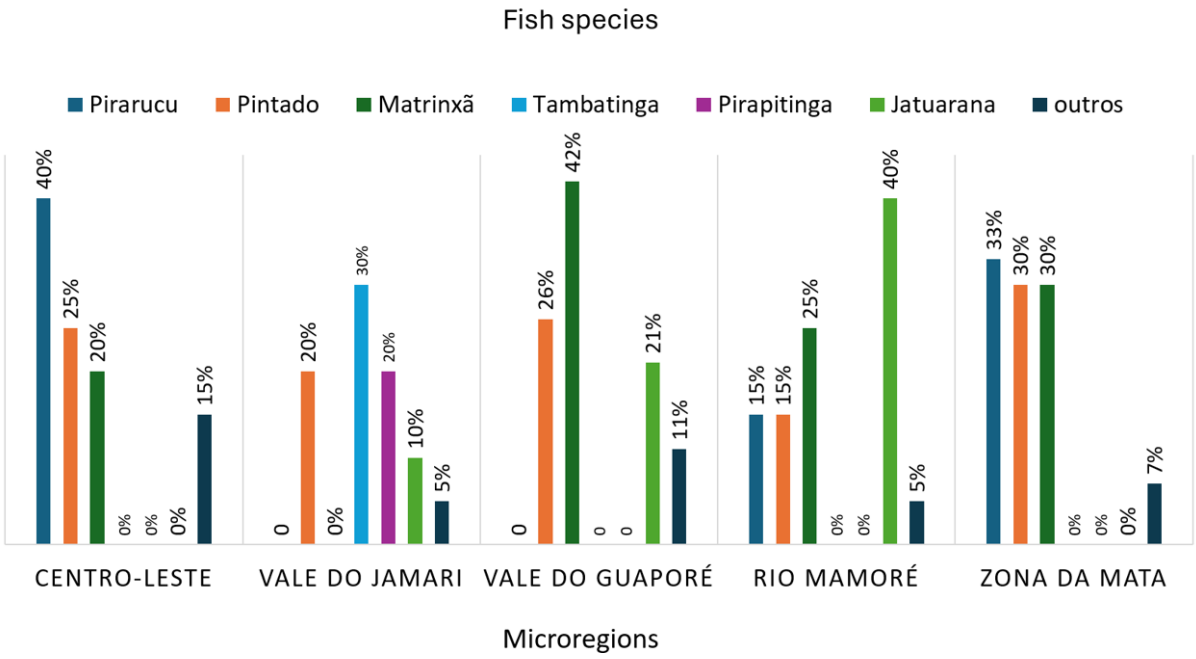


Figure 3. Main cultivated species excluding tambaqui (*Colossoma macropomum*) in the different microregions of Rondônia state, Brazil.

Regarding fish farming, all properties used semi-excavated fishponds, and the farming systems varied between single-phase, two-phase and three-phase. In the microregions of Vale do Jamari and Centro-Leste, the two-phase system was most used (80 and 93%, respectively), while in Vale do Guaporé, Rio Mamoré, and Zona da Mata, the most used system was the single-phase (92, 75 and 54%, respectively).

The Vale do Jamari and Centro-Leste had producers with the longest time dedicated to fish farming (10.67 ± 1.17 and 10.57 ± 0.70 years, respectively). On the contrary, a time of less than 28 months was observed in Vale do Guaporé (Table 1). In relation to water depth area, Vale do Jamari showed the highest average) (7.27 hectares; p <0.05). The Vale do Jamari and Central-Leste microregions had the highest averages of fish production volume (18,369.23 and 11,059.08 kg, respectively; p <0.05). The Centro-Leste, Zona da Mata, and Vale do Jamari microregions showed the highest averages of productivity per area of water depth, (3,262.24, 2,894.66 and 2,527.72 kg ha^{-1}, respectively; p <0.05)

In relation to the quantity of post-larvae acquired for each production cycle, the Vale do Jamari and Centro-Leste microregions showed the highest averages (16,689.29 and 11,508.33 post-larvae, respectively; (p <0.05). Vale do Jamari, and Zona da Mata had the lowest average cultivation times, (11.62 and 11.80 months, respectively; p <0.05). However, there was no statistical difference (p >0.05) for the commercial weight of fish between the microregions. In relation to the price per kilo of fish, Vale do Jamari and the Centro-Leste showed the highest averages (R$ 9.54 and 8.28, respectively; p <0.05) Vale do Jamari showed the highest averages of slaughter volume and revenue per slaughter, (16,650.33 kg and R$ 158,844.15, respectively; p <0.05) (Table 1).

Table 1. Socioeconomic profile of family fish farms by microregions in the Rondônia state, Brazil.

Socioeconomic information	Microrregions					*p*-value
	Centro-Leste	Vale do Jamari	Vale do Guaporé	Rio Mamoré	Zona da Mata	
Dedication (years)	10.67 ± 1.17^{a}	10.57 ± 0.70^{a}	1.4 ± 0.2^{c}	3.00 ± 0.50^{bc}	7.65 ± 0.85^{ab}	0.0245
Water surface area (ha)	3.39 ± 0.85^{b}	7.27 ± 2.27^{a}	2.32 ± 0.67^{b}	2.70 ± 1.30^{b}	2.98 ± 0.92^{b}	0.0449
Annual production volume (kg)	11.059.08 ± 2.543.59^{ab}	18.369.23 ± 3.857.54^{a}	1.371.44 ± 301.72^{c}	2.125.05 ± 467.51^{c}	8.626.10 ± 1.984.00^{b}	0.0212
Productivity* (kg ha^{-1})	3.262.24 ± 815.16^{a}	2.527.72 ± 931.93^{a}	591.14 ± 147.79^{b}	787.06 ± 196.77^{b}	2.894.66 ± 723.67^{a}	0.0170
Postlarvae acquired for the cycle	11.508.33 ± 1.361.39^{a}	16.689.29 ± 4.005.41^{a}	1.557.14 ± 186.86^{c}	3.970.71 ± 476.48^{bc}	6.608.44 ± 793.01^{b}	0.0195
Cultivation time (months)	13.76 ± 0.83^{a}	11.62 ± 0.48^{b}	12.02 ± 1.08^{a}	13.00 ± 1.00^{a}	11.80 ± 1.00^{b}	0.0455
Fish marketing weight (kg)	2.99 ± 0.45^{a}	2.56 ± 0.46^{a}	2.10 ± 0.80^{a}	2.75 ± 0.25^{a}	2.77 ± 0.73^{a}	0.1505
Price of fish/kg (R$)	8.28 ± 0.82^{a}	9.54 ± 1.24^{a}	5.94 ± 1.16^{c}	7.60 ± 0.40^{b}	7.89 ± 0.71^{b}	0.0164
Slaughter volume** (kg)	5.119.74 ± 972.75^{b}	16.650.33 ± 4.662.11^{a}	1.021.43 ± 286.07^{c}	2.297.25 ± 643.25^{bc}	2.762.90 ± 773.61^{bc}	0.0190
Average revenue per slaughter (R$)	42.385.32 ± 9.324.77^{b}	158.844.15 ± 34.485.71^{a}	6.067.29 ± 1.698.81^{c}	17.459.10 ± 4.888.50^{bc}	21.799.28 ± 6.103.80^{bc}	0.0174

*Productivity volume of fish per hectare of water surface area; **Not necessarily annual, depending on commercial demand; Means and standard deviations followed by different letters,are different according to the Tukey's test (p <0.05).

Regarding fish feeding, 53% offered commercial feed, 32% formulated their own feeds (i.e., artisanal feeds, including corn, cassava, or regional fruits), and 15% did not offer any feed, subjecting confined fish to feed solely on plankton, insects, and fruits that fell into the ponds. During visits to fish farms, poor storage conditions for feed sacks were observed. In the Centro-Leste microregion, 76% of fish farms had feed sacks that appeared to be moldy and/or fungal with apparent loss of buoyancy. In 50% of fish farms, sacks were observed stacked on the floor without protection against moisture or sunlight.

In the microregion of Vale do Jamari, 30% of fish farms had feed sacks that appeared to be moldy and/or fungal with apparent loss of buoyancy. In 40% of fish farms, sacks were observed stacked on the floor without protection against moisture or sunlight. In Vale do Guaporé, poor feeding or feed storage conditions were observed in all properties. 84% did not provide commercial feed; instead, 100% of them offered fermented corn to the fish. Of the 16% that provided commercial feed, all had feed sacks that were moldy and/or fungal with apparent loss of buoyancy. In Rio Mamoré,

it was not possible to check the feed storage sheds, although it was reported that 60% provided commercial feed and the remaining 40% provided fermented corn to the fish. Meanwhile, in the Zona da Mata, 81% of fish farms had feed sacks that appeared to be moldy and/or fungal with apparent loss of buoyancy. In 57.5% of fish farms, sacks were observed stacked on the floor without protection against moisture or sunlight.

Furthermore, in all fish farms visited in this study, feeds were subject to contact with insects and rodents. A very common occurrence was feeds stored outside the sacks, as they were stored in Polyethylene water tanks very close to the fishpond water, under conditions of humidity, sunlight (when not covered), and high temperature. In addition to fish farming, the small-scale farmers interviewed also engaged in other productive activities, with 88% in dairy and beef cattle farming. Additionally, 42% were involved in crop cultivation (20% corn, 14% coffee farming, and 8% also engaged in cocoa farming).

Other socioeconomic factors of fish farmers were considered. Families consisted of 3 to 6 members (1 to 4 children), with 88% of fish farms managed by men and 12% by women. Those who were not managers although in the role of wife/companion supplemented the family income by engaging in other activities, with 26% working in the public sector, 40% employed (domestic workers/day laborers) in the city, 17% responsible for raising other animals (chickens, pigs, etc.), or 17% maintaining a vegetable garden.

Mean age of fish farm managerswas 49.76 ± 10.69, with a normal distribution of age data in the population (W = 0.8267; p = 0.042), distributed across different age groups (Figure 4).

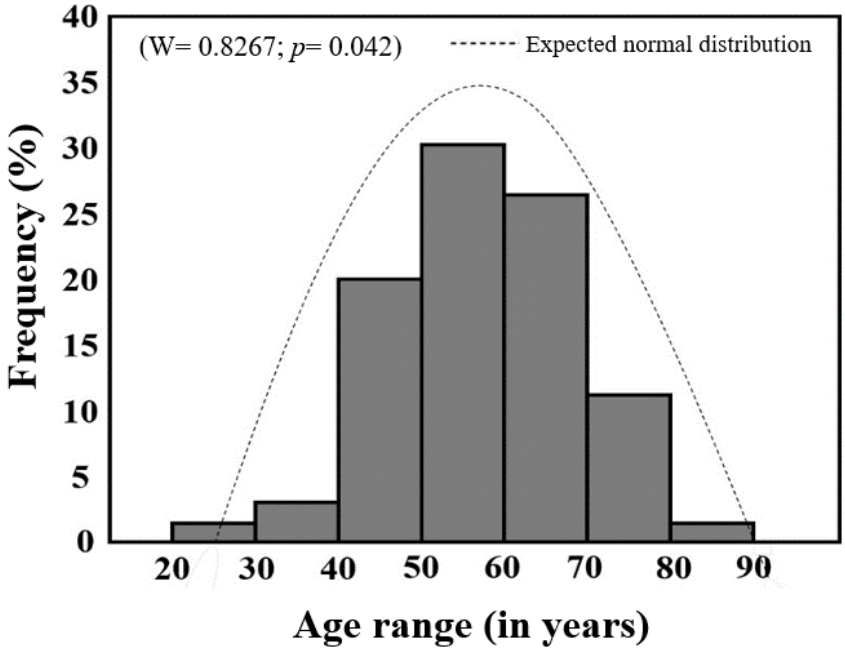


Figure 4. Absolute frequency of ages of family fish farmers in Rondônia in different ranges of normal distribution.

Water quality

Table 2 shows the variation in water quality in fish farms according to the rainy and dry seasons. For the variables temperature (°C) and pH, there was no statistical difference (p >0.05) between the means. For dissolved oxygen concentrations (mg

L^{-1}), except for Vale do Jamari, fish farms in the other microregions showed a difference (p <0.05) in means between the rainy and dry seasons, with lower concentrations during the dry season. Regarding water transparency (cm) in the fishponds, the means during the rainy and dry seasons in fish farms in the Centro-Leste and Vale do Jamari were different, although there was no variation in the other microregions (p >0.05). For nitrate (NO_3^{1-}) and nitrite (NO_2^{1-}) variables, the Centro-Leste and Zona da Mata microregions showed higher means during the rainy season compared to the dry season, while there was no variation in the other microregions (p >0.05).

Regarding the total ammonia content (mg L^{-1} $N\text{-}NH_4$) analyzed by the research team, the Vale do Jamari and Zona da Mata microregions showed the highest averages in the dry season in relation to rain, while in the other microregions there was no variation. For the values of phosphate (PO_4^{3-}), phosphorus (P), the Centro-Leste, Rio Mamoré and Zona da Mata microregions showed higher averages in the dry season in relation to the rainy season. As for alkalinity (mg L^{-1} $CaCO_3$), the Central-Leste, Rio Mamoré, and Zona da Mata microregions showed higher averages in the rainy season compared to the dry season. Finally, for hardness (mg L^{-1} $CaCO_3$), except for Vale do Guaporé, all other microregions showed higher averages (p <0.05) in the rainy season compared to the dry season (Table 2).

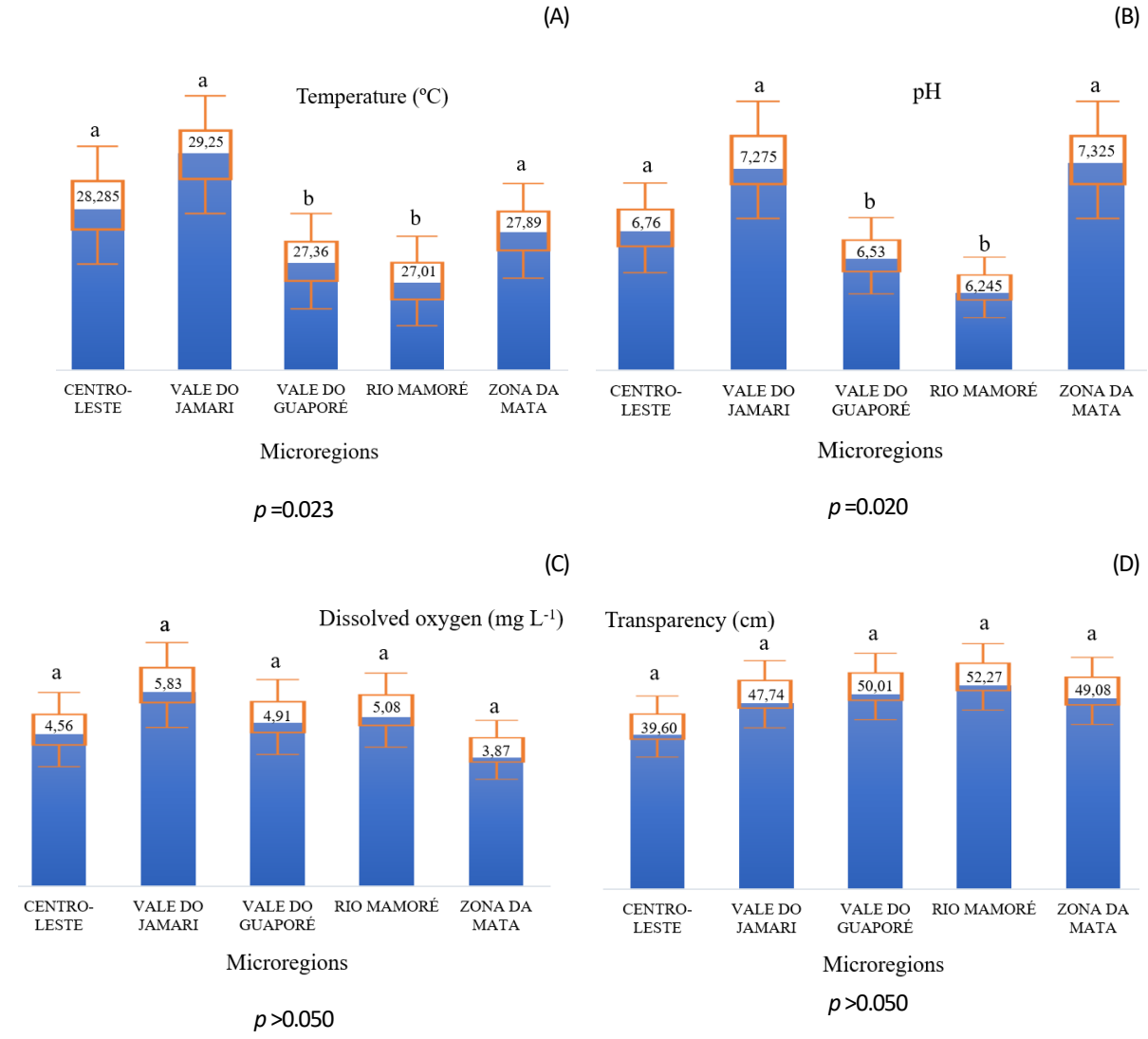
Table 2. Characterization of water quality in family fish farms by microregions in the Rondônia state, in the rainy and dry seasons.

Parameters	Microrregions									
	Centro-Leste		Vale do Jamari		Vale do Guaporé		Rio Mamoré		Zona da Mata	
	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Temperature (ºC)	27,39 ± 1,37[b]	29,18 ± 1,46[a]	29,10 ± 1,46[a]	29,40 ± 1,48[a]	26,67 ± 1,33[a]	28,05 ±1,42[a]	26,22 ± 1,31[a]	27,80 ±1,39[a]	26,90 ± 134[a]	28,88 ±1,44[a]
pH	6,35 ± 0,43[a]	7,17 ± 0,48[a]	7,42 ± 0,50[a]	7,13 ± 0,48[a]	6,22 ± 0,42[a]	6,84 ± 0,46[a]	6,05 ± 0,40[a]	6,44 ± 0,43[a]	6,95 ± 0,47[a]	7,70 ± 0,52[a]
Dissolved oxygen (mg L^{-1})	6,07 ± 0,44[a]	3,05 ± 0,22[b]	5,98 ± 0,43[a]	5,68 ± 0,41[a]	5,82 ± 0,42[a]	4,00 ± 0,29[b]	5,90 ± 0,42[a]	4,26 ± 0,31[b]	5,00 ± 0,36[a]	2,74 ± 0,20[b]
Transparency (cm)	44,71 ± 6,26[a]	34,48 ± 4,83[b]	41,33 ± 5,79[b]	54,15 ± 7,58[a]	47,80 ± 6,64[a]	52,22 ±7,31[a]	49,54 ± 6,93[a]	55,00 ±7,70[a]	50,10 ± 7,01[a]	48,05 ±6,73[a]
Nitrate (NO_3^{1-})	0,33 ± 0,07[a]	0,15 ± 0,03[b]	1,35 ± 0,29[a]	0,94 ± 0,20[a]	0,71 ± 0,15[a]	0,62 ± 0,13[a]	1,05 ± 0,22[a]	0,82 ± 0,17[a]	0,33 ± 0,07[a]	0,13 ± 0,03[b]
Nitrite (NO_2^{1-})	0,13 ± 0,03[a]	0,05 ± 0,01[b]	0,07 ± 0,02[a]	0,05 ± 0,01[a]	0,48 ± 0,14[a]	0,30 ± 0,08[a]	0,10 ± 0,02[a]	0,07 ± 0,01[a]	0,13 ± 0,03[a]	0,03 ± 0,01[b]
Total ammonia (mg $L^{-}N\text{-}NH_4$)	0,10 ± 0,03[a]	0,13 ± 0,04[a]	0,06 ± 0,02[b]	0,14 ± 0,04[a]	0,10 ± 0,03[a]	0,13 ± 0,04[a]	0,08 ± 0,02[a]	0,06 ± 0,02[a]	0,13 ± 0,04[a]	0,2 ± 0,06[b]
Phosphate (PO_4^{3-})	0,80 ± 0,16[b]	1,91 ± 0,38[a]	0,74 ± 0,15[a]	0,77 ± 0,15[a]	0,75 ± 0,15[a]	1,00 ± 0,20[a]	0,89 ± 0,17[b]	2,10 ± 0,41[a]	0,50 ±0,10[b]	1,00 ± 0,20[a]
Phosphorus (P)	0,32 ± 0,08[b]	0,78 ± 0,19[a]	0,24 ± 0,06[a]	0,25 ± 0,06[a]	0,35 ± 0,08[a]	0,42 ± 0,10[a]	0,40 ±0 ,11[b]	1,90 ± 0,45[a]	0,21 ± 0,05[b]	0,55 ± 0,14[a]
Alkalinity (mg L^{-1} $CaCO_3$)	46,33 ± 6,49[a]	34,54 ± 4,83[b]	35,67 ± 4,99[a]	29,70 ± 4,16[a]	45.64 ± 6,39[a]	42,88 ±6,00[a]	44,14 ± 6,18[a]	31,02 ± 434[b]	50,71 ± 7,10[a]	37,09 ±5,19[b]
Water hardness (mg L^{-1} $CaCO_3$)	52,15 ± 6,26[a]	31,71 ± 3,80[b]	30,50 ± 3,66[a]	24,30 ± 2,92[b]	40,45 ± 4,85[a]	35,60 ±4,28[a]	36,77 ± 4,41[a]	24,98 ±3,00[b]	57,60 ± 6,91[a]	36,70 ±4,40[b]

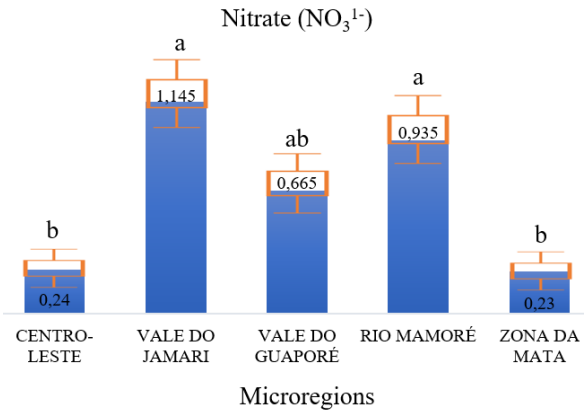
If there are means and standard deviations followed by different letters, they are different between the rainy and dry seasons, according to the Student's t-test (p <0.05).

The Figure 5 shows the comparison of physicochemical parameters of fish farm water by microregion. Regarding temperature and pH, Vale do Jamari, Centro-Leste, and Zona da Mata showed the highest averages (29.25, 28.29, and 27.87 ºC) (7.28, 6.76, 7.33 pH), respectively (Figure 5 A). Therefore, the fish farms in Vale do Guaporé,

and Rio Mamoré showed the most acidic waters, 6.53 and 6.24, respectively (Figure 5 B). It is important to highlight that for dissolved oxygen and transparency variables, there was no statistical difference (p >0.05) between microregions (Figure 5 C and D). Regarding nitrate content, Vale do Jamari, and Rio Mamoré showed the highest averages (p <0.05) 1.14 and 0.93 NO_3^{1-}, respectively (Figure 5 E). While for nitrite content, Vale do Guaporé presented the highest average (p <0.05) 0.39 NO^{2-} (Figure 5 F). For total ammonia concentration, Zona da Mata showed the highest average (p <0.05) 0.165 mg L^{-1} $N\text{-}NH_4$ (Figure 5 G). While for phosphate content, Centro-Leste and Rio Mamoré showed the highest averages (p <0.05) 1.36 and 1.49, respectively (Figure 5 H). Regarding phosphorus content, Rio Mamoré showed the highest average (p <0.05) 1.15 P (Figure 5 I). As for alkalinity, Vale do Guaporé, and Zona da Mata showed the highest averages (p <0.05) 44.76 and 43.4 (mg L^{-1} $CaCO_3$, respectively (Figure 5 J). And finally, regarding hardness, Zona da Mata and Centro-Leste showed the highest averages (p <0.05) 47.15 and 41.93 mg L^{-1} $CaCO_3$, respectively (Figure 5 K).

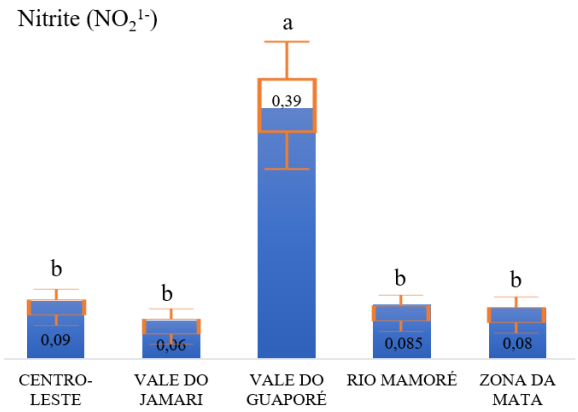


(E)



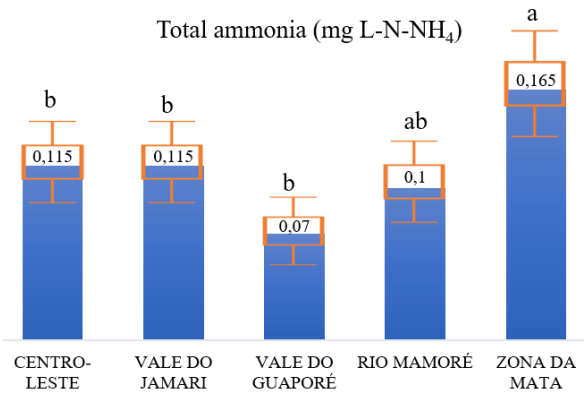
p =0.018

(F)



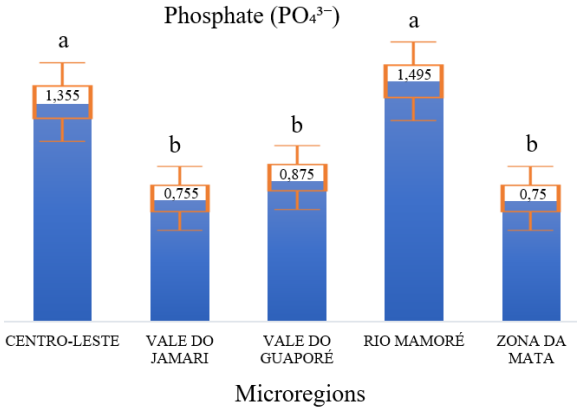
p =0.044

(G)



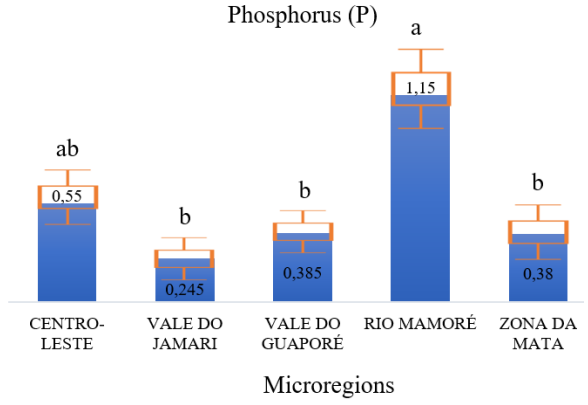
p =0.027

(H)



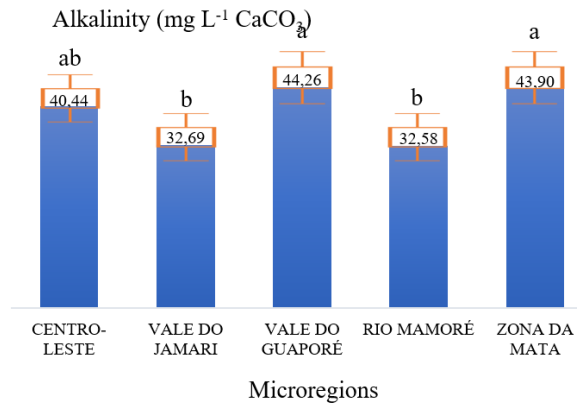
p =0.035

(I)



p =0.019

(J)



p =0.030

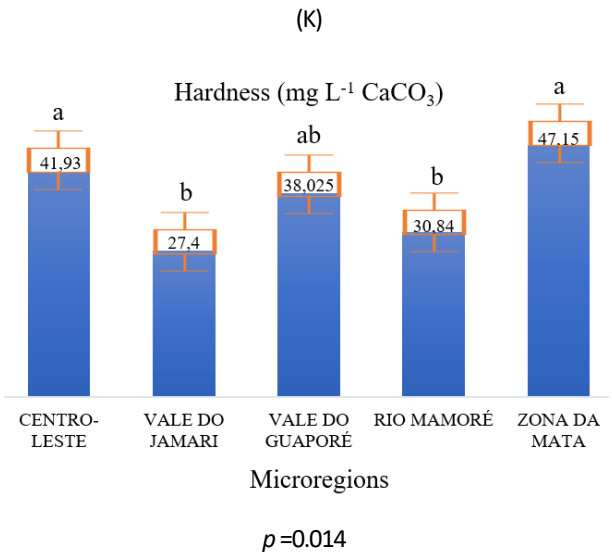


Figure 5. Graphical representation of the comparison of the average physicochemical parameters of water from family fish farms by microregions in the Rondônia state, (A) temperature, (B) pH, (C) dissolved oxygen, (D) transparency, (E) nitrate, (F) nitrite, (G) total ammonia, (H) phosphate, (I) phosphorus, (K) alkalinity and (K) water hardness. Legend: if there were different letters, find the microregions, it is because they are different according to the Tukey's test (p <0.05).

Sanitary characterization

In relation to the average fish mortality, 39.11 ± 8.99% in the Centro-Leste, 22.47 ± 6.29% in the Vale do Jamari, 62.84 ± 7.12% in the Vale do Guaporé, 30, 00 ± 10.00% in the Rio Mamoré, and 6.51 ± 3.09% in Zona da Mata. Regarding biometrics, the frequencies were, in the Centro-Leste, 33% did not do it, 29.17% did it twice a year, 25% did it once a year and 20.83% did it 3x a year. In Vale do Jamari, 7.14% did not do it, 42.86% did it 4x a year, 35.71% did it 1x a year, 7.14% did it 2x a year, and 7.14% did it 3x a year. In Vale do Guaporé, 84% do not do it and 16% do it once a year. In Rio Mamoré, 60% do not do it, 30% do it once a year and 10% do it twice a year. And finally, in Zona da Mata 29% did not do it, 28% did it twice a year, 22% did it once a year, 7.5% did it 12x a year, 5.6% did it 3x a year, 3.7% did it 6x per year and 4.2% other frequencies (Figure 6).

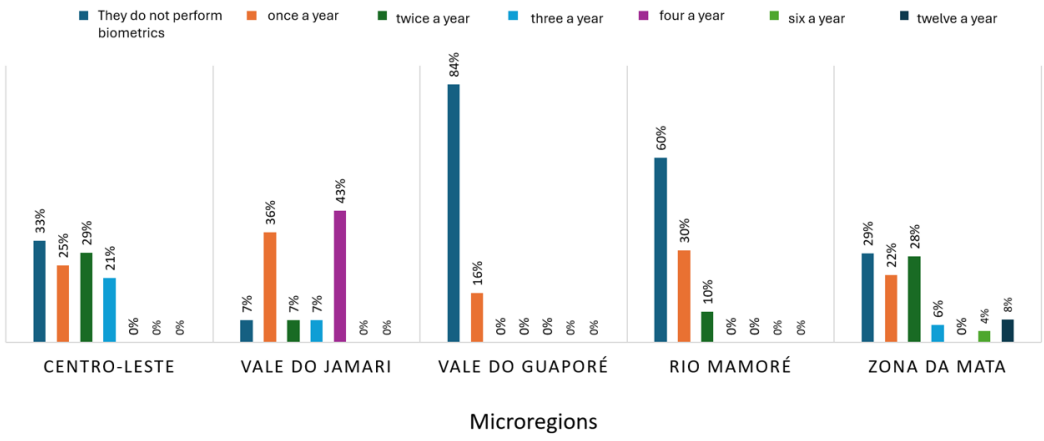


Figure 6. Frequencies of biometrics performed by family fish farms by microregions in the Rondônia state, Brazil.

Fish farmers reported on conducting chemical treatments in the fishponds (Figure 7). In Centro-Leste, 48% of fish farms did not conduct any treatments. Among the 52% that admitted to conducting these treatments, 64% apply antibiotics, 4% antiparasitics, 4% antifungals, and 28% others. In Vale do Jamari, 40% of fish farms did not conduct chemical treatments in the fishponds. Among the 60% that admitted to conducting these treatments, 60% applied antibiotics, 26% antiparasitics, 6% antifungals, and 8% others. In Vale do Guaporé, 84% of fish farms did not conduct any treatments. Among the 16% that admitted to conducting these treatments, all applied herbicides. In Rio Mamoré, 60% of fish farms do not conduct chemical treatments. Among the 40% that do, 60% apply herbicides and 40% antiparasitics. And, in Zona da Mata, 15% of fish farms did not conduct chemical treatments in the fish ponds. Among the 85% that admitted to conducting these treatments, 70% applied antiparasitics, 10% applied antibiotics, and 20% others.

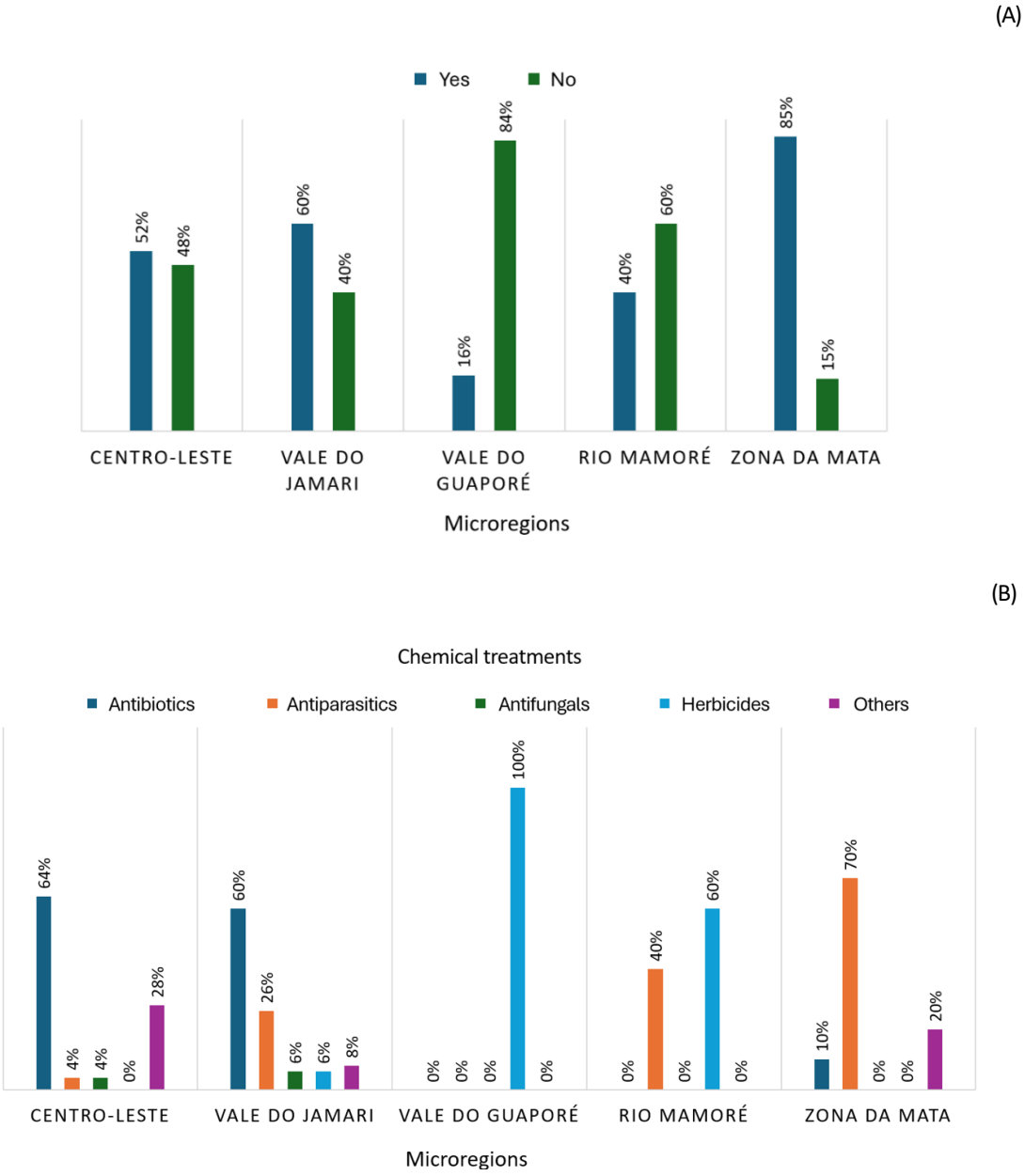


Figure 7. Chemical treatments carried out by family fish farms in the microregions of Rondônia state, (A) applied and not applied and (B) the chemicals applied.

The conditions regarding quarantine upon receiving new fish in the grow-out fishponds and acclimatization of post-larvae in the nurseries were observed (Figure 8). In Centro-Leste, 75% did not conduct quarantine upon receiving new fish, although only 8% did not acclimatize the post-larvae in the nurseries. In Vale do Jamari, 85.70% did not conduct quarantine upon receiving new fish, although only 20% did not acclimatize the post-larvae. In Vale do Guaporé, 100% did not conduct quarantine upon receiving new fish and did not acclimatize the post-larvae. In Rio Mamoré, 100% did not conduct quarantine upon receiving new fish, although 30% acclimatized the post-larvae. In Zona da Mata, 80% did not conduct quarantine upon receiving new fish, although only 29% did not acclimatize the post-larvae in the nurseries.

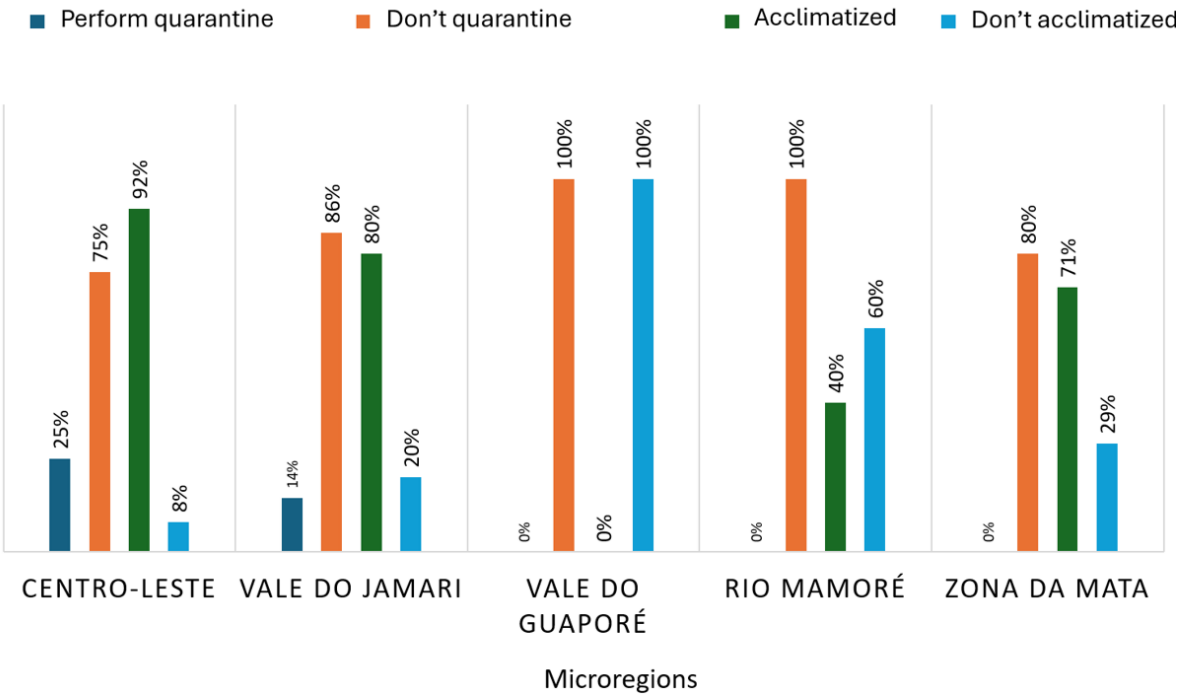


Figure 8. Carrying out quarantine when receiving new fish in the fattening ponds and acclimatization of post-larvae in the nurseries.

A large portion of fish farmers reported not implementing the sanitary break after completing the production cycle: 23.08% in Centro-Leste, 46.67% in Vale do Jamari, 84% in Vale do Guaporé, 60% in Rio Mamoré, and 46% in Zona da Mata. They also admitted not practicing species rotation, which would help inhibit parasitic infestations. These percentages were 84% in Centro-Leste, 93% in Vale do Jamari, 100% in Vale do Guaporé, 70% in Rio Mamoré, and 39% in Zona da Mata.

As for liming procedures, in Centro-Leste, 21.74% did not perform it, and among those who did, the majority applied it twice a year. In Vale do Jamari, 26.67% did not perform it, and among those who did, the majority applied it twice a year. In Vale do Guaporé, 50% did not perform it, and among those who did, the majority applied it once a year. In Rio Mamoré, 50% did not perform it, and among those who did, the majority applied it once a year. In Zona da Mata, 29% did not perform it, and among the 71% who did, the majority applied it twice a year.

Figure 9 provides information on water quality monitoring. In Centro-Leste, 12.5% did not perform it, 70.83% did it occasionally, 12.5% did it monthly, and 4.17% did it weekly. In Vale do Jamari, 6.67% did not perform it, 53.33% did it occasionally, 26.67% did it monthly, and 13.33% did it weekly. In Vale do Guaporé, 75% did not perform it, 16% did it occasionally, and 9% did it monthly. In Rio Mamoré, 50% did not perform it, 30% did it occasionally, 10% did it monthly, and 10% did it weekly. And in Zona da Mata, 31.5% did not perform it, 25% did it occasionally, 22% did it monthly, and 21.5% did it weekly.

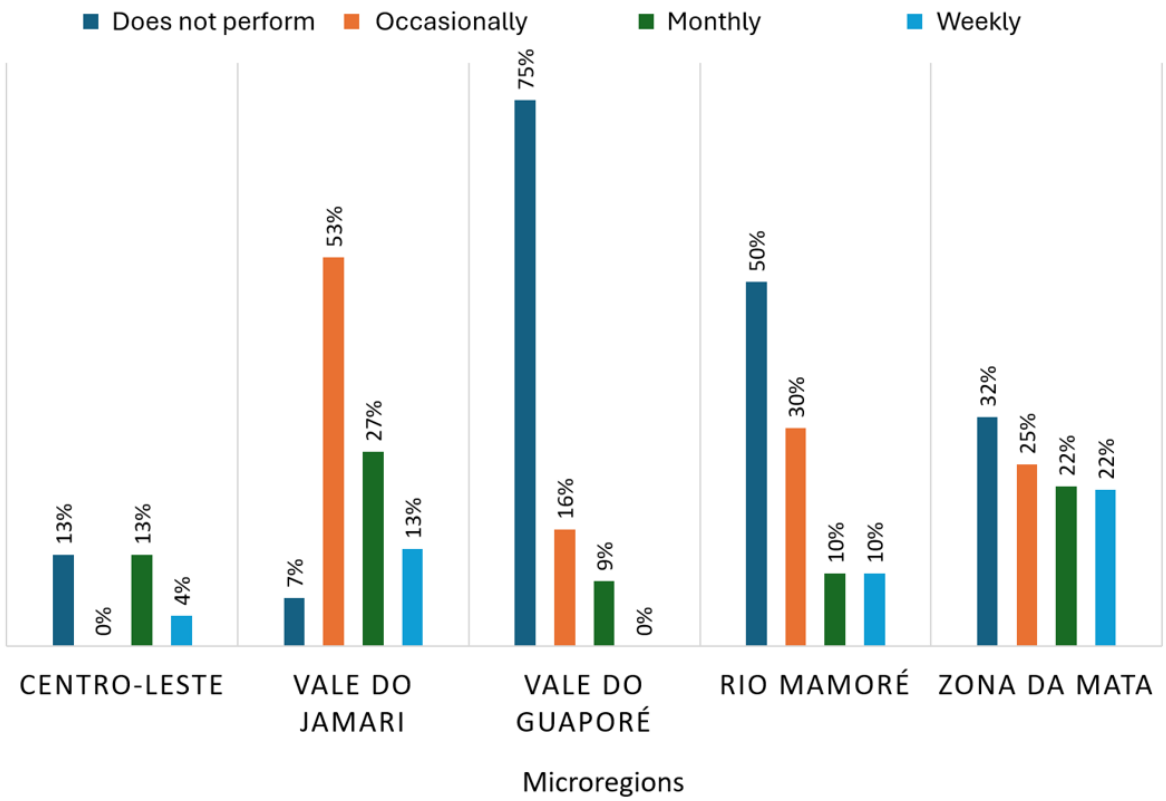


Figure 9. Frequencies of water quality monitoring by family fish farms by microregions in the Rondônia state, Brazil.

Regarding the performance of prophylactic baths and the products applied (Figure 10). In Centro-Leste, 45.83% did not perform them, although among those who did, 43.48% applied Formalin, 14.29% applied Copper Sulfate, 10.69% applied Sodium Chloride, 4.62% applied Creolin, and 26.92% applied only salt. In Vale do Jamari, 31.25% did not perform them, although among those who did, 37.50% applied Sodium Chloride, 25% Formalin, 15% applied only salt, 11% Neguvon, 6.25% Potassium Permanganate, and 16.25% others. In Vale do Guaporé, 100% did not perform them. In Rio Mamoré, 80% did not apply them, although among the 20% who did, 50% applied Copper Sulfate and 50% applied only salt. In Zona da Mata, 55% did not perform them, but among the 35% who applied them, 40% applied Copper Sulfate, 29% applied Sodium Chloride, and 31% others.

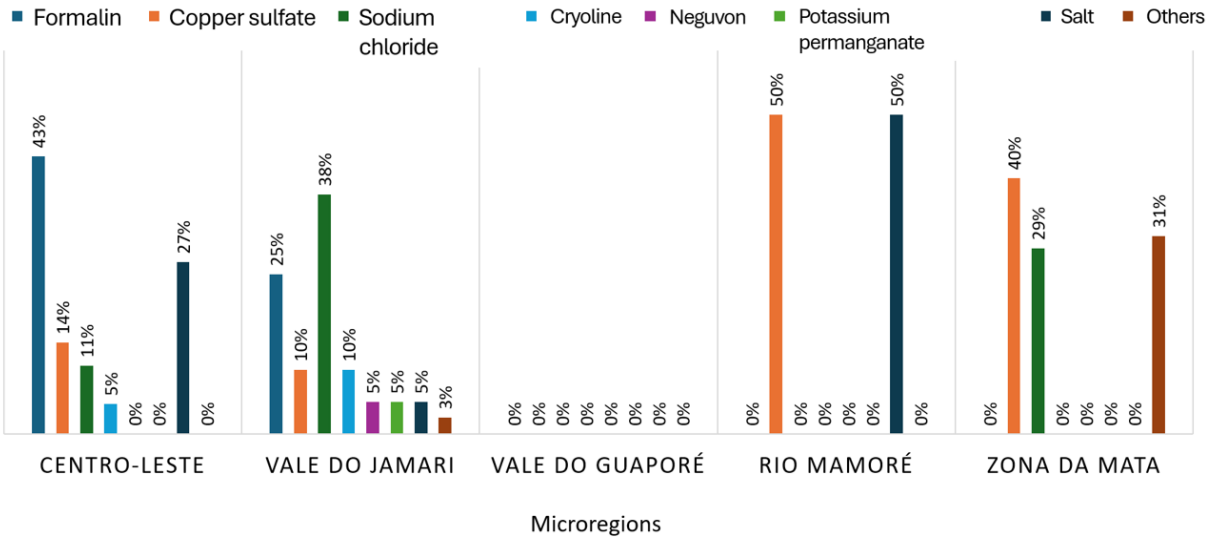


Figure 10. Frequencies of prophylactic baths and which products were applied by family fish farms in the microregions of Rondônia state.

Regarding the control of weeds and aquatic macrophytes, the producers' responses can be observed in Figure 11. In Centro-Leste, 42.31% did not carry out any control. Among the 57.69% that did, 89.47% applied Glyphosate and 10.53% only performed slope mowing. In Vale do Jamari, 33.33% did not carry out any control. Among the 66.67% that did, 95% applied Glyphosate and 5% applied 2,4-D. In Vale do Guaporé, 75% did not apply Glacial herbicide. In Rio Mamoré, 60% did not carry out any control. Among the 40% that did, 50% applied Glyphosate and 50% only performed slope mowing. And, in Zona da Mata, 46.3% did not carry out any control. Among the 53.7% that did, 91% applied Glyphosate and 9% only performed slope weeding in the pond banks.

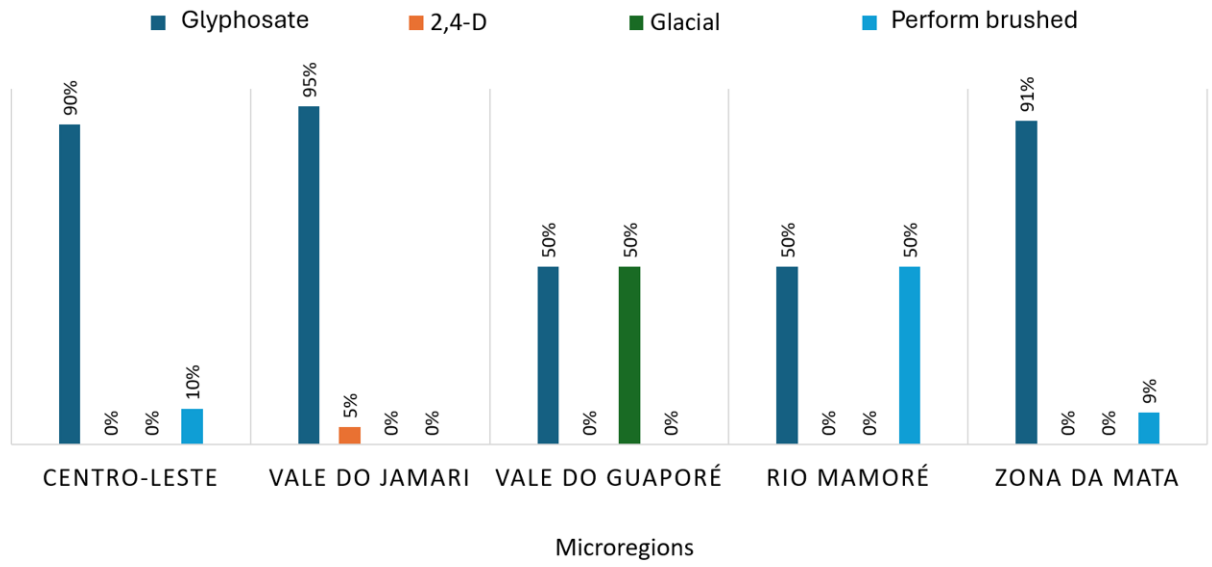


Figure 11. Control of weeds and aquatic macrophytes by family fish farms in the microregions of Rondônia state.

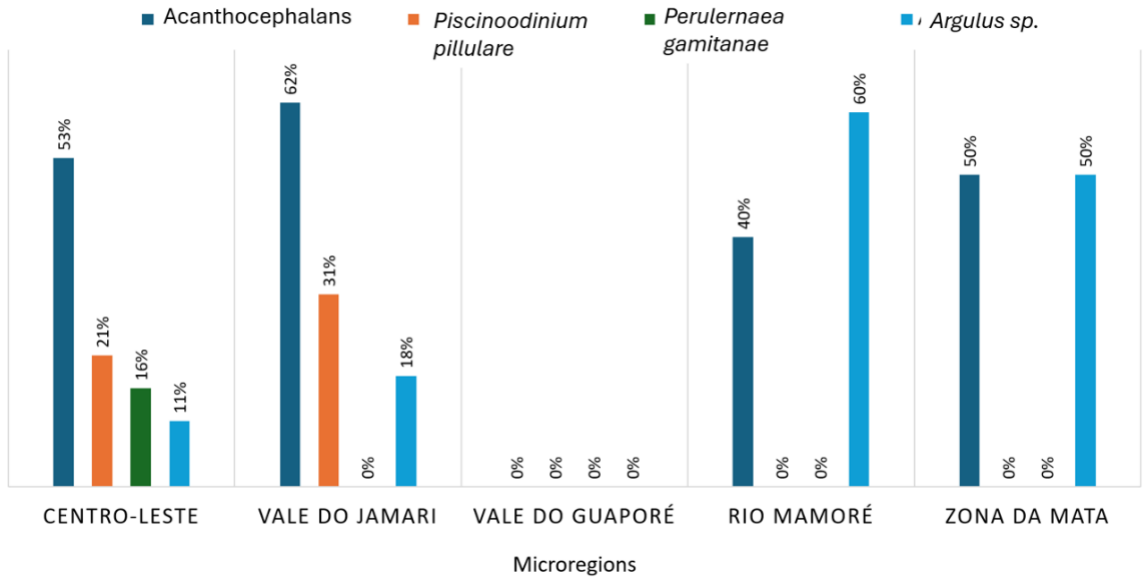
Reports of recent parasitic infestations are showed: 22.73% reported in Centro-Leste, 100% reported in Vale do Jamari, 0% reported in Vale do Guaporé, 40%

reported in Rio Mamoré, and 7.4% reported in Zona da Mata. The perception of fish farmers about the frequencies of parasites is summarized in Figure 12 (A). In Centro-Leste, 52.63% reported Acanthocephalans, 21.05% *Piscinoodinium pillulare*, 15.79% *Perulernaea gamitanae*, and 10.53% *Argulus sp*. In Vale do Jamari, 61.54% reported Acanthocephalans, 30.77% *P. pillulare*, and 17.69% *Argulus sp*. There were no reports in Vale do Guaporé, although in Rio Mamoré, 50% reported Acanthocephalans and 50% *Argulus sp*. And, in Zona da Mata, 50% reported *Argulus sp*., and 50% reported Acanthocephalans.

Figure 12 (B) shows the frequencies of parasitic infestations according to the time of year. In Centro-Leste, 20.83% did not know how to respond, 30.83% from March to May, 23.33% from August to November, 16.67% from May to August, and 8.34% from November to March. In Vale do Jamari, 50% did not know how to respond, 21.43% from November to March, 7.14% from March to May, 7.14% from May to August, and 7.14% from August to November. There were no reports in Vale do Guaporé, although in Rio Mamoré, 30% did not know how to respond, 50% from March to May, and 20% from November to March. And, in Zona da Mata, fish farmers were unable to specify the time of year when parasitic infestations occurred.

Regarding the developmental stage of the parasitized fish, the data is shown in Figure 12 (C). In Centro-Leste, 20% did not know how to respond, 40% were adults, 36% were juveniles, and 4% were post-larvae. In Vale do Jamari, 14.28% did not know how to respond, 50.01% were adults, 21.43% were juveniles, and 14.28% were post-larvae. There were no reports in Vale do Guaporé, although in Rio Mamoré, 50% did not know how to respond, 30% were adults, and 20% were juveniles. And, in Zona da Mata, 20% did not know how to respond, and 80% reported adults.

(A)



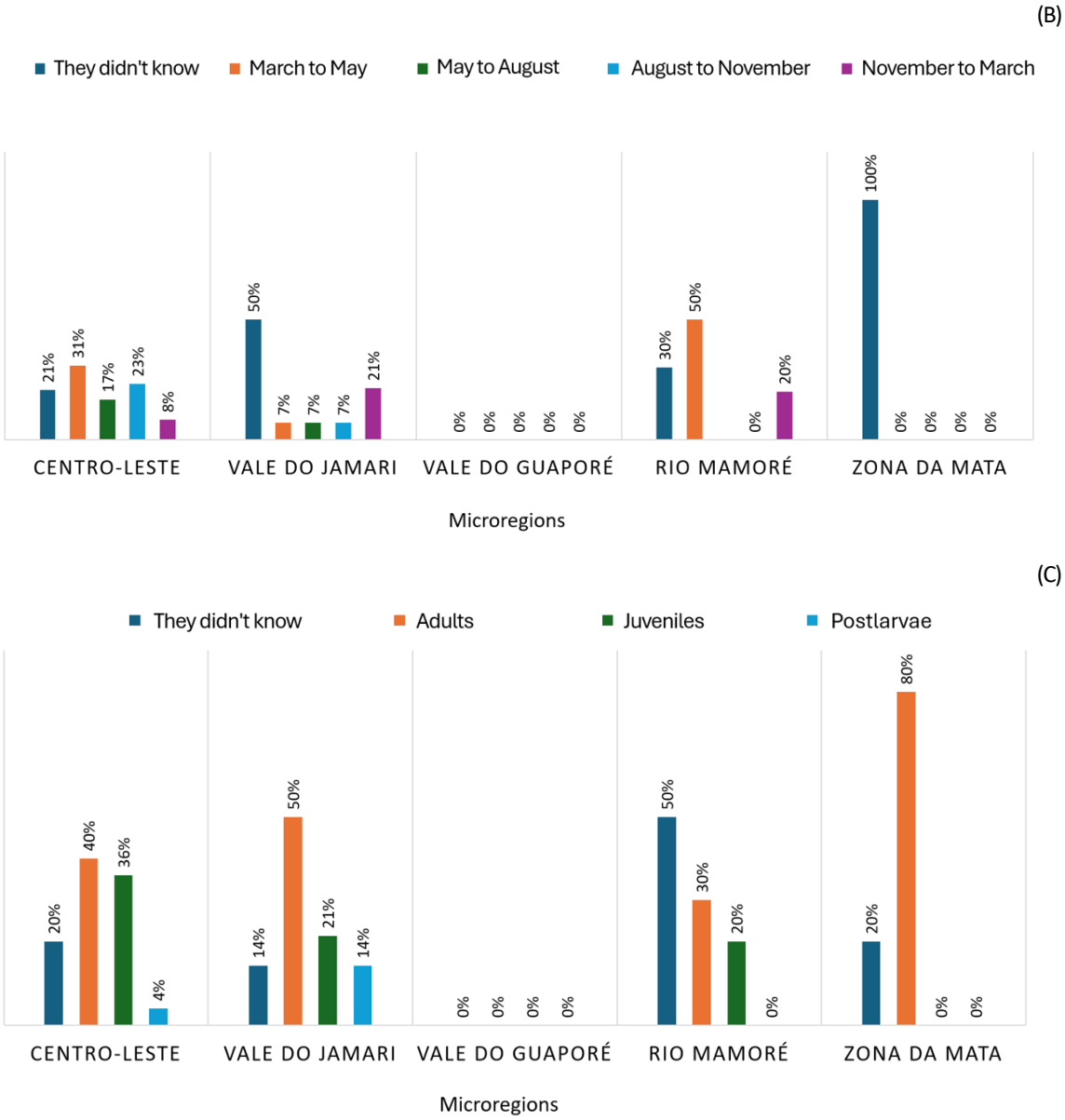


Figure 12. Parasitic indices in the perception of family fish farmers in the microregions of Rondônia state, (A) reports of parasitic infestations, (B) parasite frequencies, (C) parasitic infestations according to the period of the year and (D) fish farming phases parasitized.

In Figure 13, frequencies of the use of antiparasitic medications for fish and which medications were applied can be observed. In Centro-Leste, 40% did not apply, 45% applied once per cycle, 10% only when infestations occur, and 5% applied twice per cycle. Accordingly, the most applied veterinary medications were as follows: 19.23% did not use any, 23.08% used Albendazole, 19.23% Levamisole, 11.54% Triclosil, 7.69% Pan10, 3.85% Ivermectin, 3.85% Trichlorfon, 3.85% Ripecol, 3.85% Paraquat, and 3.85% used Creolin. In Vale do Jamari, 63.63% did not apply, 18% applied twice per cycle, 12% applied once per cycle, and 6.37% applied only when infestations occur.

Accordingly, the most applied veterinary medications were as follows: 56.25% did not use any, 12.5% used Trichlorfon, 12.5% Levamisole, 6.25% Albendazole, 6.25% Neguvon, and 6.25% Medendazole. In Rio Mamoré, 90% did not apply, and

10% applied only during parasitic infestations, and 100% applied Levamisole. In Zona da Mata, 33.5% did not apply, 48% applied once per cycle, 11% only when infestations occur, and 7.5% applied twice per cycle. Accordingly, the most applied veterinary medications were as follows: 46.3% Trichlorfon, 37% Chlorpyrifos, and 16.7% Epoxiconazole.

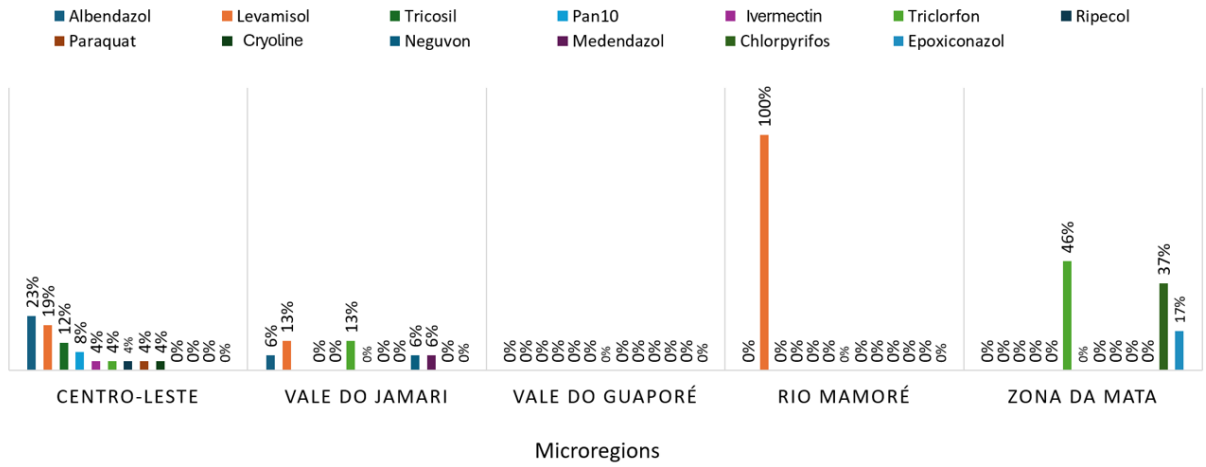


Figure 13. Frequencies of use of antiparasitics for fish and veterinary medicines applied by family fish farms by microregions of the Rondônia state.

DISCUSSION

Analyzing the presented data critically, it is possible to identify a central contradiction that defines the challenges of fish farming in Rondônia: the compliance of physicochemical water parameters with recommended limits masks a series of socioeconomic and sanitary vulnerabilities that threaten the sustainability of the activity.

Although water quality parameters are within adequate limits for the farming of tropical fish (BEZERRA NETO et al. 2023, CAVALI et al. 2020), the significant variation among microregions reveals a critical and potentially risky dependence on local water bodies. The fact that 90% of ponds are built in riverbeds or use their water directly exposes production to the environmental quality of these rivers, which is drastically unequal. While the Guaporé River has a low pollution load (CANELA et al. 2024), the Machado River is the largest sink for agricultural, industrial, and domestic effluents in the state (LOPES et al. 2022). This dependence makes aquaculture vulnerable to external environmental impacts, over which the producer has no control, contradicting the apparent stability of water quality in the ponds.

From a socioeconomic perspective, the analysis reveals a fragile sector with serious obstacles to its professionalization. The profile of the producer, with a high average age (above 52.9 years) and a lack of interest from younger generations (ESTANISLAU et al. 2021), points to a problem of rural succession. The activity is seen as risky due to market fluctuations and the high cost of inputs (PRAXEDES et al. 2021, FERREIRA et al. 2021), with feed representing a primary obstacle for 59.6% of fish farmers (SOUSA et al. 2020). The complaint about the price of feed is justifiable, as inputs came to represent over 81% of the production cost during the pandemic (MARTINS et al. 2020), creating an economic imbalance that makes operations

unfeasible on a scale larger than subsistence. The average monthly family income, which ranges from R$ 2,172.00 to R$ 4,072.88 (SOUSA et al. 2020), is unstable, as evidenced by a 55% reduction during the health crisis (MARTINS et al. 2020). This financial precariousness, combined with the almost non-existent access to rural credit—a problem also seen in Maranhão, where 94% of producers never had access (LOPES et al. 2020)—prevents investments in technology and good management practices, perpetuating a cycle of low productivity and abandonment of the activity.

Economic fragility has a direct and critical impact on fish health. The inability to invest in adequate infrastructure and management results in precarious sanitary conditions, facilitating the spread of parasites. The high prevalence rates of acanthocephalans (72 tambaquis from 32 farms), Piscinoodinium pillulare (42 tambaquis from 14 farms), and Perulernaea gamitanae (ADRIANO et al. 2023) are symptoms of deficient sanitary management. The recurrent application of antiparasitics such as Trichlorfon and Albendazole (PEDROTI et al. 2024; PEDROTI et al. 2025) appears to be a palliative measure, adopted in the absence of robust preventive strategies, such as quarantining fingerlings, sanitary emptying of ponds, and constant monitoring (LUCENA et al. 2023, NASCIMENTO et al. 2020). The study by JERÔNIMO et al. (2022), which reported 100% prevalence of Neoechinorhynchus buttnerae without mortality, may create a false sense of security, masking economic losses from reduced performance and carcass condemnation.

Therefore, based on the critical analysis, it is possible to conclude that the data indicate that fish farming in Rondônia operates in a precarious balance. Water quality, although currently within parameters, is a positive factor that is immediately neutralized by economic, generational, and sanitary vulnerabilities. The activity remains a family-based source of supplementary income but lacks effective public policies that address its central bottlenecks: access to credit, technical assistance for preventive sanitary management, and the development of value-adding commercialization chains that reduce dependence on intermediaries. Without overcoming these critical deficiencies, fish farming will remain vulnerable to crises and incapable of reaching its full socioeconomic and productive potential in a sustainable manner

CONCLUSION

Water quality varied significantly between microregions due to differences in the physicochemical and microbiological characteristics of the water bodies, as well as varying levels of routine control and monitoring. Fish farms used a semi-intensive system, with fish raised in semi-excavated fishponds, most of which were built on riverbeds in low-lying terrain.

All water quality parameters remained suitable for tropical fish farming. The Vale do Jamari and Centro-Leste microregions are the most prominent for fish production in Rondônia, including within family aquaculture. Nearly all farms were commercially active, though over half operated below 50% capacity. Two-thirds sold only within their local domestic market. Their main products were whole fresh fish and frozen eviscerated fish. In addition to tambaqui, other species included pirarucu, matrinxã, pintado, tambatinga, pirapitinga, and jatuarana. Aquaculture provided supplemental income to cattle ranching and crop farming.

Overall, family aquaculture in rural Rondônia is rustic and low-productivity, particularly in the Vale do Guaporé and Rio Mamoré microregions. Key challenges include adopting good sanitary and biosafety practices and preventing the unregulated use of harmful chemicals. Awareness programs and technological support are essential to promote sustainable practices, prevent diseases, and reduce discouragement among farmers. Competent authorities must disseminate and encourage the adoption of these management practices.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, and formal analysis, DGG, BLTS, VPP and CMMLP; software and validation, JVDF; investigation, BLTS, VPP, and MMLP; resources and data curation, MFR, and PHGG; writing-original draft preparation, mfr, phgg, AND JVDF; writing-review and editing, JVDF, and SVS; visualization, and supervision, JVDF, and SVS; project administration, SVS; funding acquisition, JVDF. All authors have read and agreed to the published version of the manuscript.

FUNDING

- PROAQUA - Programa de Apoio ao Desenvolvimento de Aquicultura MPA/SNPI/SNA • UNIR • SENAR/FAPERON EMATER FUNDAPE.
- The research was supported by National Council for Scientific and Technological Development (CNPq) through by Foundation for the Support of the Development of Scientific, Technological, and Research Actions in the State of Rondônia (FAPERO), awarded a postdoctoral scholarship to Jerônimo Vieira Dantas Filho [167879/2022-7].

INFORMED CONSENT STATEMENT

For the development of interviews with managers of fish processing units, the study was authorized by the Research Ethics Committee (CEP) of UNIR, under authorization protocol CAAE No. 60744322.5.0000.5300 and certificate No. 077412/2022 (Annex B) – Project “Sanitary Characterization of Fish Farming in Rondônia.”

DATA AVAILABILITY STATEMENT

The data can be made available under request.

ACKNOWLEDGEMENTS

Acknowledgments for the technical and financial support from PROAQUA - Programa de Apoio ao Desenvolvimento de Aquicultura MPA/SNPI/SNA • UNIR • SENAR/FAPERON EMATER FUNDAPE.

CONFLICTS OF INTEREST

The author declares there is no conflict of interest.

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