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AMAZONIAN ORNAMENTAL FISH: *Diversity Reproduction and Commercial Applications*

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Presentation

The Amazon River basin is one of the richest and most diverse aquatic ecosystems on Earth, home to an impressive diversity of fish with enormous variation in size and color patterns that attract scientists, aquaculturists, exporters, and lovers of Amazonian ichthyofauna. This Neotropical basin has around 3,000 species of freshwater fish of ecological and economic importance to countless populations in this vast region, of which more than 400 species are ornamental fish.

The fishing of ornamental fish from the Amazon Basin is an important activity for the economy of various riverside populations, mainly in Brazil, Colombia, and Peru, who survive by catching various species for export. In Brazil, it has been estimated that the ornamental fish trade began with freshwater species from the Amazon region, coinciding with the discovery of the cardinal *Paracheirodom axelrodi*. Despite its importance, this extractive activity faces major challenges, such as the need for more sustainable management. Thus, the cultivation of Amazonian ornamental fish species can help solve these problems, in addition to offering direct and indirect employment opportunities for thousands of people in the Amazon. However, there are still some obstacles to the growth of ornamental fish aquaculture, such as a lack of knowledge about the current market and various aspects related to the management of Amazonian ornamental fish in intensive cultivation.

The publication addresses important aspects for the development of intensive farming activities for ornamental fish species from the Amazon, covering the main species and their reproductive aspects, genetics, legal and conservation aspects, marketing, management, and problems related to the main frequent diseases. Therefore, this work is of great relevance to freshwater ornamental fish aquaculture, serving as a reference for those interested in producing Amazonian fish, a growing demand in this professional activity, as well as for those interested in deepening their knowledge of fish species that attract so much international interest.

This publication highlights the knowledge and experiences of various collaborators from the Federal University of Santa Catarina (UFSC) in aquaculture, who have compiled studies from the literature on the fascinating knowledge of Amazonian ornamental fish farming. It has been organized by researchers with expertise in the field of ornamental fish aquaculture, as well as in the structuring of books aimed at different audiences.

Dr. Marcos Tavares-Dias
Researcher A
Embrapa Amapá

Summary

CHAPTER 1

AMAZON BASIN AND ORNAMENTAL FISH

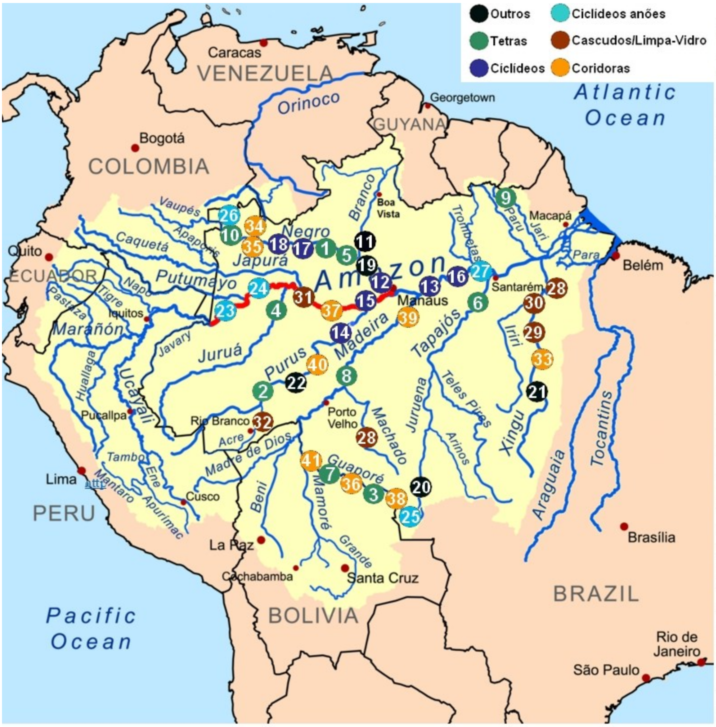
The Amazon Basin is one of the most biodiverse regions on the planet, home to an impressive variety of aquatic species, many of them endemic and of high ecological, cultural, and economic value. It is estimated that its more than seven million square kilometers harbor around three thousand fish species, of which over two thousand have already been scientifically described (Queiroz et al., 2013; Dagosta and De Pinna, 2019). This biological richness is not only due to the vastness of the basin, but also to the diversity of aquatic environments such as rivers, streams, lakes, floodplains, and blackwater areas as well as the complex hydrological regime marked by the annual flood and drought cycles.

The Amazon River, the basin's main watercourse, has over a thousand tributaries some of which are also among the largest rivers in the world forming a vast hydrographic network that connects different habitats throughout the year (Stacciarini and Feldmann, 2020). This hydrological dynamic directly influences the ecological and evolutionary patterns of aquatic species, especially ornamental fish (Figure 1). During the flood season, rivers overflow and connect lagoons and floodplains, allowing fish dispersal, access to new food resources, and reproductive activity. In the dry season, these environments become isolated, favoring endogamy and the emergence of endemic populations with specific adaptations (Hurd et al., 2016; Dagosta and De Pinna, 2019).

In addition to hydrology, factors such as watercolor, transparency, conductivity, and river width also shape species distribution. Studies conducted in the Matapi River have shown that fish community composition is strongly associated with these environmental variables (Silva et al., 2022).

The fish occupy different ecological niches and perform various roles in the food web from predators to detritivores and frugivores. The latter group plays a particularly important role in forest regeneration, as some species are seed dispersers that contribute to the maintenance of floodplain forests (Junk et al., 2010; Anderson et al., 2011).

The unique beauty of Amazonian species with vibrant colors, peculiar behaviors, and remarkable adaptations attracts aquarists worldwide, positioning Brazil as one of the leading global suppliers of Amazon fish. The Amazon ornamental fish sector remains an important source of income for traditional communities, especially in the states of Amazonas and Pará, which are responsible for over 90% of Brazil's ornamental fish exportation. Brazil exports about 20 million freshwater ornamental fish each year, generating an estimated revenue of US$4 million (Rezende and Fujimoto, 2021; Santos, 2023).



1 - *Paracheirodon axelrodi*[1]
2 - *Paracheirodon innesi*[1]
3 - *Hyphessobrycon eques*[3]
4 - *Hyphessobrycon erythrostigma*[2]
5 - *Petitella rhodostoma*[1]
6 - *Hyphessobrycon pulchripinnis*[1]
7 - *Hyphessobrycon megalopterus*[1]
8 - *Hyphessobrycon sweglesi*[1]
9 - *Pristella maxillaris*[1]
10 - *Tucanoichthys tucano*[1]
11 - *Carnegiella strigata*[2]
12 - *Symphysodon discus*[1]
13 - *Symphysodon aequifasciatus*[1]
14 - *Symphysodon tarzoo*[1]
15 - *Pterophyllum scalare*[2]
16 - *Astronotus ocellatus*[2]
17 - *Hoplarchus psittacus*[1]
18 - *Heros severus*[1]
19 - *Osteoglossum bicirrhosum*[2]
20 - *Metynnis maculatus*[3]
21 - *Potamotrygon leopoldi*[1]
22 - *Potamotrygon motoro*[3]
23- *Apistogramma cacatuoides*[1]
24 - *Apistogramma agassizii*[1]
25 - *Apistogramma trifasciata*[3]
26 - *Apistogramma elizabethae*[1]
27 - *Apistogramma regani*[2]
28 - *Baryancistrus xanthellus*[1]
29 - *Hypancistrus zebra*[1]
30 - *Peckoltia vittata*[2]
31 - *Pterygoplichthys pardalis*[2]
32 - *Otocinclus vittatus*[3]
33 - *Corydoras elegans*[2]
34 - *Corydoras adolfoi*[1]
35 - *Corydoras tukano*[1]
36 - *Corydoras caudimaculatus*[1]
37 - *Corydoras eques*[2]
38 - *Corydoras guapore*[1]
39 - *Corydoras hastatus*[3]
40 - *Corydoras schwartzi*[1]
41 - *Corydoras sterbai*[1]

Figure 1. Map of the natural distribution of several popular ornamental fish species in the Brazilian Amazon basin. Map of the Amazon basin taken from Bermann et al. (2010). Red line indicates course known as the Solimões River within Brazilian territory. Species distribution map based on occurrence data obtained from the Fishbase and Specieslink databases. Widely distributed species have been positioned on the map in the region with the most frequent occurrence records within the Amazon basin in Brazil. The superscript numbers indicate: [1]- Species endemic to the region indicated; [2]- Species with a wide distribution in the Amazon basin and [3]- Species with a natural occurrence in other river basins in Brazil.

However, this biodiversity faces growing threats. Climate change has caused extreme events such as prolonged droughts and intense flooding, significantly altering the reproductive behavior of species. Röpke et al. (2022) demonstrated that such changes could reduce the proportion of mature females and the size of individuals, affecting population recruitment. In addition, habitat degradation due to human activities such as deforestation, mining, dam construction, and water pollution has worsened environmental conditions and increased the risk of local extinctions.

In this context, local ecological knowledge is fundamental. Experienced riverine man and fishers hold valuable informations on reproductive cycles, feeding habits, and migratory behavior of ornamental species. This traditional knowledge could be integrated into sustainable management programs, contributing to more efficient and locally adapted practices (Ladislau et al., 2021). At the same time, scientific research has expanded our understanding of the biology and ecology of these species, enabling the development of captive breeding strategies and genetic improvement programs to promote conservation and to supply the national and international markets.

The sustainable use of ornamental fish depends on integrated actions, including the strengthening of environmental legislation, combatting illegal fishing, promoting community-based management, and investing in captivity technology. The combination of biodiversity conservation with income generation for traditional populations is achievable, but it requires planning, continuous monitoring, and coordination between different sectors of society.

Thus, to understand the rivers of the Amazon is to understand the ecological and physiological needs of the ornamental fish that inhabit them. This knowledge is essential not only for aquarists and researchers, but also for policymakers, entrepreneurs, and local communities. In the following chapters, we will address the legal aspects of the activity, the challenges to its sustainability, and the alternatives for captive breeding and conservation strategies, breeding technics and handling, being a key to ensuring that these species continue to thrive in the Amazon's waters and aquariums around the world.

CHAPTER 2

CONSERVATION AND SUSTAINABLE USE OF THE AMAZONIAN ORNAMENTAL FISH

The conservation of Amazonian ornamental fish species with high commercial value represents a significant challenge, deeply rooted in a historical and cultural conflict. This conflict is expressed through a dichotomous view: on one hand, fish are understood as economic and food resources; on the other, as wildlife subject to protection and conservation policies (Martins; Dias; Cazella, 2015). In practice, many species simultaneously occupy these two categories, being both fauna and fishery resources with strong social, economic, and cultural relevance (Polaz, 2019).

In Brazil, the legal framework regulating the breeding and commercialization of Amazonian species is complex and primarily aims at biodiversity conservation and combating illegal exploitation practices. Various laws and regulations make up this framework, such as Law No. 5,197/1967, which establishes wildlife protection, and Law No. 9,605/1998, which provides criminal and administrative sanctions for environmental damages. CONAMA Resolution No. 394 and IBAMA Normative Instruction No. 7/2015 regulate technical procedures for handling and commercial breeding of wild animals, while Complementary Law No. 140/2011 addresses cooperation between federal entities in environmental inspection and licensing (IBAMA, 2019). These legal documents provide the legality, traceability, and sustainability of ornamental fish production chains in the country.

The Amazonian ornamental fish market is broad and diverse, with species such as characins *Paracheirodon axelrodi* and *P. innesi*, cichlids like *Symphysodon* spp., *Pterophyllum scalare*, and *Astronotus ocellatus*, as well as siluriforms including *Corydoras* spp., *Otocinclus* spp., and *Hypostomus* spp., forming the core of production geared toward international trade (Rezende and Fujimoto, 2021).

The collection, reproduction, and commercialization of these species are strictly regulated to ensure sustainable practices and the conservation of aquatic ecosystems. Recent ordinances from the Ministry of the Environment and the Ministry of Fisheries and Aquaculture, such as SAP/MAPA Ordinance No. 17/2021 and MMA Ordinance No. 148/2022, prohibit the capture of several endangered species listed in MMA Ordinance No. 445/2014 and the CITES appendices, except under specific authorizations (BRAZIL, 2021; 2022). Among these are the silver arowana (*Osteoglossum bicirrhosum*), black arowana (*O. ferreirai*), zebra pleco (*Hypancistrus zebra*), and annual killifish species from the Rivulidae family.

Globally, the ornamental fish trade generates approximately US$ 30 billion annually, encompassing marine and freshwater species as well as equipment and supplies (Alam et al., 2024; Peh and Azra, 2025). The majority of this market comprehends 90% of the captive breeding operations, mainly located in Singapore, Japan, Malaysia, and the Czech Republic (Jain; Rane; Sinha, 2025). However, the remaining 10% comes from wild extraction, which remains significant in developing countries like Brazil. Marketing involves a diverse network of intermediaries, specialty shops, and exporters (Evers et al., 2019; Larcombe et al., 2024). In Brazil, the extraction of native species such as cardinal tetra, discus, and angelfish supplies markets in North America, Europe, and Asia (Borges et al., 2022). This reliance on wild capture in Brazil is partly due to the absence of established reproductive protocols for many species (Santos et al., 2023).

Despite concerns about overexploitation, traditional ornamental fishing in the Amazon is recognized as one of the most sustainable extractive activities in the region. This is mainly because of the low-impact methods employed, such as manual and selective collection, which prevent degradation of aquatic habitats (Yamamoto et al., 2021). Unlike activities such as mining or deforestation, ornamental fishing does not require vegetation removal or heavy machinery use (Santos et al., 2023). Additionally, successful participatory management initiatives, such as those by the Mamirauá Institute, demonstrate how local communities could be integrated into conservation strategies through clear collection rules, respect for reproductive periods, and continuous population monitoring (Chao et al., 2001; Torres, 2024).

While ecologically viable and socially just, the predominance of extraction as the main method to obtain ornamental fish necessitates strategies to ensure the activity's sustainability. These strategies include strengthening captive breeding and proper fry management to reduce pressure on wild stocks and maintain ecosystem services (Ribeiro; Marco; Fernandes, 2010). Growing demand for species with distinctive morphological traits also drives ornamental aquaculture, pushing producers to seek fish with varied colors and patterns to diversify their offerings and increase competitiveness (Costa; Mafra; Barbalho, 2024). For effective farming and conservation, it is essential to deepen scientific understanding of the ecology, diet, behavior, and reproductive patterns of these species, both in the wild and in captivity (Silva and Esper, 1991; Matos et al., 2016).

Amazonian ornamental species, although not always dominant in production volume, play a key role economically and ecologically. For many riverine families, capturing and selling species such as *Apistogramma* spp. and *Osteoglossum bicirrhosum* represent important sources of income and employment (Maldonado et al., 2017; Silva Ladislau et al., 2021). On the international stage, high-value species like the silver arowana are in great demand, especially in Asian markets, driving significant export activity that requires specialized breeding and management systems (Ruffino, 2010; Maldonado et al., 2017). The broad diversity of Amazonian species also enriches the aquarium market, catering to both novices and experienced aquarists, with dwarf cichlids from the genus Apistogramma highly prized for their colors and unique behaviors (Pinto; Mourão; Alves, 2015; Leitão et al., 2017).

Ecologically, these species are key components of the region's aquatic ecosystems, contributing to biodiversity maintenance and ecological processes, particularly those related to hydrological cycles and flood dynamics. Their reproductive behaviors and environmental interactions reflect habitat complexity, serving as indicators of aquatic ecosystem health (Leitão et al., 2021; Estivals et al., 2023). Management practices based on local ecological knowledge can align economic uses with conservation goals, promoting balanced resource governance (Silva Ladislau et al., 2021). Sustainable management of these species is also linked to important ecosystem services such as carbon sequestration and habitat preservation, directly influencing climate regulation and environmental quality (Paull; Lee; Tyler, 2024).

Nonetheless, significant challenges remain, including inconsistent fishing policies among Amazonian countries and illegal trade, especially of high-value species. Addressing these obstacles requires adaptive policies informed by scientific and local knowledge that integrate ecological, social, and economic factors, ensuring both conservation and sustainable development of ornamental aquaculture in the Amazon (Gurjão et al., 2017; Tribuzy-Neto et al., 2020; Beltrão et al., 2021).

CHAPTER 3

DIVERSITY AND BIOLOGY OF THE AMAZONIAN ORNAMENTAL FISH

Tetras

Tetras are a popular name given to many small species, primarily from the Characidae family, but also including the Alestidae and Lebiasinidae families (Esguícero and Mendonça, 2023). Characidae tetras are small, colorful, and peaceful freshwater fish highly valued in the ornamental fish trade. They also play a fundamental ecological role in Neotropical habitats. Amazonian species like the Neon Tetra (*Paracheirodon innesi*), Cardinal Tetra (*Paracheirodon axelrodi*), and Serpae Tetra (*Hyphessobrycon eques*) (Figure 3) are particularly significant, both commercially and ecologically (Bittencourt et al., 2020; Esguícero and Mendonça, 2023; Melo et al., 2024) (Figure 2).

Figure 2. Images of *Paracheirodon axelrodi* - 1, *Paracheirodon innesi* - 2, *Hyphessobrycon eques* - 3, *Hyphessobrycon erythrostigma* - 4, *Petitella rhodostoma*

- 5, *Hyphessobrycon pulchripinnis* - 6, *Hyphessobrycon megalopterus* - 7, *Pristella maxillaris* - 8 and *Tucanoichthys Tucano* - 9. Photographs available at FishBase, by Nilsson, Noren, Hoffmann, Prins, Terver and Jensen (https://www.fishbase.se/).

Ecologically, tetras are dominant in Amazonian stream fish assemblages, often comprising up to one-third of the species and individuals recorded in samples. This makes them important indicators of environmental quality (Esguícero and Mendonça, 2023).

While some tetra species occur naturally across almost the entire South American continent, the Rio Negro and its tributaries boast the greatest wealth of tetras, most of which are endemic to this area (Bittencourt et al., 2020). This region, often called the "Black Waters of Central Amazonia," is home to some of the most important species in this group, such as the Rummy-Nose Tetra (*Petitella rhodostoma*, previously *Hemigrammus rhodostomus*) and the Cardinal Tetra (*Paracheirodon axelrodi*) (Dagosta and De Pinna, 2019). The Rio Negro is the world's largest blackwater river, its dark color resulting from high concentrations of humic, fulvic, and tannin substances from the decomposition of organic matter in flooded forests (Santos et al., 1984). These characteristics result in acidic water (pH 4.5 to 6.5), high transparency, low concentrations of mineral salts, and consequently low electrical conductivity and water hardness, with temperatures ranging from 26°C to 30°C (Santos et al., 1984; Adeney and Junk, 2013). These are ideal conditions for maintaining tetras in the Rio Negro basin.

In general, a pH of 6.0-6.3 is suitable for most tetra species, especially those native to black waters. Species from clearwater rivers, such as the Lemon Tetra (*Hyphessobrycon pulchripinnis*), or whitewater rivers, like the Serpae Tetra (*Hyphessobrycon eques*), can generally adapt more easily to pH values closer to neutrality, though they still tend to prefer slightly acidic waters (Furlan-Murari et al., 2022). Finally, some less domesticated species strictly endemic to the upper Rio Negro prefer pH values below 6.0, such as the Tucano Tetra (*Tucanoichthys tucano*), which can adapt very well to pH ranges as acidic as 5.0-5.3 (Géry and Römer, 1997).

Recent advances in taxonomy and phylogeny, driven by molecular and morphological data, have led to the reclassification of the Characidae family, with subdivisions into subfamilies and even distinct families. This provides greater resolution in the phylogenetic relationships between genera and species (Rincón-Camacho et al., 2022). In this context, the genus *Paracheirodon* forms a well-defined monophyletic clade, closely related to the genus *Brittanichthys*, while other genera such as *Petitella* has recently been redefined based on genetic evidence (Rincón et al., 2023). The continuous description of new taxa reflects the constant progress in the taxonomic refinement of the group.

Thus, Amazonian tetras represent not only an ornamental resource of great economic importance but also valuable models for research in ecology, physiology, and conservation of Neotropical aquatic biodiversity (Mirande, 2018; Rincón et al., 2023).

Paracheirodon axelrodi

The Cardinal Tetra (*Paracheirodon axelrodi*), along with *P. innesi* and *P. simulans*, are morphologically similar and often confused. The main difference lies in the arrangement and proportion of their blue and red stripes along the body (Imbiriba, 2010) (Figure 3). The Cardinal Tetra has a continuous red line from tail to head, whereas in *P. innesi*, the red stripe extends only to the middle of the body. Described by Leonard Peter Schultz in 1956, *P. axelrodi* is also known as neon cardinal, or simply cardinal tetra. This species inhabits the acidic, dark waters of the Negro (Brazil) and Orinoco (Venezuela) river basins and regions of northwestern Colombia, where it's common in streams and floodplains (Chao et al., 2001; Pedraza-García et al., 2022; Sanchez-Bernal et al., 2023).

Considered one of the most popular ornamental fish among aquarists, the Cardinal Tetra holds a prominent position in international trade, alongside species such as the Goldfish (*Carassius auratus*), Betta (*Betta splendens*), and Guppy (*Poecilia reticulata*). This notoriety has elevated it to the status of the main freshwater fish exported by the Brazilian industry, accounting for about 70% of national exports (Tribuzy-Neto et al., 2020). Despite its significant market share, *P. axelrodi* export rates fell significantly in 2006 and 2009 due to advances in farming technologies in Asian countries such as Singapore, Indonesia, Malaysia, and Thailand. Furthermore, importing countries like the Czech Republic have developed reproductive protocols for this species (Evers et al., 2019; Rezende and Fujimoto, 2021).

The commercial success of the Cardinal Tetra is partly due to its neon blue stripe running horizontally across the body to the base of the adipose fin and a bright red line extending to the caudal fin (Prada-Pedreros, 1992; Castanho, 2024). The dorsal region has low pigmentation, giving it a translucent appearance. Its body follows the typical morphological pattern of the family, known as “piaba.” The intense coloration of *P. axelrodi* results from the presence of erythrophores, specialized cells with red pigments, important in visual communication and environmental adaptation (Linhares, 2015). The blue lateral stripe is due to guanine crystals in the iridophores, which reflect light, providing effective camouflage against predators (Linhares, 2015).

In nature, *P. axelrodi* forms schools and prefers shallow habitats, up to 50 cm deep, with low currents, abundant shade, and accumulated leaf litter (Geisler and Annibal, 1986). Under these conditions, it explores the entire water column; in deeper locations, it tends to remain in the surface and middle layers. A small species, *P. axelrodi* measures between 3.1 and 5 cm (Imbiriba, 2010), exhibiting positive allometric growth, meaning body mass gain exceeds length increase (Castanho, 2024). Its longevity varies from 12 months to 5 years, with records of individuals living up to 10 years (Castanho, 2024; Bittencourt et al., 2017; Golob, 2019).

The *P. axelrodi* are highly sensitive to variations in limnological parameters like pH and conductivity, and are therefore used as bioindicators in environmental monitoring studies. Physiologically, these fish exhibit specific adaptations to their ecological niche, including behavioral and metabolic responses to temperature changes, which directly influence their feeding activity and the expression of appetite-regulating genes (Bittencourt et al., 2020).

Anatomical studies on key species also reveal specializations in their olfactory and digestive systems, consistent with their predominantly carnivorous diets and distinct ecological habits. This species feeding throughout the water column and its natural diet includes Chironomidae larvae, zooplankton microcrustaceans, eggs and larvae of invertebrates and fish, fruits, leaves, and organic matter (Walker, 2004; Marshall et al., 2008; Rincón et al., 2023).

The Cardinal Tetra exhibits obvious sexual dimorphism: males are smaller, with a narrow, straight belly, and have a hook-shaped modification on the first ray of the anal fin; females are larger and have a bulky belly, especially during the reproductive period (Wootton, 1989). Sexual maturity occurs between eight and nine months, with spawning intervals of 21 to 30 days (Anjos and Anjos, 2006). Females between 28.2 mm and 35.5 mm can produce 154 to 562 oocytes, a number that can increase depending on the size of the fish and environmental conditions (Anjos and Anjos, 2006). In nature, fecundity can vary between 234 and 1,386 oocytes (Rodrigues, 2017).

Paracheirodon innesi

The Neon Tetra (*Paracheirodon innesi*), also known simply as neon or bandeirinha, is a small freshwater fish highly prized in aquariums due to its vibrant coloration and gregarious behavior. Myers described the species in 1936, having been discovered shortly before by Rabaut near Tabatinga, Brazil (Balon, 2004). Belonging to the order Characiformes and the family Characidae, *P. innesi* is native to South America and is found in southeastern Colombia, eastern Peru, and western Brazil, especially in the tributaries of Santa Isabel and Barcelos, both located on the Negro River in the state of Amazonas (Walker, 2004; Rezende and Fujimoto, 2021; Kuhn et al., 2023; Fishbase, 2025). Its natural habitat comprises streams located in flooded forest areas, characterized by shallow waters, low current and shady cover (Geisler and Annibal, 1986; Prada-Pedreros, 1992).

The species is one of the most popular in the global ornamental fish trade (Mirande, 2010; Dey, 2016), highly valued by hobbyists for its beauty and sociability. Although some specimens sold still come from extractive fishing in the Negro River basin, most originate from farming systems in Southeast Asia (Yamamoto et al., 2021; Carvalho et al., 2023). Its body is blue and red in the wild, with an iridescent blue stripe along the side and a silvery-white abdomen. The albino variety has an orange-yellow body with bright red fins and a white lateral stripe, red pupils, and white irises (Kadtan and Shillewar, 2023). During the day, it displays a blue-green lateral stripe, a reddish ventral region, while at night the stripe turns violet, and the red coloration disappears. This iridescence is generated by optical interference in the iridophores, cells whose structure reflects light sensitively (Lythgoe and Shand, 1983; Clothier and Lythgoe, 1987), and is even being investigated as a possible biological matrix for Bragg reflectors (Ryan Sheffield et al., 2024).

The behavior of *P. innesi* is peaceful and gregarious, forming schools both in nature and in aquariums, and is compatible with other species when kept under suitable environmental conditions (Golob, 2025). It is even recommended for beginner aquarists due to its small size, generally between 3 and 6 cm, and ease of adaptation to captivity (Ferreira Marinho, 2017; Kadtan and Shillewar, 2023). The species is omnivorous and, in its natural environment, feeds on small invertebrates, microcrustaceans, insects, organic matter, and aquatic vegetation (Kasprzak et al., 2021; Kuhn et al., 2023).

Hyphessobrycon eques

Hyphessobrycon eques, commonly known as Serpae Tetra, Blood Tetra, or simply Mato Grosso Tetra, is a Neotropical teleost fish of the family Characidae, widely appreciated in aquarium keeping (Carvalho and Del Claro, 2004; Batista et al., 2023). The genus *Hyphessobrycon* includes about 65 species (Berra, 2001), characterized by remarkable morphological diversity and wide distribution in freshwater ecosystems in South America. The geographical distribution of *H. eques* covers several South American river basins, from the La Plata River system (Paraná-Paraguay-Uruguay-La Plata) to coastal areas of southeastern Brazil, as well as regions in the northeast, north, and the Amazon Basin (Martinez et al., 2012; Castelletto et al., 2020). Naturally, *H. eques* inhabits warm, slow-flowing waters with moderate to high concentrations of dissolved oxygen (Batista et al., 2023).

Initially described as *Tetragonopterus eques* by Steindachner in 1882, the fish was later reclassified into the genus *Hyphessobrycon* based on morphological revisions (Lima et al., 2003). Despite similarities with other species of the same genus, taxonomic and phylogenetic studies have provided greater insight into its systematic position and evolutionary relationships within the Characiformes (Bertaco and Malabarba, 2005; Fricke et al., 2023), revealing its proximity to species such as *Hyphessobrycon erythrostigma* and *Hyphessobrycon socolofi* (Oliveira et al., 2011).

In its natural habitat, *H. eques* prefers lentic waters with dense marginal vegetation, forming hierarchical schools (Reis et al., 2003). Studies by Wootton (1999) show the formation of complex social structures in groups of six or more individuals, in which a decrease in group size is associated with increased intraspecific aggression, chronic stress, and loss of characteristic coloration. In general, they are diurnal, sociable animals with gregarious behavior (Carvalho and Del Claro, 2004).

In the aquarium market, *H. eques* stands out for its small size and striking red coloration. Individuals have a standard size of about 32.0 mm but can reach up to 58.0 mm (Graça and Pavanelli, 2007). Its intense coloration, with a dark humeral patch and a conspicuous black spot on the dorsal region often surrounded by white, yellow, or red hues, is one of its main attractions. The fins are mostly reddish, with the dorsal and anal fins pigmented with dark coloration. The dentition includes two to three teeth in the maxilla and up to six in the inner row of the premaxilla (Hein, 2008).

The species exhibits evident sexual dimorphism: males have a slimmer body and more vibrant coloration, while females have a more rounded abdomen, especially during the reproductive period. It is an oviparous species with no parental care, laying multiple clutches and releasing between 100 and 200 eggs per event. Egg incubation lasts 24 to 36 hours at 28°C, with larval feeding beginning on the fourth day (Wootton, 1990; Furlan-Murari et al., 2022).

The diet of *H. eques* is omnivorous, consisting of approximately 62% aquatic invertebrates, such as Ostracoda, Cladocera, Copepoda, and insect larvae, as well as plant material

(Carvalho and Del Claro, 2004; Bezerra, 2008). Plant matter represents about 28% of the diet, while detritus accounts for approximately 10% (Carvalho and Del Claro, 2004).

Cichlids

The Cichlidae family represents one of the most diverse groups of ornamental fish in the Amazon (Figure 3). Amazonian cichlids stand out for their remarkable morphological, behavioral, and reproductive diversity (Mikkola, 2024), making them fundamental models for evolutionary and ecological studies. This diversity, often underestimated, includes a wide variety of body shapes, color patterns, and specific adaptations to different ecological niches. Many genera, such as *Apistogramma*, *Crenicichla*, *Bujurquina*, and *Symphysodon*, have cryptic and as yet undescribed lineages, suggesting a genetic richness that is still only partially revealed (Carvalho et al., 2018; Estivals et al., 2020; Scaia; Cavallino; Pandolfi, 2020; Říčan et al., 2022).

Distinct morphological characteristics, such as the circular shape and vibrant coloration in *Symphysodon*, the compressed body with long fins in *Pterophyllum*, the large size and variable coloration of *Astronotus*, and the high endemism and chromatic diversity in

Apistogramma, reflect not only ecological adaptations but also mechanisms of reproductive isolation. Subtle color differences, for example, may indicate distinct species even among morphologically similar individuals, as has been demonstrated in several studies (Ready et al., 2006; Raffini and Meyer, 2018; Carvalho et al., 2018).

From a behavioral point of view, Amazonian cichlids exhibit a complex variety of mating strategies, parental care, and social interactions, including sophisticated behaviors for defending offspring and feeding young. Social status directly influences reproductive physiology, allowing for rapid hormonal changes and behavioral changes according to hierarchical position within the group, which reveals high adaptive plasticity (Maruska, 2014; Scaia; Cavallino; Pandolfi, 2020). In addition, sexual selection and behaviors associated with coloration play a central role in speciation, promoting reproductive isolation and intraspecific diversification (Říčan et al., 2021). Together, this wealth of forms, behaviors, and reproductive strategies highlights Amazonian cichlids as one of the most relevant groups of Neotropical ichthyofauna, with direct implications for biodiversity conservation, the improvement of reproductive techniques, and the sustainable development of ornamental aquaculture (Maan and Sefc, 2013; Raffini and Meyer, 2018). These characteristics highlight the urgent need for integrated studies that reveal the true extent of this still largely unknown diversity.

Figure 3. Images of *Symphysodon aequifasciatus* - 11, *Symphysodon discus* - 12, *Pterophyllum scalare* - 13, *Heros severus* - 14, *Hoplarchus Psittacus* - 15, and *Astronotus ocellatus* - 16. Photographs available on FishBase, by Terver, Jensen, Albering, and Schüür (https://www.fishbase.se/).

Discus cichlids (*Symphysodon* spp.)

The Discus cichlids (*Symphysodon* spp.) are native to the Amazon basin and widely recognized for their exotic appearance and unique behavior (Sousa, 2025). Their body is rounded and laterally flattened, with coloring that varies between blue, red, green, and other shades. They can reach up to 20 cm in length and inhabit calm, warm, and acidic rivers. Discus has an omnivorous diet (Rezende et al., 2024).

They are generally peaceful fish but become territorial during the breeding season. The species forms monogamous pairs and exhibits remarkable parental care; after demersal spawning and hatching, the fry feed on the mucus produced by their parents' skin (Mattos et al., 2017).

Regarding Discus cichlids, recent taxonomic organization has recognized three different species under this popular name: the well-known *S. discus* and *S. aequifasciatus*, and finally *S. tarzoo* (Hercos et al., 2017). All three species inhabit lentic bodies of water, as evidenced by their extremely flattened shape, which is poorly adapted to environments with currents. However, *S. discus* is endemic to the Rio Negro and its tributaries, living in blackwater with very low hardness, while *S. aequifasciatus* can be found in clear, white, or black water to the east of the meeting between the Solimões and Negro rivers. *S. tarzoo* is endemic to the region west of the meeting between the same rivers (Crampton, 2008; Dagosta and De Pinna, 2019). This mainly implies that *S. tarzoo* is more adapted to pH closer to neutrality, while *S. aequifasciatus* (also known as the Blue Discus) can vary depending on the population it comes from (Dagosta and De Pinna, 2019).

Freshwater angelfish (*Pterophyllum scalare*)

The angelfish (*Pterophyllum scalare*) is a species native to the Amazon Basin, found in calm, warm, and slightly acidic to neutral rivers, often associated with areas with submerged vegetation and natural refuges. It has a laterally flattened body, elongated disc shape, with well-developed dorsal and anal fins, giving it an elegant appearance, similar to a flag. It can reach 12 to 20 cm in total length, exhibiting a wide variety of colors and patterns resulting from artificial selection in aquariums (Pandolfi et al., 2021). It is an omnivorous species, consuming everything from small invertebrates to plant matter. Its behavior is generally peaceful, although it can become territorial during the breeding season, reproduction occurs by demersal spawning on smooth surfaces such as leaves or stones and is characterized by biparental care, the pair removes unfertilized eggs with their fins, preventing the development of fungi (Jones et al., 2022).

Oscar (*Astronotus ocellatus*)

The Oscar (*Astronotus ocellatus*) is a large cichlid native to the Amazon, highly prized for its intelligence, interaction with its environment, and curious behavior (Castro-Castellón et al., 2020). It can reach up to 35 cm in length and has variable coloration, usually with dark tones and orange or reddish spots. A spot on the caudal fin resembles an “eye” (ocellus), inspiring its scientific name (Rana, 2020). It is oviparous, laying eggs on flat surfaces such as rocks or aquarium glass. The pair, which is usually monogamous, prepares the spawning site and takes care of the eggs and larvae (Kannan et al., 2019) (Figure 3).

Nanocichlids

Nanocichlids, popularly called "American dwarf cichlids," are also fish from the Cichlidae family, inhabiting the same lentic environments as the main Amazonian ornamental cichlids. They thrive in high temperatures, low hardness, and pH values ranging from very acidic to near neutral depending on the species. For example, wild specimens of *Apistogramma agassizii* may require a pH close to 4.0 to reproduce, while clearwater river species like *Apistogramma trifasciata* adapt well to values close to 7.0 (Dagosta and De Pinna, 2019) (Figure 4).

Figure 4. Images of *Apistogramma cacatuoides* - 19, *Apistogramma agassizii* - 20, *Apistogramma trifasciata* - 21, *Apistogramma elizabethae* - 22, and *Apistogramma regain* - 23. Photographs available on FishBase, by Stawikowski and Maceda (https://www.fishbase.se/).

The primary distinction between this group and large cichlids, as their name suggests, is their size; the vast majority of species do not exceed 5 centimeters in length. Reproductive behavior is often as complex as that of large cichlids, with the deposition of few (on average fewer than 200 per female in one complete spawning per season), adhesive, and voluminous eggs on leaves or trunks, most likely due to their smaller size, dwarf cichlids have evolved a more opportunistic life cycle and reproductive strategy (Oliveira and

Queiroz, 2017). This implies that, although the formation of pairs is common, especially during the reproductive period, serial monogamy is the most accurate term to describe the reproductive behavior of these species, there is also a marked sexual difference in most species, with males being larger and having more developed fins (Kochhann and Val, 2017; Silva et al., 2022).

Like large cichlids, South American dwarf cichlids have a characteristic parental care system. However, it is more common among these species for parental care to be uniparental maternal, while the male concentrates on protecting the territory (Alves et al., 2009). An exception is the Ramirezi (*Mikrogeophagus ramirezi*), a species that does not occur in the Brazilian Amazon but is restricted to the Orinoco River basin in Colombia and Venezuela. This species exhibits biparental care and is the most commercially important dwarf cichlid, being the only one produced in captivity on a significant scale, although this production has so far failed to fully meet market demand, which continues to depend on extractivism (Azizah et al., 2024). The key to success in breeding and reproduction of South American dwarf cichlids is understanding and managing their complex sociability, which is so pronounced that they have been chosen as some of the best model species for studies of behavior and even memory in fish (Kochhann and Val, 2017; Tsang et al., 2022).

Apistogramma agassizii

Apistogramma agassizii is a nanocichlid and naturally occurs in the Amazon basins of Brazil, Peru, Colombia, and Bolivia, as well as in tributaries of the Paraguay River (Kullander, 1982; Díaz et al., 2012; Estivals et al., 2020). It prefers shallow, acidic, lentic lakes and streams with sandy substrates and abundant decomposing organic matter, such as leaves, roots, and logs (Barata and Lazzarotto, 2008; Römer and Hahn, 2013). Males reach up to 8 cm in length and have elongated dorsal and caudal fins, as well as blue, yellow, or red coloration, depending on the geographical variety (Chellappa; Câmara; Verani, 2005; Díaz et al., 2012). Females are smaller (up to 5 cm), yellowish in color, and have a dark lateral stripe that is more evident during the breeding season (Kullander, 1986). Sexual dimorphism is quite pronounced in adults, with males being larger, more colorful, and having more developed fins (Silva et al., 2022).

Due to its small size and vibrant colors, the species is highly valued in the ornamental fish trade, with varieties such as “Fire Red” and “Double Red” being especially popular (Mendonça and Camargo, 2006; FishBase, 2023). *Apistogramma agassizii* is a territorial and polygamous species: males defend territories that shelter groups of females (Kochhann; Campos; Val, 2015; Kochhann and Val, 2017). Its reproductive strategy is opportunistic, common in lakes and streams, with spawning occurring in patches, where females release all available mature oocytes in each spawning event (Amadio, 2016).

Catfish and armored catfish (Callichthyidae and Loricariidae families)

Family Loricariidae (Plecos)

The loricarids are fish of the order Siluriformes, most of whose species are popularly known as catfish (Sassi; Cioffi; Moreira-Filho, 2024). Catfish and armored catfish of the Loricariidae family constitute a highly diverse group of benthic fish with important ecological functions and significant functional roles in aquatic environments (Reis et al., 2024) (Figure 5). The Tapajós and Xingu rivers stand out as habitats, in most cases endemic, for many of the most popular aquarium species, most of which are wild-caught (Sousa; Maciel; Rodrigues, 2018).

Figure 5. Images of *Baryancistrus xanthellus* - 24, *Hypancistrus zebra* - 25, *Peckoltia vittata* - 26, and *Pterygoplichthys pardalis* - 27. Photographs available at FishBase, by Jensen, Seidel, Togni, and Shirantha (https://www.fishbase.se/).

As fish of clearwater rivers, catfishes are adapted to flowing environments with transparent water and a wide availability of logs and especially rocks (Queiroz et al., 2013). Although most species prefer a slightly acidic pH, most adapt to neutral water (Ambruster and Lujan, 2016). Most species are fully spawning and polygynous, where the male attracts the females to his burrow to spawn, and is also responsible for the parental care of the eggs (Lampert et al., 2022).

***Otocinclus* species**

The family Loricariidae comprehends a wide diversity of armored catfish widely distributed across South America. Among them, the genus *Otocinclus* stands out with species such as *O. affinis* and *O. vittatus* (Figure 6), the latter occurring in the Amazon basin (Dagosta and De Pinna, 2019). Popularly known as “glass cleaner,” *Otocinclus* is a small Amazonian catfish (3–5 cm), widely used in planted aquariums due to its algae consumption (Mejía de Loayza, 2021). Its body is elongated, with a flattened belly and sucker-shaped mouth. It is peaceful, gregarious, and feeds on algae and plant debris, reproduction is oviparous, with demersal spawning on smooth surfaces, without parental care (Pinheiro Santos et al., 2023). Given their small size, *Otocinclus* species show opportunistic reproductive behavior, with partial spawning and relatively high fecundity (Pereira and Súarez, 2018).

Other notable loricariids include *Hypostomus plecostomus*, a robust species reaching up to 30 cm in length, commonly found in slow-flowing rivers and floodplain lakes (Mejía de Loayza, 2021). It is detritivorous, feeding on organic matter and algae scraped from submerged surfaces, reproduction occurs in cavities or burrows dug in riverbanks, where eggs are deposited and males may exhibit some degree of parental care by guarding the nest (Dagosta and De Pinna, 2019).

Ancistrus cirrhosus, known as the “bristlenose pleco,” inhabits small streams with rocky substrates. It measures between 10 and 15 cm and is also used in aquariums for its algae-eating habits, unlike many other loricariids, *Ancistrus* males actively guard the eggs until hatching, a strategy that increases offspring survival (Pinheiro Santos et al., 2023). The species shows seasonal reproductive patterns and prefers well-oxygenated environments for spawning.

Figure 6. Image of *Otocinclus vittatus*. Photograph available on FishBase, by Nore (https://www.fishbase.se/).

Hypancystrus zebra

The *Hypancistrus zebra* is a species of ornamental fish belonging to the Loricariidae family, endemic to the middle section of the Xingu River in Brazil. It has a black and white striped body pattern, which makes it highly valued in the international aquarium market (Viana et al., 2018). Biologically, it is a rheophilic species that inhabits areas of strong currents and rocky substrates, where it takes refuge in crevices and cavities, a behavior that is also directly related to its mode of reproduction (Sousa et al., 2021). It is a demersal species, with omnivorous feeding habits and a tendency to be detritivorous, and reproduces in a substrate-hidden manner, with parental care exercised by the male (Barros et al., 2023). Due to its restricted geographical distribution and anthropogenic pressure on its natural habitat (especially as a result of the construction of hydroelectric plants), the species is classified as vulnerable in the wild, which has generated growing interest in the development of protocols for its reproduction in captivity, although there are still technical limitations that prevent the expansion of this practice on a large scale (Pereira and Henriques, 2019).

Peckoltia vittata

Peckoltia vittata, commonly known as the tiger pleco, is an ornamental fish belonging to the Loricariidae family, widely distributed in the Amazon basin, especially in rivers with moderate currents and rocky or sandy substrates (Pety et al., 2018). This species has a dorsoventrally flattened body and characteristic coloring with dark vertical stripes on a yellowish or light brown background, which gives it its common name (Armbruster and Lujan, 2016). It is a nocturnal species with territorial behavior, feeding mainly on organic matter, algae, and debris present on the bottom. *P. vittata* has stood out among Loricariidae for its significant success in reproduction in captivity, being considered a promising model for reproductive management studies in controlled environments (Ramos et al., 2015).

Pterygoplichthys spp.

Certain species of armored catfish, such as *Pterygoplichthys* spp., have become invasive outside their native range, colonizing new habitats and impacting local ecosystems. Native to South and Central America, these catfish are characterized by a bony armor covering their body, a ventrally positioned suctorial mouth adapted for scraping surfaces, and a modified stomach that allows facultative air breathing (Bijukumar et al., 2015). *Pterygoplichthys* species exhibit high environmental tolerance, including to hypoxia and pollution, and demonstrate rapid growth, early maturation, and high fecundity (Sánchez et al., 2015). Their wide dispersal capacity is favored by river connectivity, aquaculture escapes, and environmental changes, making their management a challenge for environmental authorities (Frederico et al., 2019; Soria-Barreto et al., 2024).

Hypostomus plecostomus

Hypostomus plecostomus a common pleco is a large catfish, reaching 30 to 50 cm in length. Native to South American rivers, it is widely popular in aquariums (Correa et al., 2024). It has a robust body, sucker mouth, and brownish coloration with dark spots, it is omnivorous with a tendency toward herbivory, feeding on algae, detritus, and feed, due to its size and waste production, it requires large aquariums. It reproduces by demersal spawning, often in cavities, the male takes on parental care of the eggs (Silva Soares, 2023).

Family Callichthyidae (*Coridoras* species)

Together with the Catfish, the coridoras are the most popular siluriformes in the ornamental fish market (Figure 7). These species belong to the Callichthyidae family. Fish of this family have dermal bone plates that serve as armor and have an adaptation in the posterior intestine, which is highly vascularized and capable of performing gas exchange, making these fish facultative breathers of atmospheric air (Satora et al., 2017). This adaptation is important for the animals' survival in hypoxic environments, common in floodplain areas where several species of coridoras are endemic (Plaul et al., 2016; Dagosta and De Pinna, 2019). In situations of low dissolved oxygen in aquariums, it is common to see coridoras quickly climbing to the surface to suck in air bubbles (Plaul et al., 2021).

Among the best-known and most commercially available species in the ornamental market are:

a) *Corydoras aeneus* (bronze Corydoras): A robust and resistant species, widely distributed in South America. It has a bronze metallic coloration and peaceful behavior. It is widely used in aquariums due to its hardiness and ability to tolerate variations in water quality (Kuradomi et al., 2023).

b) *Corydoras panda* (Corydora panda): Native to the Ucayali River basin in Peru, this species is recognized by the dark spots around the eyes and at the base of the caudal fin, resembling the color pattern of a panda. It is gregarious and prefers sandy substrates (Sulistyowati and Alifuddin, 2005).

c) *Corydoras sterbai* (Corydora sterbai): Native to the Guaporé River basin, it has dark brown coloring with white spots on its body and orange stripes on its pectoral fins, it is one of the most appreciated species by aquarists, especially for its beauty and active behavior (Choi et al., 2019).

These species share similar behavioral characteristics, such as benthic habits, predominantly diurnal activity, and gregarious behavior, and are recommended for keeping in groups in aquariums.

Figure 7. Images of *Corydoras elegans* - 29, *Corydoras adolfoi* - 30, *Corydoras tukano* - 31, *Corydoras caudimaculatus* - 32*, Corydoras eques* - 33, and *Corydoras guapore* - 34. Photographs available on FishBase and Fish-Pedia, by Janiczak, Jensen, Hoffmann, Wang (https://www.fishbase.se/; https://www.fishi-pedia.com/).

Corydoras are small bottom-dwelling fish, measuring between 2.5 and 9 cm, native to the Amazon region; they have protective bone plates and sensory barbels on their mouths, and are very peaceful, gregarious, and ideal for community aquariums (Pecunioso et al., 2024). They are omnivorous and help clean the substrate, they reproduce by demersal spawning, which can occur in groups or in pairs. The female lays her eggs on smooth surfaces and does not show any parental care (Jones et al., 2022).

The genus *Corydoras* has a wide distribution on the South American continent, but in the Amazon basin there is an incalculable wealth of this group (Dagosta and De Pinna, 2019) with new species constantly being described (Britto and Lima, 2003; Tencatt et al., 2022). Among dozens of relatively common species found in ornamental fish dealers and stores, *C. schwartzi* and *C. sterbai* are the two most popular species native to the Amazon basin (Figure 8).

Between the clear-water species from the Guaporé River, such as *C. guapore*, capable of adapting to neutral pH water (although they have preferences for slightly acidic water) and the endemic species from the Negro River, such as *C. adolfoi*, adapted to extremely acidic environments, there is one thing in common between all of them: adaptation to sandy and cunning sediments, manifested in their ventrally bulging shape (Queiroz et al., 2013; Chiang et al., 2024). It is therefore ideal to keep coridoras in aquariums with fine sediments in order to avoid injury.

The small *C. hastatus* (Figure 9), known as the dwarf coridora because it hardly exceeds 3 cm in total length, is an exception, shows a slightly different swimming behaviour to the majority of species in the genus, swimming in shoals in the middle of the water column, although it spends much of its time on the bottom and has a preference for the same type of sediment (Qiao et al., 2024).

Figure 8. Images of *Corydoras schwartzi* - 35 and *Corydoras sterbai* - 36. Photographs available on FishBase, by Fuller and Terver (https://www.fishbase.se/).

Figure 9. Image of *Corydoras hastatus*. Photograph available in Aquarist's Guide, by Braga (2024) (https://guiadoaquarismo.com.br/corydoras-hastatus-ana/).

The most intriguing characteristic that still generates debate about coridoras is their reproductive behavior. Coridoras are siluriform fish with a tendency towards nocturnal habits like the catfish, but they are highly sociable, living together in large groups or shoals, which can form communities with more than one species (Borges and Morais, 2025). They are opportunistic, with males inseminating several females, who lay their eggs adhered to leaves, trunks or rocks, with no parental care afterwards (Maulana et al., 2022). The breeding season occurs during the rainy season and can be stimulated in captivity by raising the water level with the gradual addition of relatively cold water (22 to 24 ºC) (Kaatz and Lobel, 1999).

What is intriguing, however, is courtship and fertilization. In some species, a characteristic sound is produced exclusively by the male during courtship, caused by the movement of the spines of the pectoral fins against his own body (Pruzsinszky and Ladich, 1998; Kaatz and Lobel, 1999; Kaatz et al., 2025). Most species show the famous T-position insemination behavior (Figure 10) where the male projects himself perpendicular to the female and theoretically releases the sperm into the female's mouth (Kohda et al., 1995). We repeat theoretically, because although this possible ingestion of sperm by the female has been described in the scientific literature, it is not completely established or understood and, in fact, there is a great deal of discussion, so far it has not been possible to conclude whether: 1 - the females actually collect the sperm with their mouths, or if only a mass of sperm is guided through the female's belly to a pouch formed by the ventral fins with subsequent fertilization of the eggs and 2 - in the event of sperm ingestion, whether the female immediately spits it out onto the substrate and then deposits it on the eggs, fertilizing them, or whether there really is an ingestion, with the sperm passing through the intestinal tract and the eggs being fertilized internally before release (Zarske and Greven, 2015).

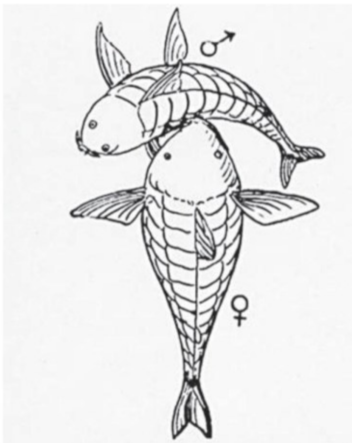


Figure 10. First illustration of T-position, for the species *Callichthys punctatus* (today called *Corydoras punctatus*). Source: Zarske and Greven (2015).

Family Osteoglossidae

Osteoglossum bicirrhosum

The Arowana (*Osteoglossum bicirrhosum*) (Figure 11), also known as the silver arowana, amaná, lebreia, língua-de-osso, sulamba, and macaco-d'água, belongs to the Osteoglossidae family one of the oldest groups of freshwater bony fish, with fossil records dating back to the Cretaceous period (Nelson et al., 2016). This family is subdivided into the subfamily Osteoglossinae, represented exclusively by the genus *Osteoglossum*, which includes two species: the white aruanã (*Osteoglossum bicirrhosum*) and the black aruanã (*Osteoglossum ferreirai*) (Aragão, 1981).

Figure 11. Image of *Osteoglossum bicirrhosum*. Photograph available on FishBase, by B. Alenda (2012) (https://www.fishbase.se/).

The species *O. bicirrhosum* is widely distributed in the river basins of South America and has been recorded in rivers in the Guianas, such as the Rupununi and Essequibo rivers. However, it is predominantly found in the Amazonian floodplain, especially in blackwater rivers and floodplain forests, during the flood season, this environment provides greater availability of shelter and food resources (Aragão, 1984; Goulding, 1980; Chaves et al., 2008; Escobar et al., 2013). In the early stages of development, juveniles prefer protected areas with dense roots and aquatic vegetation (Saint-Paul et al., 2000). This species is of great scientific interest due to its ecological and economic importance. It acts as a top predator in its ecosystem, contributing to the balance of food chains and the maintenance of biodiversity. In addition, it has been relevant in both commercial and artisanal fishing and in the aquarium market (Escobar et al., 2013; Maldonado et al., 2017).

Morphologically, the silver arowana has an elongated and laterally compressed body, reaching up to 120 cm in length and 8 kg in natural environments (Duponchelle et al., 2012). Its scales are broad, silvery, and metallic in appearance, and the two sensory barbels on its chin aid in detecting prey (Greenwood et al., 1966). The oblique, upward-facing mouth facilitates the capture of organisms on the surface (Goulding, 1980).

The species is monogamous and exhibits cooperative parental care, reproduction occurs at the beginning of the Amazonian flood season, with the possibility of multiple spawning per season, sexual maturity occurs in the second year of life, with evident sexual dimorphism: males measure between 43–45 cm and females between 46–50 cm (Duponchelle et al., 2015). Spawning is staggered and can occur up to twice a year, with 90 to 300 eggs released per event and an incubation period of eight to nine weeks (Moro, 2013).

During the reproductive ritual, the male courts the female by swimming around her, and she deposits her eggs on the substrate, after fertilization, the male collects the eggs in his mouth, where they remain until hatching (Goulding, 1980; Rabello-Neto, 2008). Parental care lasts for about six weeks, and it is common for the larvae to return to the father's mouth after feeding or when threatened, remaining under his protection until they reach approximately 10 cm in length (Lowe-McConnell, 1999; Queiroz, 2008; Verba et al., 2014). During this period, the male fasts, minimizing the opening of his mouth and thus the risk of losing the eggs.

Behaviorally, *O. bicirrhosum* is a benthopelagic and diurnal fish, famous for its leaps to capture prey at the surface (Saint-Paul et al., 2000). Its diet is broad and opportunistic, consisting mainly of arthropods (72%), followed by plant debris (13%), fish (10%), reptiles (3%), and mammals (2%) (Freitas et al., 2025).

In the ornamental market, the silver arowana is highly valued. Its price can be up to 68% higher than that of species such as koi carp (*Cyprinus carpio*) (Fagun et al., 2020), due to its rarity, morphological characteristics, and high demand, especially in Asia, where it is a symbol of prosperity, due to its similarity to endangered Asian species, its international trade is regulated (Nelson, 2006). In artisanal fishing, the species is consumed by riverside communities, playing an important role in regional food security.

Although not globally threatened, populations of *O. bicirrhosum* face pressures from environmental degradation and overfishing (Costa et al., 2009). Legal capture is restricted to fry with yolk sacs, a practice that, however, involves the removal of adult males responsible for parental care, negatively affecting the reproductive cycle of the species (Rabello, 1999; Alcántara et al., 2007). The species is also targeted by wildlife trafficking due to its high value in the aquarium trade, especially rare or large specimens. This encourages illegal fishing practices, posing a threat to aquatic biodiversity (Beltrão et al., 2021).

Given this scenario, research focused on captive breeding has been developed in Brazil, with the aim of meeting commercial demand

and reducing pressure on natural populations (Costa et al., 2009). The arowana is also appreciated as a food source, notable for its low fat content (0.08%) and high protein content (15.19%). The average fillet yield of the species is around 29% (Costa et al., 2009; Balbi Tristao et al., 2011), which reinforces its potential for human consumption, especially in regions dependent on artisanal fishing.

Family Potamotrygonidae (Stingrays)

The freshwater stingrays are increasingly attracting interest in the ornamental market; however, their trade still relies heavily on specimens captured from natural environments, there are, nonetheless, reports of successful captive production in countries such as Thailand and Indonesia (Jerikho et al., 2023). In Brazil, the two most popular species from the Amazon basin are *Potamotrygon leopoldi* and *Potamotrygon motoro* (Figure 12).

Potamotrygon leopoldi, commonly known as the Xingu River ray or black diamond stingray, is endemic to the Xingu River basin. It is characterized by a dark dorsal coloration with distinctive white or yellowish spots and a round disc, this species inhabits clearwater river bottoms with rocky and sandy substrates, it is a benthic species that feeds mainly on invertebrates and small fish, sexual dimorphism is evident, with males possessing claspers, reproduction is aplacental viviparous, with the development of embryos occurring inside the female's uterus, nourished initially by yolk and later by uterine secretions (Anderson et al., 2023).

Potamotrygon motoro, known as the ocellate river stingray or "raia-pintada", has a wide distribution across the Amazon, Orinoco, and Paraná-Paraguay river basins. It presents a more variable color pattern, usually with a brown or reddish dorsal surface adorned with orange to yellow ocelli surrounded by darker rings. It is also a benthic feeder, preying on worms, crustaceans, and small fishes, similar to *P. leopoldi*, this species exhibits aplacental viviparity and shows strong maternal investment in the development of offspring, *Potamotrygon motoro* is considered one of the most adaptable freshwater stingrays to captive conditions, which contributes to its popularity in the aquarium trade (Dagosta and De Pinna, 2019; Anderson et al., 2023).

Figure 12. Image of *Potamotrygon leopoldi* and *Potamotrygon motoro*. Photograph available on FishBase, by Murch (https://www.fishbase.se/).

Other popular species

Pacu *Metynnis maculatus* (Figure 13), which is a relatively small species for jumbo aquariums (around 20 cm), docile, schooling and omnivorous with a tendency to herbivory (Pereira et al., 2013).

Figure 13. Image of *Metynnis maculatus*. Photograph available on FishBase, by Alenda (2010) (https://www.fishbase.se/).

The butterflyfish *Carnegiella strigata* (Figure 14), is a member of the Gasteropelecidae family, it is widely distributed in the black water rivers of the Amazon basin, in environments exactly as described in the tetra section and lives in sympatry with dozens of tetras (Lobato et al., 2022), it is constantly present in community tetra aquariums and ends up being part of this niche market and among aquarists.

Figure 14. Image of *Carnegiella strigata*. Photograph available on FishBase, by Prins (2002) (https://www.fishbase.se/).

CHAPTER 4

REPRODUCTION FOR CONSERVATION AND CAPTURE REDUCTION

The knowledge of the reproductive strategies of exploited fish species is essential for the effective management of fish stocks and the long-term conservation of these resources (Vazzoler, 1996). Elements such as spawning season, fecundity, and size at first sexual maturity provide valuable input for the development of measures aimed at the sustainability of fishing activities, enabling the continuous and rational management of exploited populations (Portella et al., 2021).

In the Amazonian ichthyofauna, there is a remarkable diversity of reproductive strategies and tactics, resulting from long evolutionary processes mediated by natural selection (Wootton, 1984; Vazzoler, 1996). Reproductive strategies is known as general patterns adopted by populations with the aim of maintaining population stability in specific ecological contexts (Vazzoler, 1996). In contrast, reproductive tactics refer to phenotypic variations within these strategic patterns, expressed in response to environmental fluctuations and pressures (Vazzoler, 1996; Wolf, 2014). Among the main parameters that exemplify these reproductive tactics, characteristics such as body size, sex ratio, weight-length ratio, size at first gonadal maturation, degree of gonadal development, fecundity, and type of spawning adopted by each species stand out (Chellappa; Nascimento; Chellappa, 2011).

The reproductive strategies of organisms can be classified according to the triangular model proposed by Winemiller (1989), which identifies three main categories: opportunistic, seasonal, and balanced. Fish that use opportunistic strategy are generally small, reach sexual maturity early, have multiple spawning, low fertility, and exhibit reduced or no parental care (Winemiller, 1989; Winemille; Rose, 1992). The seasonal strategy, in turn, is typical of larger species with high fecundity, spawning synchronized with predictable environmental cycles, and no parental care. Finally, the balanced strategy is characterized by medium-sized species that reach sexual maturity late, have moderate fertility, and invest in parental care to increase the survival of their offspring (Winemiller, 1989; Winemiller; Rose, 1992).

Studies focused on the reproductive biology of species are extremely important, as they support the definition of specific management tactics. Practical examples include the implementation of closed seasons, the stipulation of minimum catch sizes, the prohibition of the collection of certain species, regulating the use of fishing gear, and limiting the number of individuals caught per unit of fishing effort (Batista; Isaac; Viana, 2003; Silva, 2019). Such measures, when based on robust scientific data, are effective tools for ensuring biodiversity conservation and maintaining ecosystem services associated with fishing.

Reproduction is one of the most fundamental aspects of fish biology, directly influencing their survival, distribution, social behavior, and evolutionary success (Lodé, 2012; Espírito-Santo et al., 2013, Kuradomi et al., 2023). In the context of Amazonian ichthyofauna, reproductive mechanisms have become complex and diverse, reflecting the wide variety of ecological niches, hydrological cycles, and environmental pressures that characterize the Amazon River basin (Kuradomi et al., 2023; Althoff et al., 2024).

Oviparity is the most common type of reproduction among Amazonian ornamental fish. In this form of reproduction, the female releases the eggs into the aquatic environment while the male fertilizes the gametes externally, usually in behavioral synchrony (Blackburn, 1999; Lodé, 2012). Although oviparity broadly allows for internal or external fertilization, the latter is characteristic of these fish (Lima et al., 2013). The ecological diversity of the Amazon has influenced the emergence of three main oviparous reproductive strategies: egg dispersal, parental care, and nest building (Hostache and Mol, 1998) (Table 1). Each of these strategies reflects specific adaptations to environmental conditions, such as the presence of predators, current intensity, and availability of shelter (Kuradomi et al., 2023).

a) Egg dispersers

These dispersive species release their eggs into the water column or among vegetation, without offering any post-laying parental care (Pavlov and Emel'yanova, 2016). This strategy involves massive egg production with independent development, aiming to increase the survival chance of part of the offspring. The eggs are often adhesive and left on aquatic plants or substrates, hatching on their own (Pavlov and Emel'yanova, 2016).

The Neon tetra (*Paracheirodon innesi)*, Cardinal Tetra (*Paracheirodon axelrodi*) and Serpae tetra *(Hyphessobrycon eques)* are classic representatives of dispersive fish (Anjos and Anos, 2006; Kucharczyk et al., 2010; Sanchez-Bernal et al., 2023). During spawning, tetras release adhesive eggs that attach themselves to various types of substrates, depending on the species, such as aquatic plants, floating roots, rocks, plant debris on the bottom, or even smooth surfaces such as aquarium glass, in the case of aquarium keeping (Anjos and Anos, 2006; Kucharczyk et al., 2010; Sanchez-Bernal et al., 2023). Fertilization is external and there is no parental care, with adults commonly consuming their own eggs, which is characteristic of cannibalistic behavior (Monticini, 2010; Kuradomi et al., 2023).

Corydoras and *Otocinclus*, although not exclusive dispersers, exhibit similar behaviors in some species. *Corydoras aeneus*, for example, deposits adhesive eggs on substrates such as the leaf surface of aquatic macrophytes, stones, and aquarium glass, abandoning them shortly after laying (Kuradomi et al., 2023). *Otocinclus affinis* follows a similar pattern, releasing eggs on stable surfaces without offering parental care. This lack of protection characterizes an opportunistic reproductive model, distinct from nest builders or parental protectors (Yanong, 1996, Armbruster, 2004).

b) Parental protectors

Unlike dispersers, parental protectors, usually one or both parents, actively protect eggs and larvae after spawning, considerably increasing the survival rate of offspring. This form of oviparity requires fewer eggs per reproductive cycle and is associated with species with territorial behavior (Coleman et al., 1999).

The Angelfish (*Pterophyllum scalare*) exhibits highly developed parental behavior, with the pair first cleaning the surface of the spawning site, usually broad leaves or flat substrate (Barlow, 2008; Lima *et al.,* 2013). After laying, both parents care for the eggs, oxygenating them with fin movements, removing dead or fungal eggs, and protecting them from predators (Barlow, 2008; Lima et al., 2013). This care extends to newly hatched larvae until they are able to swim freely, a classic example of parental protection in Amazonian cichlids (Barlow, 2008; Lima et al., 2013).

Discus cichlids (*Symphysodon aequifasciatus*) are another example of protective oviparous fish, not only protecting their eggs but also secreting a nutritious substance from their skin to feed the larvae after hatching (Bleher, 2006; Payne, 2019). The pair forms monogamous pairs and chooses flat surfaces of aquatic leaves and rocks to spawn, the parents' dedication lasts for several days after hatching, showing a high degree of reproductive investment (Bleher, 2006; Payne, 2019).

The Oscar (*Astronotus ocellatus*), another protective cichlid, chooses flat surfaces for spawning and shows aggression in defending its offspring (Monticini, 2010, Lima et al., 2013). Prolonged guarding behavior is typical of this species, with both parents taking on roles in protecting the brood (Monticini, 2010, Lima et al., 2013).

The Silver arowana (*Osteoglossum bicirrhosum*) exhibits oral parental care. After external fertilization, the male collects the fertilized eggs in his mouth, where they remain incubating until the offspring are sufficiently developed to swim freely (Yanong, 1996; Lima et al., 2013).

c) Nest builders

Nest-building fish construct specific sites to protect their eggs and manipulate the environment to create structures that favor egg incubation and development (Taborsky *et al.,* 2008). In most cases, the male is responsible for digging and protecting the nest (Taborsky et al., 2008).

Apistogrammas (*Apistogramma agassizii*) are known for building nests in cavities and crevices. The female usually stays in the nest caring for the offspring, while the male defends the territory. This strategy favors a high survival rate in unstable environments (Rodrigues et al., 2012; Payne, 2019).

Plecos (*Ancistrus* sp.), males usually choose hollow logs or excavated caves where females lay their eggs. After laying, the male protects the eggs, oxygenating them until they hatch. The construction and choice of nest is crucial for reproductive success (Payne, 2019).

Platydoras hancockii construct physical structures to protect their eggs and promote their development (Alves et al., 2009; Van et al., 2020). Catfish (*Corydoras* spp.*),* although they do not build elaborate nests, *Corydoras* adopt unique behaviors, such as retaining eggs in the female's pelvic fin for later attachment to safe locations, which is considered an intermediate behavior (Monticini, 2010; Kohda et al., 1995).

The diversity of reproductive strategies in Amazonian ornamental fish is vast and strongly influenced by ecological pressures such as predation, shelter availability, and water seasonality. Table 1 summarises the reproductive behavior of the main species of ornamental interest of the Amazonian ichthyofauna.

Table 1. Reproductive strategies of theAmazonian ornamental fish.

Common Name	**Scientific Name**	**Reproduction**	**Reproductive Strategy**	**Reference**
Neon tetra	*Paracheirodon innesi*	Oviparous	Egg disperser, without parental care	Yanong (1996)
Cardinal	*Paracheirodon axelrodi*	Oviparous	Egg dispersal, seasonality associated with flooding	Espírito-Santo et al. (2013)
Serpae tetra	*Hyphessobrycon eques*	Oviparous	Scatterbrain, without parental care	Yanong (1996)
Discus fish	*Symphysodon aequifasciatus*	Oviparous	Biparental parenting with egg and larva care	Rodrigues et al. (2012)
Angelfish	*Pterophyllum scalare*	Oviparous	Biparental parental with egg cleaning and oxygenation	Yanong (1996)
Oscar	*Astronotus ocellatus*	Oviparous	Aggressive parent, posture on flat surfaces	Yanong (1996)
Corydoras	*Corydoras aeneus*	Oviparous	Hidden eggs, low protection	Yanong (1996)
Otocinclus	*Otocinclus affinis*	Oviparous	Posture on surfaces, without parental supervision	Yanong (1996)
Pleco	*Hypostomus plecostomus*	Oviparous	Eggs in cavities; males may protect them	Caldas et al. (2019)
Apistogramma	*Apistogramma hippolytae*	Oviparous	Nest builder with unique maternal care	Rodrigues et al. (2012)
Silver arowana	*Osteoglossum bicirrhosum*	Oviparous	Paternal mouth incubation	Yanong (1996)

Semelparity (a reproductive strategy in which an organism reproduces only once in its life and then dies) and iteroparity (they reproduce more than once throughout their lives), also reproductive strategies from Amazonian fish. Some species have a single annual breeding season, while others reproduce several times throughout their lives; such strategies are influenced by environmental conditions and habitat occupation (Waddell et al., 2019). Other species, such as *Apistogramma agassizii* and *Apistogramma bitaeniata*, have developed opportunistic reproductive strategies characterized by low fecundity and short spawning periods, allowing them to adapt to the dynamic environmental conditions of the Amazon floodplain (Oliveira and Queiroz, 2017).

Discus fish, normally reproduce at the beginning of the flood season, this interval ensures that their young have enough time to grow before the dry season, when resources become scarce (Crampton, 2008; Rossoni et al., 2010). These fish exhibit iteroparous and partial spawning behavior, which means that they can spawn several times throughout their lives, their fecundity probably varying due to differences in body size and environmental conditions (Crampton, 2008; Rossoni et al., 2010). They are known for their high degree of parental care, which includes guarding and nurturing the eggs and larvae. This behavior is crucial for the survival of the offspring in the predator-rich environments of the Amazon (Câmara, 2004; Crampton, 2008).

Finally, this topic explored the main reproductive strategies of the best-known Amazonian ornamental species in an integrated manner, bringing together behavioral, ecological, and physiological information (Kuradomi et al., 2023). Understanding these strategies is essential for successful assisted reproduction, and the preservation of Amazonian biodiversity in controlled and natural environments (Caldas et al., 2019).

CHAPTER 5

CAPTIVITY REARING OF THE AMAZONIAN ORNAMENTAL FISH

Ornamental fish farming is a great economic and socio-environmental activity, generating income and jobs for local populations, as well as contributing to the enhancement of the sustainability of Amazonian communities (Abe et al., 2019).

Production systems

Amazonian ornamental fish can be farmed using different systems, ranging from extensive dugout ponds to highly technical systems such as recirculating aquaculture systems (RAS). The choice of the most suitable system depends on factors such as the target species, the commercial value of the fish, the level of investment available, and the physical space available on the property.

1. Extensive and Semi-intensive Systems

In rural areas, it is common to use excavated ponds, taking advantage of local water resources, in these systems, water is partially or totally renewed, with low stocking density and feeding based, in part, on the natural productivity of the environment, these systems require less initial investment but offer less control over environmental parameters, which can compromise the quality of ornamental fish (Yue, 2019).

2. Intensive systems with water recirculation (RAS)

Recirculation systems have emerged as an efficient alternative for the production of high-value Amazonian ornamental species. They allow precise control of temperature, oxygenation, pH, ammonia, nitrite, and other parameters that are fundamental to the well-being of fish (Jug-Dujaković et al., 2008; Rodríguez-Ibarra et al., 2024).

Despite the high initial implementation cost, these systems are economically viable in the long term due to reduced water use and greater biosecurity, in addition to enabling high stocking densities (Oparaku and Nnaji, 2013; Pereira and Henriques, 2019). In some cases, they are integrated with aquaponics systems, optimizing the use of nitrogenous waste.

3. Water quality

Maintaining water quality is a critical factor in any system. Parameters such as temperature, pH, hardness, electrical conductivity, total ammonia, and dissolved oxygen must be monitored regularly, Amazonian species, such as the cardinal tetra (*Paracheirodon axelrodi*), are particularly sensitive to sudden changes, requiring stable environmental conditions (Nurhidayat; Wardin; Sitorus, 2016).

4. Stocking density

Stocking density varies according to the species and the system used, in RAS systems, it is possible to work with higher densities, provided there is strict control of water quality and good aeration, in extensive systems, the density tends to be lower, in line with the natural carrying capacity of the environment (Campos et al., 2017).

5. Feeding and nutrition

Feeding should be appropriate for the species and stage of development of the ornamental fish, commercial diets specific to ornamental fish are still limited in Brazil, and it is common to use feed adapted for tropical species, at some stages, it may be necessary to provide live food, such as *Artemia* nauplii or micro worms, especially for oviparous species with small larvae (Nurhidayat; Wardin; Sitorus, 2016).

In short, although there are few specific technical publications on Amazonian ornamental fish farming systems, there is a growing trend toward the adoption of controlled systems, such as RAS, especially for species of high commercial value and sensitive to environmental stress (Rodríguez-Ibarra et al., 2024). The development of technologies adapted to the reality of the Amazon is still a challenge, but essential to strengthen ornamental aquaculture in the region.

Especific handling in captivity

Tetras

Amazonian tetras, such as the neon tetra (*Paracheirodon innesi*), cardinal tetra (*Paracheirodon axelrodi*), and Serpae tetra (*Hyphessobrycon eques*), are among the most popular and widely traded species in the ornamental freshwater fish market (Silva, 2024). These fish are small, social behaviour that naturally live in shoals and are highly sensitive to environmental fluctuations. This characteristic demands strict management from the earliest stages of development (Fernandes; Ribeiro; Silva Neto, 2021). Keeping them in groups is essential, as it fosters social behavior, reduces stress, and contributes to the overall balance and stability of the aquarium, creating a healthier environment (Silva, 2024).

In general, these species are particularly sensitive to fluctuations in temperature (optimal: 24–28°C), pH (6.0–7.0), and total ammonia concentrations (< 0.05 mg/L), especially during the larval stage, which occurs in pelagic environments (Watson and Shireman, 1996; Araujo, 2017). As they do not exhibit parental care, eggs and larvae are left fully exposed to predation and to infections caused by fungi and bacteria. Larval feeding poses a major challenge, as fry have a small buccal opening (typically < 150 µm in the first days) and high metabolic demands, requiring a continuous supply of live feed such as rotifers (*Brachionus* spp.) or infusoria offered at densities of 10–15 individuals/mL (Fernandes; Ribeiro; Silva Neto, 2021). Feeding should be provided 5 to 6 times a day to avoid starvation. The initial rearing density for these tetras should not exceed 100 larvae/L, as overcrowding increases stress and mortality, under controlled hatchery conditions, survival rates from hatching to active feeding stage typically range from 30% to 60%, depending on water quality, microbial management, and feeding efficiency (Rodrigues et al., 2021; Silva, 2024). Additionally, the presence of microalgae (green water technique) or artificial shelters can help reduce visual stress and improve larval performance.

The larvae are small and must be fed live food during their first days, such as *Artemia salina* nauplii or microworms (Diemer et al., 2012; Oliveira et al., 2020). Tetra are highly susceptible to bacterial and parasitic infections when exposed to stress, making it essential to maintain stable water parameters and implement strict biosecurity measures, including quarantine for broodstock (Carvalho, 2020; Fernandes; Ribeiro; Silva Neto, 2021).

Regarding feeding, most tetra species are primarily carnivorous with omnivorous tendencies, feeding in the wild on microcrustaceans and insect larvae. During the dry season, they may also consume algae and plant detritus (Marshall et al., 2008). There is a wide variety of commercial feeds formulated specifically for tetras, generally containing crude protein levels ranging from 35% to 45%, which are suitable for maintenance and growth, diets formulated for juveniles typically require higher protein content (above 40%), while maintenance diets for adults can have slightly lower levels. These feeds usually combine animal-based protein sources, such as fish meal or shrimp meal, with plant-derived components like soybean meal (Rezende et al., 2021). However, for breeding purposes or when dealing with less domesticated species, supplementation with live food such as *Alphitobius diaperinus* larvae and microworms (*Panagrellus redivivus*) is ideal, as it enhances palatability and provides essential amino acids and lipids important for gonadal development.

All popular tetra species are schooling fish, with no clearly distinguishable external sexual dimorphism and external fertilization without parental care (Oliveira et al., 2023). The eggs are typically adhesive or semi-adhesive and sink after spawning, as observed in the Mato Grosso tetra (Park et al., 2014) and cardinal tetra (Cindelaras et al., 2025). Broodstock must be separated from the eggs and larvae, which usually hatch 15 to 20 hours after spawning at the yolk-sac stage (Park et al., 2014; Cindelaras et al., 2025).

As schooling fish, the male-to-female ratio is not particularly important for reproduction. Instead, forming a stable school is more crucial for maintaining a socially active group ready for maturation and spawning (Santana; Tondato; Súarez, 2018). For this reason, it is recommended to keep at least 10 individuals of each species per tank. Even when captive breeding is not the goal, maintaining them in groups is vital for their health, as individuals kept in small numbers may become stressed exhibiting shy or lethargic behavior when housed with larger or more active species, or becoming aggressive when kept with smaller or more passive ones (Goodall et al., 2024).

In addition to social grouping, environmental enrichment is key. Based on their natural habitat, optimal conditions include fine gravel or clay substrates, driftwood, branches, and aquatic plants (Matsuo and Val, 2007). Dark-colored water commonly referred to as "blackwater" with low lighting and minimal turbulence provides ideal conditions for tetras to exhibit their full sociability. Without these elements, they may become shy or aggressive (Linhares et al., 2018).

From a health perspective, tetras are prone to diseases such as columnaris and opportunistic infections caused by *Aeromonas* spp. and *Pseudomonas* spp., particularly in conditions of overcrowding or inadequate management (Ishikawa et al., 2012; Fernandes; Ribeiro; Silva Neto, 2021).

Once these basic requirements are met, most tetra species exhibit docile and highly sociable behavior, often coexisting in sympatry in the wild with a variety of other ornamental fish species (Dagosta and De Pinna, 2019).

Paracheirodon axelrodi

In captivity, *Paracheirodon axelrodi* readily accepts live feed such as *Artemia salina* nauplii (Brito and Bazzoli, 2017). Its behavior typically ranges from the mid-water column to the bottom of the tank (Prang, 1996; Golob, 2019). The species has a crude protein requirement that varies between 30% and 35%, potentially reaching up to 40% in specific cases (Silva et al., 2011; Lemos et al., 2015; Damasceno, 2016).

Cardinal tetras tolerate high temperatures up to 23 – 28 °C and a broad pH range between 4.0 – 6.5. Safe concentrations of total ammonia in aquariums should be close to zero (< 0.05 mg/L). However, prolonged exposure to temperatures below 19.6 °C or nitrite levels above 1.1 mg/L (NO_2) compromises survival (Oliveira et al., 2008; Imbiriba, 2010; Damasceno, 2016). Experimental data indicate that cardinal tetras can tolerate acute exposure to temperatures up to

33.3 °C, though thermal stress increases significantly above optimal ranges (Campos et al., 2017). Ideal water parameters include dissolved oxygen levels between 6.0 and 6.6 mg/L, alkalinity ranging from 22.66 to 33.98 ppm, and hardness between 26.17 and 57.00 ppm (Nurhidayat; Wardin; Sitorus, 2016).

Paracheirodon axelrodi

Paracheirodon axelrodi requires specific environmental conditions to initiate the spawning process. Studies indicate that manipulating the water parameters could stimulate the reproductive behavior. Among the recommended procedures, the gradual reduction of the water level over several days stands out, followed by a sudden rise simulating the onset of the rainy season, as well as adjusting the pH to slightly acidic values (around 5.5 to 6.0) and decreasing the electrical conductivity (below 100 µS/cm), conditions that mimic the species' natural breeding environment (Anjos and Anjos, 2006). The species spawns in batches, releasing eggs in groups. The eggs are adhesive, attaching themselves to surfaces in the environment. However, *P. axelrodi* is highly sensitive to environmental stressors, such as exposure to ammonium and sudden pH variations, which can cause gill lesions and increased mortality, highlighting the need for strict water quality management (Duncan, 2021).

Paracheirodon innesi

In captivity, *Paracheirodon innesi* readily accepts both live foods such as *Anopheles spp.* larvae (Davis et al., 2019), *Artemia* nauplii (Lipscomb et al., 2023), zooplankton, rotifers (*Brachionus* spp.), *Paramecium* spp., and inert foods like commercial pellets, flakes, and freeze-dried products (Kasprzak et al., 2021).

Juveniles require approximately 53.5% crude protein in their diet; lower levels can negatively affect growth performance (Luna-Figueroa et al., 2001). Diets containing 45–55% protein from either plant or marine sources are well accepted (Sealey et al., 2009), and their energy requirement is estimated at 0.07 kJ/day (Sales and Janssens, 2003). The optimal temperature for feeding ranges from 24°C to 32°C, while values below 20°C significantly reduce intake (Kuhn et al., 2023).

Captive breeding of *P. innesi* is already well-established but still demands technical precision, especially in maintaining acidic, soft water with stable physical and chemical parameters. Sexual maturity occurs early, between 5 and 6 months of age (Chapman et al., 1998), and the species presents noticeable sexual dimorphism: males exhibit slimmer bodies and straight blue stripes, while females are more rounded with curved blue stripes (Ferreira Marinho, 2017).

In neon tetras (*Paracheirodon innesi*), spawning typically occurs in the early morning and lasts 1 to 3 hours. Females lay between 100 and 200 small, translucent, adhesive eggs (Kadtan and Shillewar, 2023; Golob, 2025). Under optimal conditions (24–26 °C), most eggs hatch within 22 to 26 hours, both eggs and larvae are highly sensitive to light and should be kept in low-light or dark environments during incubation. In laboratory settings, larval yields vary significantly depending on broodstock condition and environmental parameters, and are generally lower under uncontrolled or outdoor conditions (Chapman et al., 1998; Golob, 2025). Females typically undergo 5 to 6 reproductive cycles, with 15 to 20-day intervals between spawnings (Kucharczyk et al., 2010). For proper gonadal maturation, broodstock should be kept at 22°C before pairing (Kucharczyk et al., 2010; Kadtan and Shillewar, 2023).

The larvae initially feed on green water and zooplankton (Sanaye et al., 2014). Weaning can begin around day 13 post-hatching with *Artemia* nauplii (Lipscomb et al., 2023), or as early as day 6 using feed containing 53.3% protein combined with live zooplankton (Sanaye et al., 2012). At this stage, the main food items remain rotifers, *Paramecium spp.*, and *Artemia franciscana* nauplii (Chapman et al., 1998; Sanaye et al., 2014).

Paracheirodon innesi is considered a relatively robust species, capable of tolerating moderate environmental fluctuations. In laboratory conditions, optimal growth and health are generally observed between 26°C and 28°C, although the species may tolerate up to 31°C for short periods without significant mortality (Campos et al., 2017; Kuhn et al., 2023). Temperatures exceeding 33.3°C are lethal (Cooper et al., 2019). In its native habitat, such as the Solimões River, average water temperatures often reach 28°C (Campos et al., 2021). The species thrives in acidic, soft waters, tolerating pH levels between 4.0 and 7.0 and water hardness from 18 to 71 ppm (Gonzalez and Preest, 1999). Ideally, nitrogenous waste compounds such as ammonia and nitrite should remain below 0.02 mg/L to prevent physiological stress (Ardi et al., 2020). To ensure fish health, a quarantine period of at least two weeks is recommended before introducing individuals into community tanks, along with rigorous water quality monitoring and sanitary measures (Sugiani et al., 2020).

***Hyphessobrycon* spp.**

Hyphessobrycon species adapt well to both inert diets and live food sources, including zooplankton and microalgae such as *Haematococcus pluvialis* (Morais, 2013). Diets formulated with approximately 40.88% crude protein and supplemented with

0.50 mg/kg of *Hibiscus sabdariffa* extract has improved the zootechnical performance (Cruz et al., 2023).

These species need dissolved oxygen levels between 5.0 and 7.0 mg/L and can endure short periods with levels as low as 3.0 mg/L (Nunes, 2011). Under severe hypoxia (DO < 3.0 mg/L), they exhibit shallow water breathing (SWB) behavior, utilizing the water-air interface to capture oxygen (Kramer and McClure, 1982). Their gills possess specialized filaments that enhance respiratory efficiency (Gonzalez et al., 2018).

Metabolic oxygen demand increases significantly at 28 °C, making it necessary to adjust DO levels accordingly (Wootton, 1999). Optimal environmental parameters include temperatures between 24 °C and 26 °C, slightly acidic pH (5.5–8.0), and water hardness between 22 and 31 ppm (Morais, 2013). Maintaining these physical and chemical conditions is critical for expressing the species' natural behavior and vivid coloration (Furlan-Murari et al., 2022).

Cichlids

The most striking aspect of cichlids, and one that has great practical implications for their maintenance and reproduction in captivity, is the complex social behavior of the species in general and, above all, the presence of robust parental care for the offspring (Jordan *et al*., 2021). Amazonian cichlids, such as those from the genera *Apistogramma* and *Symphysodon* (discus), display territorial behavior and provide pronounced parental care (Mendes; Ricioli; Guillermo-Ferreira, 2021). Although this behavior improves fry survival, it also poses unique management challenges (Carvalho, 2020). External disturbances such as excessive movement or intense lighting may cause parents to cannibalize their eggs or larvae (Mendes; Ricioli; Guillermo-Ferreira, 2021). Reproduction typically occurs on specific substrates or inside cavities, requiring carefully structured environments with low water turbulence (Silva, 2017).

All the species shown in Figure 3 are monogamous and reproduce during the flood season in their habitats, so that the increase in water volume and the frequency of partial water changes serve as a stimulus for reproduction in captivity (Röpke et al., 2024). In addition, they are territorial species, especially during reproduction and incubation of the eggs, which are deposited in some structure (trunks and leaves in the wild; glass or substrates made exclusively for this purpose in captivity, such as clay plates, pipes or PVC sheets) and receive biparental care until hatching (Figure 15), which occurs on average between 48 and 74 hours, resulting in well-formed larvae, which continue to live together and receive protection from the breeders (Mattos et al., 2016).

In the case of the Discus, there is an additional factor, essential for the development of the offspring, known as "suckling" (Figure 16), which is the production of a mucus by the broodstock that serves as the larvae's main food during the first few days of life (Wei et al., 2021). In captivity, some techniques have already been developed for spreading pasteous feed rich in fat and protein on PVC sheets that are placed in larviculture tanks, simulating the suckling period and making it possible to separate broodstock and larvae in the first few days, however, the natural method is still the most widely used in practice (Rezende and Fujimoto, 2021).

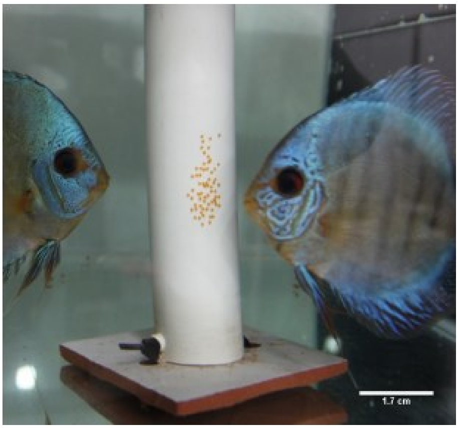


Figure 15. Parental care of *Symphysodon aequifasciatus* during incubation. Source: (Mattos et al., 2016).

Figure 16. Parental care of *Symphysodon aequifasciatus* after hatching of the larvae, which remain close to the broodstock and feed on the mucus released by them. Source: (Mattos et al., 2016).

Nanocichlids

Considering environmental comfort for nanocichlids breeding pairs in an aquarium, the enrichment of environment with lots of vegetation and logs is extremely beneficial for maintaining these animals (Rodrigues et al., 2012). However, in a production context, with higher densities and a greater focus on efficiency, high environmental enrichment can generate a phenomenon of increased value of resources (in this case, objects such as territory), which will be conquered by dominant males and may lead to an increase in aggressive behavior (Kochhann and Val, 2017). In this view, as occurs for other species of non-Amazonian cichlids of extreme economic importance, such as tilapia, avoiding the presence of natural or artificial structures (e.g., stones, PVC pipes, or other objects that allow territorial delimitation) in the tanks and maintaining stocking densities between 20 and 40 kg/m³ as recommended by Rodrigues et al. (2021) can stimulate schooling behavior and reduce the frequency of agonistic interactions.

***Apistograma* spp.**

The species is omnivorous, with a diet based mainly on small benthic invertebrates, such as insect larvae and microcrustaceans, as well as organic debris (Virgilio et al., 2022). In captivity, it accepts live food (*Artemia*, *Daphnia*), frozen food, and commercial feed with high protein content (40 to 45%) (FishBase, 2023). In terms of environmental conditions, *A. agassizii* tolerates a wide range of physical and chemical conditions, preferring pH between 4.0 and 6.5, low conductivity (10 to 50 µS/cm), and temperatures between 24 and 30 °C. The ideal water hardness is less than 10 dGH, with dissolved oxygen above 5.0 mg/L (Römer, 2001; FishBase, 2023). However, it is sensitive to the presence of nitrites and ammonia, requiring efficient biological filtration to maintain water quality (FishBase, 2023).

Reproduction occurs in cavities, such as leaves or logs, where the female lays up to 100 adhesive eggs (Virgilio et al., 2022). Parental care is exclusive to the female, who protects the eggs and larvae, while the male guards the territory (Barlow, 2000). Hatching occurs between 48 and 72 hours, and the fry become independent after 7 to 10 days (Silva et al., 2022).

During the larval and juvenile stages, these fish require environments with shelter and a spatial structure that allows for the division of territories, since constant proximity between individuals can generate aggression, especially in confined spaces (Oliveira, 2016). Competition for food between fry is intense and is exacerbated by asymmetrical growth and social hierarchy. This requires food to be divided into multiple daily portions and batches to be segmented by size (Alves; Rojas; Romagosa, 2009; Silva et al., 2022). Inadequate management, such as overcrowding and insufficient food supply, contributes to episodes of cannibalism and the spread of diseases, often associated with opportunistic pathogens such as *Aeromonas* and *Pseudomonas*, as well as external parasites such as *Ichthyophthirius multifiliis* and *Gyrodactylus* spp. (Barreto and Volpato, 2004; Alves; Rojas; Romagosa, 2009).

Loricarids

In the case of ornamental siluriformes, such as loricariids (plecos) and callichthyids (*Corydoras* spp.), the benthic behavior and peaceful nature of the adults contrasts with the vulnerability of the fry to physical injuries and secondary infections. These species exhibit reproductive strategies involving substrate spawning, where eggs are generally adhesive and deposited on vertical surfaces, plant leaves, or inside shelters and PVC tubes, depending on the species and environmental stimuli (Fernandes; Ribeiro; Silva Neto, 2021). For successful incubation, it is crucial to maintain high levels of dissolved oxygen (above 6 mg/L) and gentle water circulation to prevent the accumulation of detritus without causing excessive turbulence that could dislodge or damage the eggs. The use of air stones or low-flow sponge filters is recommended for maintaining water quality and oxygenation during incubation (Corrêa and Cerqueira, 2007).

After hatching, *Corydoras* and *pleco* larvae exhibit sensitive fin spines and a high susceptibility to physical injuries, especially when kept on coarse or abrasive substrates. Therefore, smooth-bottom tanks or fine sand substrates are preferred. Handling must be minimized, and, when necessary, performed using soft-mesh nets or pipettes to avoid damage. During the first days post-hatching, fry rely on yolk sac reserves but require the introduction of suitable exogenous feed (e.g., infusoria, rotifers, or commercial microdiets) within 2–3 days, followed by gradual inclusion of Artemia nauplii or finely powdered feed to ensure adequate growth and survival (Riley et al., 2020; Chiang, et al., 2024).

Cannibalism is uncommon in these species; however, size heterogeneity may emerge rapidly, particularly under high-density conditions or limited feed availability. Thus, it is recommended to provide multiple small feedings (4–6 times/day) and implement size grading as necessary (Corrêa and Cerqueira, 2007). The use of submerged shelters (e.g., ceramic tubes, synthetic plants, or mesh structures) reduces stress and interspecific aggression, while also mimicking natural microhabitats.

Diseases such as bacterial infections by *Flavobacterium columnare*, *Aeromonas hydrophila*, and *Edwardsiella* spp. are frequent in poorly managed systems, especially after rough handling or water quality fluctuations that compromise the protective mucous layer, preventive strategies include maintaining stable water parameters (temperature between 24–28 °C, pH around 6.5–7.2, and low ammonia/nitrite), using probiotic-enriched diets, and avoiding overcrowding (Ishikawa et al., 2012; Fernandes; Ribeiro; Silva Neto, 2021).

Aruanã

In captivity, it accepts a variety of foods, such as earthworms, chironomid larvae, crickets, live fish, balanced feed, and insects (Méndez et al., 2019; Kusumanti et al., 2023). For maintenance in aquariums, the species requires specific physical and chemical parameters: temperature between 24 and 30 °C, pH between 5.5 and 8.9, hardness between 5 and 15 dGH, maximum ammonia of 0.25 mg/L, and dissolved oxygen greater than 6 mg/L (Kusumanti et al., 2023). Due to its size and active behavior, it requires large tanks (5,000 to 10,000 liters). Individuals between 15 and 50 cm require aquariums between 2 and 3.5 m long, with a minimum recommended height of 50 cm to ensure comfort (Fauna Tropical, 2025). The silver aruanã (*Osteoglossum bicirrhosum*), one of the largest ornamental species in the Amazon ichthyofauna, has a different set of requirements, including warm water temperatures (26–30 °C), low to moderate water flow, slightly acidic to neutral pH (6.0–7.0), and a spacious environment due to its large size and territorial behavior (Rezende and Fujimoto, 2021).

Fast-growing, predatory and territorial, *Osteoglossum bicirrhosum* demands spacious tanks with a low stocking density, preferably with a structure that minimizes shocks against rigid surfaces, given its tendency to jump (Birchmeier, 2000). Competition for food in this species is less associated with the volume of food available and more related to hierarchical dominance and accessibility to feed or live food (Moreau and Coomes, 2006).

Dietary management should prioritize the provision of a diet with a high energy density, balanced in animal protein and divided throughout the day to avoid gastric overload (Brown, 1995). Health challenges include bacterial and parasitic infections, especially in systems with low water renewal and an accumulation of organic matter (Tavares-Dias and Mariano, 2015). Susceptibility to fungal infections, such as *saprolegniosis*, is high in individuals with dermal lesions or in environments with compromised water quality (Varello et al., 2019). In addition, predation and cannibalism are relevant risks during the initial cultivation phase, and separate management by size range and the elimination of stressors are recommended (Brown, 1995; Rezende and Fujimoto, 2021).

Potamotrygonidae

The Potamotrygonidae family is the only group of elasmobranchs exclusive to freshwater environments (Padilha et al., 2021). Within this family, the genus *Potamotrygon* stands out as having the largest number of species and the greatest commercial interest. Some species of the genus, such as *Potamotrygon magdalenae*, are highly endemic, with most of these species endemic to the Rio Negro basin and adapted to more acidic waters, with a pH between 6.0 and 6.8, while others, such as *Potamotrygon motoro*, occur in more than one river basin and adapt more easily to a pH close to neutrality, between 6.5 and 7.2 (Ramos-Espinoza; Chuquipiondo; Serrano-Martínez, 2017; Márquez-Velásquez et al., 2019).

Like elasmobranchs in general, these species of freshwater stingrays are carnivorous, consuming a range of prey in their natural habitat, from arthropods and mollusks to bony fish (Shibuya; Zuanon; Tanaka, 2012).

Sexual dimorphism occurs mainly through the presence of the claspers in males, a pair of sexual organs used to inseminate the female (Morales-Gamba et al., 2019). Reproduction in captivity is uncommon, and the market is supplied by specimens captured in the wild. However, due to capture pressure and, mainly, environmental degradation, several species of the Potamotrygonidae family are at risk of extinction (Vazquez and Lucifora, 2023), which has generated growing interest in techniques for collecting and preserving male sperm, even though a future process of inseminating females in captivity is complex, since fertilization occurs internally (Padilha et al., 2021).

In captivity, freshwater stingrays tend to be docile and calm, and it is preferable not to keep them with very agitated or nibbling fish, so that they do not become severely cornered. At the same time, the presence of smaller fish that fit in their mouths should be avoided, so that predation does not occur, additional care is required when handling these species, as they have stingers and produce venom, which can result in accidents if handled incorrectly, these tend to cause intense local pain, usually without significant systemic manifestations (Brisset et al., 2006), although these are possible and can cause nausea, vomiting, salivation, profuse sweating, respiratory depression, muscle fasciculations, and convulsions, although fatalities are rare (Lameiras, Costa; Dos-Santos, 2020).

Reproduction induction in capitivity

The captive reproduction of Amazonian ornamental fish is fundamental for species conservation and sustainable market supply (Silva et al., 2022; Sousa et al., 2024). Several groups, such as tetras, cichlids, catfish, armored catfish, and others, have reproductive potential in controlled environments, if adequate management, environmental, and feeding conditions are observed (Pereira and Henriques, 2019). Reproduction in captivity is feasible for several

Amazonian ornamental species, but depends on specific practices for each group and species (Caldas and Godoy, 2019).

Factors affecting reproduction in captivity:

a) Environmental enrichment: Enriched environments that simulate the natural habitat improve gamete quality and reduce anomalies in larvae, as observed in tetras (*Astyanax bimaculatus*) (Sousa et al., 2024).
b) Feed management and density: For cichlids such as *Heros severus*, fractional feeding (four times a day) and a density of up to five larvae/L promote better growth and survival (Abe et al., 2016).
c) Social structure and territoriality: Dwarf cichlids (*Apistogramma agassizii*) exhibit parental care and territoriality, with good reproductive rates in captivity, making them suitable for the ornamental trade (Silva et al., 2022).

There are various methods of breeding fish in captivity, but the reproductive biology of the species in question, environmental conditions and available facilities must be taken into account (Sousa et al., 2024). Captive breeding techniques enable new technologies to be used in the commercial production of ornamental fish, increasing production and conserving the stock of endangered endemic species (Vazzoler, 1996; Mercy, 2003). As soon as the animal matures in its reproductive cycle, the stages of reproduction in vertebrates are coordinated first by the nervous system and then by the endocrine system (Kirschbaum, 1987). This action can occur naturally, with environmental stimuli that induce reproduction, or through hormonal induction (Vidal, 2003).

The first criterion for successful reproduction is to select mature animals, which is not always explicit, as a number of characteristics must be taken into account. Each species has specific characteristics for its reproductive strategies.

Reproductive success, however, is conditioned by multiple factors, including the ability of organisms to reproduce in highly variable environments and the efficient allocation of energy resources for reproduction (Vazzoler, 1996). For such investment to result in reproductive success, individuals of each species develop specific sets of characteristics that make up their reproductive strategy (Vazzoler, 1996; Lima, 2024). These strategies, in turn, are unique to each species, although they are adaptable to environmental fluctuations. Such adaptations are known as reproductive tactics, representing phenotypic responses to environmental conditions, as evidenced by Wootton (1990) and Vazzoler (1996).

Many Amazonian ornamental fish have reproductive cycles related to periods of drought or rainfall, with reproduction being common during the rainy season and the gonads regressing during droughts (Lowe-McConnell, 1975). Regarding this relationship, there are hypotheses that physicochemical factors in the water, turbidity and changes in photoperiod are the main factors responsible for these stimuli that encourage reproduction in some species (Schwassmann 1980). This often requires changes in the environment, such as a new water supply, an increase in the pond's water level, or the presence of certain vegetation as an egg collector for the animals to build their nests (Kirschbaum, 1987; Wootton, 1990).

During the reproductive cycle, changes are more easily observed in the gonads, which go through the following stages: immature; resting; initial maturation; final maturation; regression; and exhausted (Rodrigues, 2013). During this process of hormonal changes, the gamete development stages occur, namely gametogenesis. Gonadal enlargement and maturation can be caused by manipulations in the environment, such as decreasing the conductivity of the water, increasing the water level and imitating rain, while gonadal regression can be caused by a continuous increase in conductivity (Kirschbaum, 1979; Wootton, 1990).

Some animals show dimorphism, such as the cardinal tetra, with females being larger than males. These are characteristics that make it possible to distinguish sexually mature individuals (Wootton, 1990; Rodrigues, 2013). Vazzoler (1996) states that fecundity in fish is directly related to body size or environmental conditions. When the spawners are mature, it is common to see an enlarged and soft abdomen in the females, and swollen and reddish genital papillae (Rodrigues, 2013). Males, on the other hand, release small amounts of semen when pressed on the abdomen. The time it takes for them to reach maturity varies from one species to another, for example, the Dwarf-cichlid (*Apistogramma cacatuoides*) can have its first spawning at six months of age (Alves, 2009).

Thus, environmental factors such as food availability, stress, social interactions, photoperiod and water quality may be the main stimuli for reproduction (Muron et al., 1990; Sousa et al., 2024). Chapman (1998), studying the reproductive performance of the Neon tetra (*Paracheirodon innesi*) in captivity, found that wild individuals hardly reproduce in captivity, while those that have been domesticated for a few generations do so easily (Beltrão, 2006). Receiving environmental stimuli, such as daylight or photoperiod, as well as temperature and rainfall, is a function of the nervous system and involves passing information from sensory receptors to the brain

(Rodrigues, 2013). Through chemical messengers, the pituitary gland releases a hormone called gonadotrophin whose target organ is the gonad (Beltrão, 2006). It stimulates the production of sex steroids in the gonad and these steroids are responsible for the maturation of gametes (Rodrigues, 2013; Sousa et al., 2024). In other words, the reproductive process depends on endogenous regulation but is influenced by external factors.

Reproduction in captivity using the hypophysial technique as a hormonal induction has been carried out in Brazil for decades because it is an artificial and effective control. In females, it causes the final maturation of the gametes, ruptures the follicular envelope and releases the mature oocytes (Rodrigues, 2013). In males, it produces an increase in semen volume, increasing fluidity and the number of sperm. With hormone induction, it is usually only the females that are injected with the hormone, which triggers the process of final maturation of the eggs for reproduction (Kirschbaum, 1987; Beltrão, 2006). Females can be cannulated using a urethral probe to take samples of the oocytes, which must be a certain color and size depending on the species selected for reproduction (Rodrigues, 2013). The hormone induction procedure is more common in females (Alves, 2009), but, when necessary, males can also undergo the process.

According to Rodrigues (2013), the most commonly used inducing agents are:

a) Pituitary extract: most commonly used for its practicality. The pituitary gland is where gonadotrophic hormones accumulate in sexually mature fish. The pituitary gland is taken from sexually mature fish and marketed. Its preparation consists of macerating it in a crucible and diluting it in physiological solution.
b) hCG (human chorionic gonadotrophin): induces maturation by acting directly on the gonad.
c) LH-RH (luteinizing hormone-releasing hormone): is commonly used in combination with a dopamine inhibitor, a common technique for spawning catfish (Junior 2003). Its response usually takes longer and its commercial cost is higher (Rodrigues, 2013)
d) GnRH (gonadotropin-releasing hormone): stimulates animals to synthesize their own GtH.

With the use of pituitary extract, rheophilic fish commonly use two doses. The first dose is the preparatory dose and after a period of time, on average 12 hours, another so-called definitive dose is applied (Vazzoler, 1996). This technique is also used for ornamental fish species, but the oocyte maturation peaks of each species must be known beforehand (Junior, 2003). The application should be intramuscular or intraperitoneal (Rodrigues, 2013). Egg maturation and spawning occur more quickly as the water temperature increases, within the thermal comfort range for the species (Junior, 2003; Rodrigues, 2013). Hour-degrees should be monitored to be more certain of the spawning time.

One difficulty in this process is that in ornamental fish, the matrices are often less than 15 grams, so they are sensitive animals and can still be aggressive, which is why handling must be cautious (Kirschbaum, 1987). Oocytes and sperm should be collected in dry containers, avoiding contact with water as the hydration of oocytes and semen leads to a rapid reduction in fertilization capacity (Rodrigues, 2013). The female's belly should be compressed in an antero-caudal direction until the oocytes appear to be completely removed. With the male, the same process must be repeated until there is no more semen. The male and female gametes must be carefully mixed before finally hydrating with water and taking the eggs to the incubators (Junior, 2003; Rodrigues, 2013).

Incubation period and embryonary development of ornamental fish species in captivity

The species of tetras, Neon (*Paracheirodon innesi*), Cardinal (*Paracheirodon axelrodi*) and Serpae tetra (*Hyphessobrycon eques*), belong to the order Characiformes and have similar reproductive strategies, with total spawning and external fertilization (Beltrão et al., 2006). Under controlled laboratory conditions, hatching occurs between 18 and 30 hours after fertilization, depending on the species and the water temperature, which ideally ranges from 24 to 28 °C (Godinho; Lamas; Godinho, 2010).

Embryogenesis takes about 22 hours at 26 °C, and the embryos show rotatory movements between 16 and 18 hours after fertilization, with complete hatching at 2 days (Beltrão et al., 2006; Godinho; Lamas; Godinho, 2010). During the initial stages of development, the tetras present embryos with a defined notochord, visible somites and accentuated ocular pigmentation before hatching, the larvae hatch with a yolk vesicle and begin exogenous feeding after around three days, variations in the electrical conductivity and pH of the water affect the hatching rate (Rezende and Fujimoto, 2021).

The cardinal tetra (*Paracheirodon axelrodi*) produces spherical, translucent, adhesive, and demersal eggs, with an average diameter of 0.93 mm. Spawning is of the batch type. Oocyte development is trimodal, with diameters ranging from 0.06 to 0.66 mm, embryonic development at 26°C lasts approximately 19 to 20 hours, resulting in larvae measuring about 2.9 ± 0.2 mm at hatching. By day five, larvae reach 4.1 ± 0.2 mm and show early fin development, at 12 days, red pigmentation begins to appear at the base of the anal fin, followed by the characteristic metallic blue stripe. By day 22, juveniles resemble adults, measuring approximately 11.0 ± 1.0 mm, from the sixth day after hatching, larvae begin feeding on *Artemia* nauplii (250–350 µm), continuing for up to 60 days (Anjos and Anjos, 2006).

Among the ornamental cichlids, there are the Discus fish (*Symphysodon* spp, the banner cichlid (*Pterophyllum scalare*) and the Oscar (*Astronotus ocellatus*), species that show intense parental care, with guarding and ventilation of the eggs, incubation occurs between 36 and 72 hours after laying, in waters with a temperature between 27 and 30 °C and a slightly acidic pH, 6.0-6.8 (Morais, 2005). Reproduction in captivity requires vertical substrates for the adhesion of the eggs, which are transparent and measure around 1.5 mm. The hatching rate is dependent on oxygenation and the cleanliness of the surface. After hatching, the parents continue to protect the fry, which feed on the mucus secreted by the epidermis of the adults in the first few days (Morais, 2005; Soares, 2015). The freshwater angelfish (*Pterophyllum scalare*) has faster embryonic development compared to the Discus fish (*Symphysodon* spp.), hatching in up to 36 hours, and is also oviparous and has similar biparental care (Soares, 2015). The Oscar (*Astronotus ocellatus*), on the other hand, has larger eggs, 1.8-2.0 mm, and embryonic development occurs between 48 and 72 hours, with hatching dependent on temperature, the parents removing unfertilized eggs and ventilating the embryos through fin movements (Rezende and Fujimoto, 2021).

Species of nanocichlid such as *Apistogramma cacatuoides*, possess oviparous reproduction, usually in cavities, the eggs are adhesive and carefully guarded by the female, hatching occurs between 48 and 72 hours, with thermal dependence around 26-28 °C, the larva remains in the nest until the vitelline vesicle is reabsorbed, being led by the female to safe areas (Alves, 2007; Soares, 2015).

Ornamental catfish species, especially those belonging to the families *Callichthyidae*, *Corydoras* spp. and *Loricariidae*, *Otocinclus* spp. and *Hypostomus* spp. exhibit high reproductive diversity. *Corydoras* perform external fertilization with characteristic "T-position" behavior (specific posture during the spawning process, where the fish position themselves so that their ventrals are facing each other), and their adhesive eggs are deposited on vegetated surfaces or artificial substrates, hatching between 72 and 96 hours, depending on the temperature (Vasquez, 2015).

Otocinclus spp. are known for having small, translucent eggs, with incubation estimated at between 36 and 48 hours at a temperature of 25 °C. Few data are found in the literature due to the difficulty of reproduction in captivity, while Plecos, e.g. *Hypostomus* spp., *Pterygoplichthys* spp. spawn in cavities, hollow trunks or excavated substrates, showing male parental care (Rezende and Fujimoto, 2021). Egg incubation can last between 96 and 120 hours, with variations by species and temperature (Soares, 2015; Ohara et al., 2017). In the case of *Hypostomus rondoni*, a species endemic to the Teles Pires River, the eggs measure around 3 mm and are laid in burrow nests built in sandy substrates, guarded by the male (Ohara et al., 2017).

The silver aruanã (*Osteoglossum bicirrhosum*) has one of the most unique reproductive strategies among Amazonian ornamental fish. It is a male buccal incubator species. The eggs, which are large in diameter (around 8 mm), are deposited by the female and immediately collected in the male's oral cavity, where they remain for 3 to 4 weeks, until the fully developed juveniles are released (Rezende and Fujimoto, 2021; Ohara et al., 2017). This long incubation period in the mouth and the small number of eggs give the aruanã high vulnerability in natural environments and explain its high value in the ornamental market, making it one of the most desired and targeted species by aquarists in Brazil (Soares, 2015).

Larvae and fry production

Finfish fry play a fundamental role in the Amazonian ornamental fish production chain, being the basis of reproduction and captive breeding, whether through natural spawning or artificial reproduction, guarantees the continuity of the species and the supply of fish for aquarists and breeders (Andrade and Yasui, 2003). The availability of healthy and well-adapted fry is essential to ensure an efficient production cycle, with a lower mortality rate and better growth rates, essential aspects for the competitiveness and sustainability of the activity (Lima et al., 2017).

In the Amazon region, where species of high ornamental value are common, such as tetras, dwarf cichlids, wild guppies, catfish the proper management of fry is essential to ensure the sustainability of the activity and the conservation of local biodiversity (Rezende and Fujimoto, 2021). Many of these species have biological and behavioral characteristics that require specific care from the initial stages of development (Abe et al., 2016). Thus, attention to the fry stage contributes not only to reproductive success in farming systems, but also to reducing pressure on natural populations, promoting the sustainable use of resources and the viability of the production chain (Oliveira et al., 2020).

The fry stage is one of the most critical periods in ornamental fish farming, especially in fish farming for Amazonian species (MAPA, 2013). At this early stage, the organisms are extremely sensitive to environmental variations, pathogens and stress factors, which requires special and continuous care on the part of the breeders, the vulnerability of the fry is directly reflected in the survival rates, growth and final quality of the fish, affecting the entire production chain (Zuanon; Salaro; Furuya, 2011).

Fish species can be classified as precocial or altricial (David-Ruales; Machado-Fracalossi; Vásquez-Torres, 2018). Precocial species exhibit larger eggs and more developed larvae at birth, allowing them to feed independently earlier and greater acceptance of a formulated diet from the start of exogenous feeding (Portella et al., 2012; Piesiewicz et al., 2024). On the other hand, altricial species have poorly developed larvae at birth, usually with an immature digestive system, initially without oral and anal openings (Gao LuJiao; Shi ZhaoHong; Yan Ying, 2007) and depend on the yolk sac for nourishment during the first days of life (Zakeri Nasab et al., 2020). This difference highlights the different evolutionary strategies that fish use to adapt to their environments (David-Ruales; Fracalossi; Vásquez-Torres, 2018).

The larvae of altricial species initially depend on limited reserves in the yolk sac. After opening the mouth and anus, they begin the transition to exogenous feeding, preferably with live food to ensure a higher survival rate (David-Ruales; Fracalossi; Vásquez-Torres, 2018; Pan; Souissi; Jepsen, 2022). Due to their high nutritional value, easy digestibility and small size, the main live foods used in fish larviculture are *Artemia*, *Daphnia* and rotifers (Anetekhai et al., 2005; Schwepe et al., 2022).

In Tetra fish, such as Neon (*Paracheirodon innesi*), the mouth of the larvae opens and exogenous feeding begins four days after hatching, with complete absorption of the yolk sac on the sixth day (Ferreira Marinho, 2017). In the Cardinal (*Paracheirodon axelrodi*), exogenous feeding begins on the sixth day after hatching, and the yolk sac is completely absorbed on the fifth day after hatching (Anjos and Anjos, 2006). In the Serpae tetra (*Hyphessobrycon eques*), the opening of the mouth and anus, as well as the start of exogenous feeding, occurs between the third and fifth day after hatching (Park et al., 2014; Çelik and Cirik, 2020).

In cichlids, such as the Discus fish (*Symphysodon aequifasciatus*), the larvae hatch with a large yolk sac, which is completely absorbed after seven days (Satoh et al., 2017). The digestive tract differentiates on the third day and, at five days old, they start actively feeding, with developed jaws and gill arches (Önal; Celik; Cirik, 2010). For *Pterophyllum scalare* larvae, exogenous feeding begins at 5 days after hatching (Eiras et al., 2023). The yolk sac remains present during this period, providing essential nutrients until the larvae can make the complete transition to external feeding (Radael et al., 2013). In the Oscar (*Astronotus ocellatus*), the start of exogenous feeding was observed from 157 hours after hatching, and from hatching to absorption of the yolk sac, around 257 hours (Paes et al., 2012). During the larval stage, the digestive system develops and taste buds appear (Paes et al., 2015).

Fish known as “bottom feeders” or "pepper coridoras *Corydoras* aff. *paleatus*, the larvae begin feeding exogenously between the eighth and ninth day post-fertilization, with the yolk sac being absorbed between the 11th and 14th day (Rodríguez-Ithurralde; del Puerto; Fernández-Bornia, 2014). *Corydoras panda* larvae absorb the yolk sac around the fifth day and begin to feed exogenously on the third day (Sulistyowati and Alifuddin, 2005). The zebra catfish, also popularly known as the imperial zebra catfish, acari-zebra, and zebrinha (*Hypancistrus zebra*) larvae hatch with a bulky yolk sac that is completely absorbed by the tenth day, and although the mouth opens on the first day after hatching, exogenous feeding only begins on the eighth day (Ramos, 2016). Similarly, Reis et al. (2021) observed that Plecostomus Tigre (*Hypancistrus* sp.) larvae began consuming brine shrimp on the eighth day, coinciding with the development of the appropriate mouth size for this feeding.

In other popular species, such as *Apistogramma*, feeding of the larvae can begin on the fifth day after hatching (Zanfurlin-Lima et al., 2024). In the case of the Silver Aruanã, also a popular species, the male incubates the eggs in the mouth cavity, ceasing parental care after the yolk sac has been completely absorbed (Garzón-Ortíz et al., 2015; Veneza et al., 2023). Exogenous feeding begins around the 65th day, and incubation can last up to six weeks. (Queiroz, 2008).

In this sense, the development of larvae and juveniles is directly linked to the type of food offered and the water temperature (Anjos and Anjos, 2006; Zakeri Nasab et al., 2020). Food is a critical factor for the survival and performance of fry, directly influencing their growth and development (Ladago; Marsden; Evans, 2016). Any imbalance in nutrition in the early stages can harm their development and health, as fry are very sensitive to diet quality compared to juveniles (Adewumi, 2018). The diet must be rich in nutrients and meet the requirements of this sensitive stage, with a high concentration of protein and energy, as the animals are still forming organs and tissues (Taipale et al., 2022). Feeding frequency should also be higher, due to the high metabolic rate and rapid growth (Anjos and Anjos, 2006; Rahman et al., 2023).

The initial feeding of larvae is full of challenges, mainly due to the small size of the mouth and the need for nutritionally dense food particles, often with movement to stimulate feeding behavior (Santhosh and Anil, 2013; Vidhya and Pavithra, 2024). At this early stage, larvae need nutrients not only for maintenance and activity, but also for growth (Pratiwy, 2023).

Larvae have specific nutritional needs and digestive systems that are still underdeveloped, making it difficult to formulate suitable diets for this critical stage (Megahed and Aly, 2009; Santhosh and Anil, 2013). In this context, the transition from live foods to formulated diets represents one of the main obstacles, since organisms such as rotifers and *Artemia* spp. are expensive and can represent a health risk due to the possible transmission of pathogens (Megahed and Aly, 2009; Manickam et al., 2019).

However, despite these advances, live feed is still considered essential in the early stages of development, as it provides fundamental nutrients and stimulates the larvae's natural feeding behavior (Hayashi, 2014). The current major challenge remains the formulation of micro-diets capable of completely replacing live food without compromising the growth and survival of the animals (Manickam et al., 2019).

In recent years, advances in biotechnology have made it possible to improve microdiet manufacturing processes, resulting in products with greater nutritional value and better digestibility (Melaku et al., 2024). Microparticulate diets are developed to simulate the nutritional profile of live food and have shown promise in improving acceptance and digestive efficiency by larvae, representing a viable alternative especially for the later stages of larval development (El-Dahhar et al., 2021; Melaku *et al*., 2024). The transition to exogenous feeding occurs around 5-7 days after hatching, depending on the species, when the digestive system matures and digestive enzymes become active (Chakrabarti and Sharma, 2005; Hamza; Ostaszewska; Kestemont, 2015). The synchronization of the resorption of the yolk sac and the start of feeding is fundamental for the survival and growth of the larvae (Chakrabarti and Sharma, 2005; Zakeri Nasab et al., 2020).

Competition for food is one of the main challenges in the management of ornamental fish fry, especially in intensive systems (Ward; Webster; Hart, 2006). During the early stages of development, fry have different nutritional requirements and growth rates, which can intensify the competition for limited resources (Volpato et al., 1989; Rodrigues; Bergamin; Santos, 2013). This competitive behavior occurs both between individuals of the same species and between different species that share the same rearing environment (Ward; Webster; Hart, 2006; Begon; Townsend; Harper, 2007). In view of this, it is essential to understand the specific nutritional needs of each stage and cultivated species, to offer quality feed and to distribute it in a way that is appropriate to the type of system used (such as intensive cultivation, dugouts, stalls, among others) (SENAR, 2019; Rezende and Fujimoto, 2021). In addition, it is essential to adopt management strategies that reduce competition for food, favoring fish welfare, feed efficiency and productive performance (Corrêa and Souza, 2022).

Competition for food can lead to various negative impacts on fry rearing, including uneven growth, increased physiological stress, reduced feed efficiency, increased cannibalism and reduced survival (Suresh and Lin, 1992; Luz et al., 2002; Zuanon; Assano; Fernandes, 2004). These effects are particularly pronounced in crops with high population density, where access to food can be unequal, favoring more aggressive or larger individuals and compromising the development of smaller ones **(**Salaro et al., 2003; Lima, 2013).

In species with territorial or hierarchical behavior, such as some Amazonian cichlids, competition for food can trigger aggression, which in addition to compromising zootechnical performance, increases the incidence of injuries, predisposing the fry to secondary infections (Souza et al., 2021; Ferreira, 2023). In smaller species or those with gregarious behavior, such as tetras, competition is expressed through the speed of food capture, which requires feed formulations with high attractiveness and digestibility, as well as supply strategies that take group dynamics into account (Oliveira et al., 2020).

To mitigate these effects, it is recommended to segment the flocks by size or age, reducing group heterogeneity and promoting a more equitable distribution of feed (Barcellos, 2022). Fractioning the daily diet and the use of automatic feeders optimizes the food supply, avoiding the accumulation of feed at the bottom of the tanks and ensuring equitable access, which favours animal welfare, feed conversion and the maintenance of water quality (Barcellos, 2022). In intensive systems, adequate feeding frequency is essential to keep up with the fast intestinal passage rate, minimize competition and dominant behaviour, prevent gastric distension and maximize digestive efficiency (Barcellos, 2022; Corrêa and Souza, 2022). Supply automation also contributes to precise feed management, reducing losses and ensuring the necessary nutritional intake for all individuals in the flock.

In addition, it is essential that the feed used has the right nutritional balance for each stage of development, containing optimal levels of protein, lipids, vitamins and minerals (Zuanon; Salaro; Furuya, 2011; Rodrigues; Bergamin; Santos, 2013). The inclusion of functional additives such as prebiotics, probiotics and immunomodulators is also recommended (Ferreira et al., 2017; Acunha et al., 2023). These compounds not only promote the balance of the intestinal microbiota, but also increase the fry's resistance to environmental and health stress, contributing to better survival rates, productive performance and the fry's resistance to stress (Toutou et al., 2016; Acunha et al., 2023).

Competition for food is therefore a critical factor that directly influences the zootechnical performance, well-being and sustainability of Amazonian ornamental fish farms (Corrêa and Souza, 2022). Adequate feed management, which involves everything from balanced feed formulation to the adoption of supply strategies and batch segmentation, is essential for minimizing the negative effects of competition and promoting uniform growth of the fry (Ward; Webster; Hart, 2006; Kubitza, 2009). The inclusion of functional additives and strict control of water quality enhance the positive results of nutritional management, contributing to more efficient and resilient ornamental fish farming (Moraes and Martins, 2004; Ferreira et al., 2017). Therefore, investing in understanding the specific nutritional requirements of each species and the associated management practices is essential for successful breeding.

The management of Amazonian ornamental fish fry requires attention to the biological, behavioral and environmental particularities of each taxonomic group (Baras and Jobling, 2002). Each category has different requirements in terms of water quality, reproductive strategies, susceptibility to disease and behavioral patterns, especially in relation to aggression, cannibalism and competition for food

(Piedras and Pouyei, 2004; Corrêa and Silva, 2022). Knowing these differences is fundamental to formulating efficient breeding and rearing protocols capable of minimizing losses and maximizing the viability of offspring.

In short, the success in rearing Amazonian ornamental fish fry depends on the ability of the producer or aquaculture farmer to recognize the specific needs of each group and implement strategies that are compatible with their biology (Alves; Rojas; Romagosa, 2009; Tavares-Dias and Mariano, 2015). Adequate food supply, maintenance of stable environmental conditions and careful health management are indispensable elements for ensuring high survival and zootechnical performance of the fry (Tavares-Dias and Mariano, 2015).

CHAPTER 6

BIOSECUTITY, DISEASES AND PREDATORS

There are several challenges faced in the management of Amazon ornamental fish and they can vary according to the species, variety and farming conditions adopted, from the type of feed to the way they are handled (Piedras and Pouyei, 2004). Among the main obstacles observed are the occurrence of diseases, such as bacterial infections caused by *Aeromonas hydrophila*, *Flavobacterium columnare* and *Edwardsiella tarda*, as well as parasites such as protozoa of the genus *Ichthyophthirius multifiliis* and *Trichodina* species., which compromise the integrity of the skin and gills (Viadanna; Paixão; Fujimoto, 2022). Also recurrent are predation, biosecurity and competition for food, which can generate uneven growth and compromise the zootechnical development and health of individuals (Lima et al., 2013). Understanding these challenges, together with the application of good management and welfare practices, is fundamental to promoting more efficient breeding, reducing losses and ensuring the sustainability of ornamental aquaculture (MAPA, 2013).

Firstly, biosecurity and health are fundamental aspects of fish farming and must be carefully considered at all stages of aquaculture production (MAPA, 2020). Even with the adoption of appropriate nutritional management practices and favorable environmental conditions, these factors alone are not able to guarantee the full zootechnical and reproductive performance of aquatic organisms when the health status is compromised (SENAR, 2017). For this reason, health management should always be adopted and carried out as thoroughly as possible in order to reduce the mortality rate and improve production rates in fish farming (CNA, 2018).

Maintaining the health of the fish is fundamental to guaranteeing proper development, since organisms at an early stage of life have an immature immune system and are therefore highly susceptible to infections and environmental imbalances (Andrade et al., 2004). The implementation of biosecurity measures aims to develop and implement strict operational measures and standards to protect livestock, reducing mortality and promoting animal welfare (MAPA, 2013; Souza, 2021). In this context, understanding the main risks, recommended practices and peculiarities of the health of Amazonian species is fundamental to promoting more efficient, sustainable and resilient production systems (Cardoso and Balian, 2018).

Proper planning, based on a structured biosecurity program, is the first essential step for the success of an aquaculture production system, in the development phase, it is necessary to define initial strategies, such as the careful selection of reliable suppliers for the acquisition of health fry (Soares et al., 2002; Zanolo and Vasquez, 2021). In addition to the appropriate choice of species, it is important to consider the biological compatibility between the species worked on and the specifications of the production facilities (ponds, tanks, aquariums, among others) (SENAR, 2018).

Biosecurity measures must be adopted, such as quarantine of the new batches of fish, establishment of a sanitary vacuum, installing physical and chemical barriers, and standardizing handling, cleaning and disinfection procedures (MAPA, 2013; Cardoso and Balian, 2018). Continuous supervision is essential and should include systematic monitoring of the animals, the completion of health records and the early identification of behavioral changes or clinical signs of disease (CONCEA, 2018). Finally, it is essential that all these actions are integrated into an active prophylaxis approach, aimed at maintaining the health of the fish and the sustainability of the production system (Portz et al., 2013).

In addition to the biosecurity guidelines established in each pillar, it is essential to correctly determine the stocking density for the species under culture, as it is an important biological factor that affects the survival, behavior and development of the fish (Andrade et al., 2004; Lima et al., 2013). Overcrowding compromises the delicate balance between the pathogen load, the physical-chemical parameters of the water and the fish biomass, reducing the animals' resistance and increasing the risk of disease outbreaks (Iwashita and Maciel, 2013). This imbalance in the parasite/host/environment relationship can result in clinical signs such as apathy, crowding at the entrance to the water or on the surface due to respiratory problems, hemorrhages in the body, gills or internal organs, corrosion of fins, opacity of the eyes, itching and behavioral changes caused by ectoparasites, highlighting the importance of proper management to avoid negative impacts on the health of organisms (Portz et al., 2013).

Recurring diseases have been one of the obstacles in the management of ornamental fish fry, affecting both productive performance and the health of the farm (Rezende and Fujimoto, 2021). During the initial development phase, fry are particularly vulnerable to a variety of diseases due to the immaturity of the immune system, the high stocking density and the rearing conditions (Lima et al., 2013; Alves, 2024). In addition, the relationship between pathogens and fish can be amplified by factors such as inadequate water quality, poor feeding and stress generated by poor management practices (SENAR, 2017; Rezende and Fujimoto, 2021). Disease control, therefore, requires an integrated approach that considers both preventive and curative aspects, seeking to ensure fish welfare, optimize productivity and reduce economic losses (MAPA, 2013). In this context, understanding the main pathogens that affect ornamental fish fry, as well as the conditions that favor the emergence and spread of these diseases, is essential for the success of ornamental aquaculture.

Diseases in ornamental fish fry are often caused by an imbalance in the host-pathogen-environment relationship (Portz et al., 2013). However, diseases do not always have a direct origin in a specific pathogen, such as parasites, bacteria, viruses or fungi (MS, 2001; Dotta and Piazza, 2012). Often, they are a reflection of inadequate management conditions, such as poor water quality, unbalanced nutrition or genetic factors in the fish (MAPA, 2013). An environmental imbalance that compromises water quality or nutrition can cause stress in the fry, favoring disease outbreaks (Rezende and Fujimoto, 2021). This context reinforces the importance of good management practices to ensure the health and well-being of the animals.

Diseases can be classified according to their causative agent, such as bacteria, viruses, fungi and parasites (SENAR, 2017). Bacteria are among the most important disease-causing agents in both farmed and ornamental fish (Yesmin et al., 2004). It is important to note that most of the bacteria that cause disease in fish are considered opportunistic, i.e. they are part of the normal microbiota present in the water, skin and intestines of fish (Rezende and Fujimoto, 2021). When the balance between these microorganisms and the fish's organism is disrupted, whether due to stress factors, compromised immunity or inadequate handling conditions, opportunistic bacteria can proliferate, making the fish vulnerable to infection (Dotta and Piazza, 2012; Marra; Rocha; Tavares, 2022).

Gram-negative bacteria, such as *Aeromonas*, *Citrobacter*, *Edwardsiella*, *Flavobacterium*, *Mycobacterium*, *Pseudomonas* and *Vibrio*, are the main causes of mortality in ornamental fish (Canabarro et al., 1992; SENAR, 2017). Regardless of the pathology, fish generally show non-specific clinical signs, which are common to various diseases. These signs can manifest themselves in different ways: behaviorally, with inappetence, erratic swimming, lethargy and breathing difficulties; externally, with deformities, pale gills, increased mucus, depigmented or hemorrhagic areas, fringed fins, exophthalmos, skin lesions, loose or raised scales, distended abdomen and the presence of visible parasites; and internally, during necropsy, enlargement and darkening of the spleen, hemorrhagic liver, enlargement of the heart and kidneys, presence of blood in the intestine and anal region, as well as accumulation of opaque or bloody fluid in the abdominal cavity can be observed (Lima et al., 2013; Barcellos, 2022; Viadanna; Paixão; Fujimoto, 2022). "

Fungal disease is one of the most recurrent in ornamental fish and, like opportunistic bacterial infections, is generally associated with the presence of fungi that already exist in the aquatic environment, whose pathogenic action depends on predisposing factors, such as stress or lesions that act as entry points (Rodrigues; Bergamin; Santos, 2013; Rezende and Fujimoto, 2021). Among the various pathogenic genera, *Saprolegnia, Achlya* and *Branchiomyces* stand out as the most common, taking advantage of damage to the epidermis, physiological stress, immunosuppression or deterioration in water quality to establish themselves. These infections can cause skin lesions, gill involvement and, in severe cases, systemic infections (Viadanna; Paixão; Fujimoto, 2022). Clinically, the appearance of cottony growths on the skin and fins is characteristic, with the possibility of necrosis and respiratory failure (Dotta and Piazza, 2012). Prevention is based on good management practices, quarantine of new individuals, strict control of water quality and reduction of stressors, with prophylaxis being the main strategy to prevent outbreaks (MAPA, 2020).

Parasites are one of the most frequent and worrying groups, especially due to their high dissemination capacity and direct impact on the health and productive performance of fish (Valladão, 2022). These organisms can be classified as ectoparasites, which have contact with the skin of the hosts, and endoparasites, which have deep contact with the tissues and organs of the hosts (Dotta and Piazza, 2012). The most common ectoparasites in Amazonian ornamental fish include protozoa such as *Ichthyophthirius multifiliis* ("white spot disease") (Figure 17), *Trichodina reticulate* and *T. nobilis* (Figure 18), *Ichthyobodo* spp. (Rogers, 2014) (Figure 19) and *Epystilis* spp. (Figure 20), monogenean species of the genus *Dactylogyrus*, such as *Dactylogyrus anchoratus*, *Dactylogyrus baueri*, and *Dactylogyrus formosus* (Figure 21), which adhere to external tissues, causing irritation, increased mucus production, necrosis and respiratory difficulty (Pádua et al., 2012; Portz et al., 2013). Endoparasites, such as nematodes (*Camallanus* sp.) (Figure 22), cestodes *Schyzocotyle* (=*Bothriocephalus* sp.) (Figure 23) and myxozoan (Figure 24), can cause progressive weight loss, abdominal distension, internal lesions and impaired metabolism (Dotta and Piazza, 2012; Rezende and Fujimoto, 2021; Viadanna; Paixão; Fujimoto, 2022).

Figure 17. *Pseudoplatystoma* sp. Parasitized by *Ichthyophthirius multifiliis* causative agent of “white spot disease”. Source: Martins et al. (2015).

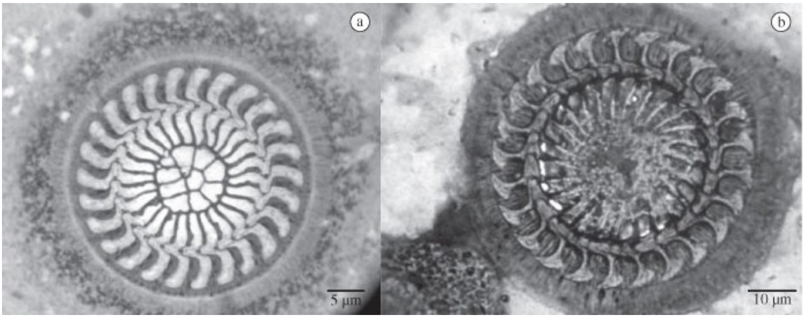


Figure 18. Photomicrographs view of *Trichodina reticulata* (a) and *T. nobilis* (b). parasitizing ornamental freshwater fish cultured in the state of Santa Catarina, Brazil. Source: Martins et al. (2012).

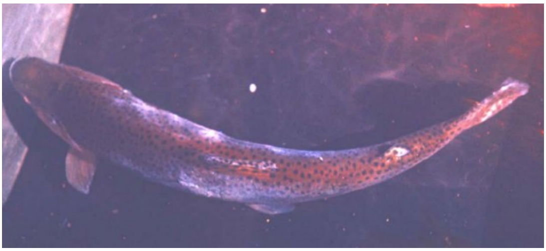


Figure 19. *Ichtyobodo* spp. infection with skin turbidity. Source: Rogers (2014).

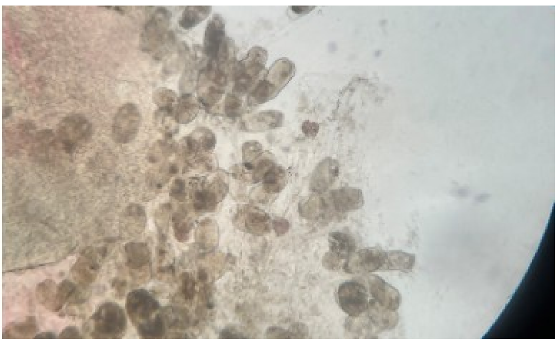


Figure 20. *Epistylis* on wet mount preparations under a light microscope at 20 x magnification. Source: Maciel et al. (2024).

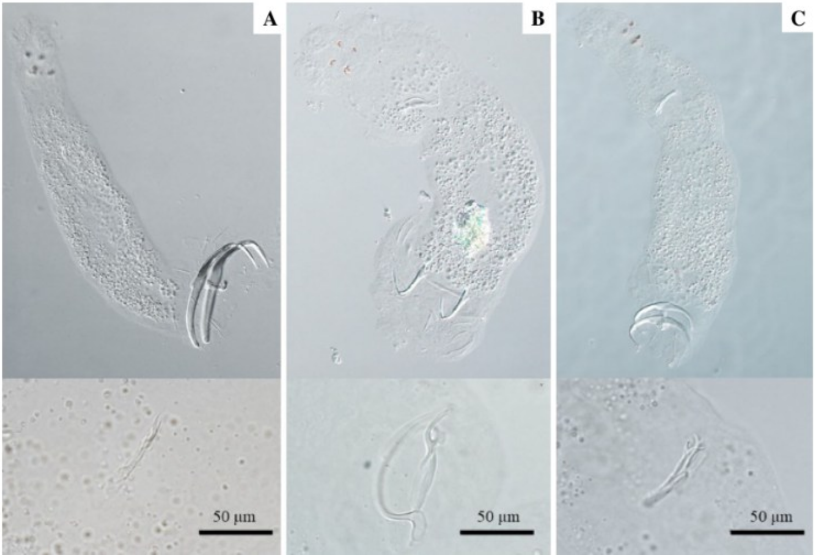


Figure 21. Photomicrographs of monogenetic parasites of the genus Dactylogyrus found in the gills of *Carassius auratus* farmed in southern Brazil. (a) *Dactylogyrus anchoratus*; (b) *Dactylogyrus baueri*; (c) *Dactylogyrus formosus*. Source: Tancredo and Martins (2019).

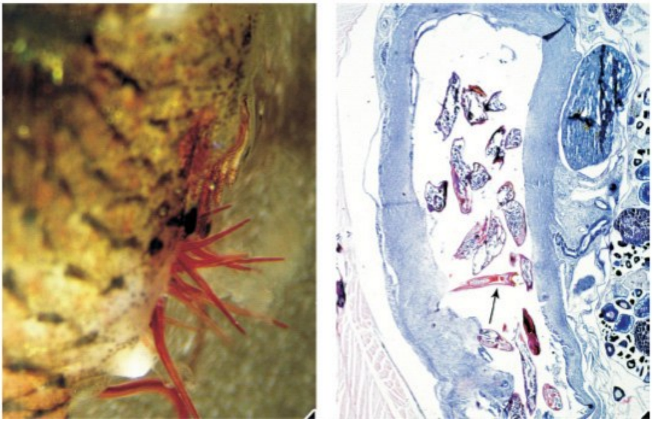


Figure 22. Presence of *Camallanus* spp. in the intestinal tract of ornamental fish and microscopic view. Source: Menezes et al. (2006).

Figure 23. Presence of *Schyzocotyle* sp. in the intestinal tract of ornamental fish. Source: eSHa Labs (2022).

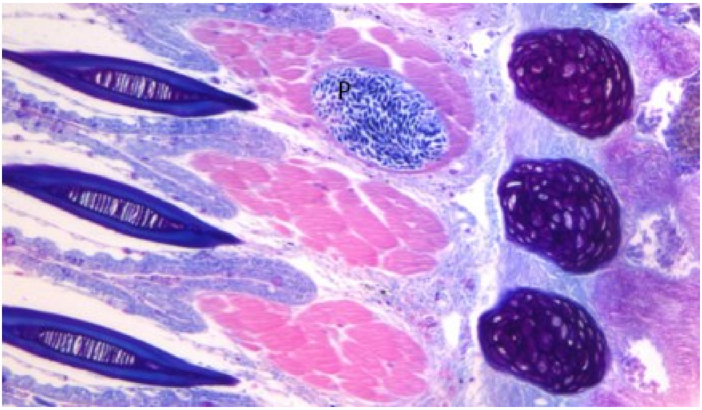


Figure 24. Microscopic view of myxosporean (P) parasitizing the gill of *Oreochromis niloticus*. Source: Teixeira et al. (2018).

Viral diseases, although less frequent, represent a serious threat to the health of fry in ornamental rearing, mainly due to their high potential for dissemination, lack of specific treatments and significant economic impact, viruses can cause high mortalities, especially in systems with high density and low biosecurity (Kim et al., 2024). Among the viruses already recorded in tropical ornamental fish, Iridovirus stands out, which especially affects species such as cichlids, causing clinical signs such as lethargy, darkening of the skin, ascites (accumulation of fluid in the abdominal cavity), hemorrhages and high mortality (Subramaniam et al., 2013; Rocha et al., 2022). Other viruses of importance include Nodavirus (which causes encephalopathy and retinal necrosis) and herpesviruses, such as *Cyprinid herpesvirus*

(CyHV), which is associated with diseases in ornamental carp (Rezende and Fujimoto, 2021; Barcellos, 2022).

Viral transmission can occur horizontally (direct contact between infected and healthy fish, or through contaminated water) or vertically (transmission from broodstock to offspring), which reinforces the need for sanitary care from breeding to fattening (Rezende and Fujimoto, 2021; Barcellos, 2022). As the viruses do not respond to antibiotics or conventional chemical treatments, the main strategy remains prevention (CRMV-MG, 2023).

The prevention and control of diseases in ornamental fish fry requires the implementation of an integrated set of measures, including environmental management, biosecurity practices and early diagnosis (SENAR, 2017; Barcellos, 2022). Quarantine of new fish is essential to prevent the introduction of pathogens, with constant monitoring during the isolation period (MAPA, 2013). Maintaining optimal physicochemical parameters in the water, such as pH, dissolved oxygen and ammonia, is crucial to reduce stress and prevent infections (MAPA, 2013; CNA, 2018). In addition, biosecurity strategies, such as regular disinfection of equipment and access control, are key to minimizing the spread of pathogens (Cardoso and Balian, 2018). Nutrition also plays an important role, with the use of functional additives that promote the immune resistance of fish (Toutou et al., 2016).

Early diagnosis is the key to effective intervention, with monitoring of clinical signs, such as inappetence and behavioral changes, and laboratory tests to accurately identify the pathogens (Barcellos, 2022). Treatment should be based on specific diagnoses, with the controlled use of drugs to avoid resistance (Dotta and Piazza, 2012; Gazal et al., 2022). Finally, the continuous training of aquaculture professionals is essential for the effective application of management practices and sanitary control, guaranteeing the health and productivity of the fry (SENAR, 2017).

Predation represents a significant challenge in the management of fry, especially during the early stages of development, when individuals are small, physiologically fragile and have a low capacity for evasion (Andrade et al., 2004; Tavares-Dias, 2012). This phenomenon can occur either intraspecifically, characterized by cannibalism between individuals of the same species, or by interspecific predation, involving other farmed fish or external predators that access the rearing system (Santos and Krupek, 2013). Understanding these mechanisms is fundamental to adopting preventive management practices that guarantee the survival and zootechnical performance of the flocks (Lima et al., 2013).

Interspecific predation is a common behavior among carnivorous fish species, usually associated with aggression and the presence of strong social dominance (Carvalho, 2020). However, it can also occur in species that show large variations in size between individuals of the same offspring (Baras; Kestemont; Mélard, 2003; Barcellos, 2022). In these cases, juveniles have greater growth capacity than adults, consume proportionally more feed in relation to their body size and are prone to compensatory growth, factors that can favor and intensify cannibalism (Hecht and Pienaar, 1993; Baras, 1998; Duk et al., 2017). In addition, cannibalistic behavior can be triggered by environmental factors, such as incompatibility between species, inadequate stocking density, lighting and, above all, insufficient feeding (Faria; Hayashi; Soares, 2001; Duk et al., 2017).

Cannibalism in farmed fish is influenced by multiple environmental and physiological factors, with food deficiency being one of the main behavioral triggers (Kubitza, 2009; Lima et al., 2013). Nutritional restriction is directly related to increased aggression and intensified cannibalistic behavior, especially in the early stages of development (Duk et al., 2017). Food scarcity encourages dominant individuals to attack smaller ones as a way of accessing nutrients, aggravating intraspecific mortality (Obirikorang; Madkour; Adjei-Boateng, 2014; Duk et al., 2017). In addition, an inadequate supply of protein or essential amino acids, such as tryptophan, can compromise the synthesis of serotonin, the neurotransmitter responsible for modulating aggression, thus favoring the emergence of extreme territorial behavior and attacks between co-species (Vieira, 2013). Therefore, proper nutritional management is an essential strategy to mitigate cannibalism in intensive aquaculture systems.

Another aspect that favors predation between individuals of the same species is the absence of escape mechanisms (Brasileiro et al., 2021). In farming environments, this limitation is common, especially due to the low turbidity of the water and the lack of structures in the tanks that provide natural hiding places for the fry, which would reduce visual contact with predators (Baras and Jobling, 2002; Duk et al., 2017). Studies show that the use of biofloc technology (BFT) in farming systems increases water turbidity, reducing visibility and, consequently, visual and physical interaction between fish, which contributes to a reduction in episodes of aggression and cannibalism (Brasileiro et al., 2021).

The complete elimination of cannibalism in aquaculture, especially during larviculture, is considered probably impossible (Baras and Jobling, 2002; Atencio-García, 2006). However, it may be possible to mitigate cannibalism by adopting one or several procedures, which would depend on cannibalistic behavior and the ontogeny of cannibalism in different species (Pereira; Agostinho; Winemiller, 2017). In other words, although it is not feasible to completely eradicate cannibalism in aquaculture production systems, it is possible to implement species-specific prophylactic strategies capable of reducing its occurrence, increasing the survival rate of individuals and minimizing economic losses (Atencio-García, 2006; Duk et al., 2017; Pereira; Agostinho; Winemiller, 2017).

These birds can cause considerable damage to aquaculture production, not only through direct predation of fry, but also through indirect effects, such as physical injuries, stress that inhibits feeding, and the potential spread of pathogens and parasites (Bevan; Chandroo; Moccia, 2002; Carvalho; Vilarinho; Franchin, 2003). In addition to birds, aquatic predators, such as insects of the order Odonata, also pose a significant threat during the fry stage. *Neuraeschna* (Aeshnidae) larvae have a high predatory impact on common carp (*Cyprinus carpio*) fry, with an average consumption of up to 7.2 fry per predator over a 27-hour period. It was also observed that the use of an ethanolic extract of *Melia azedarach* adsorbed on silica significantly reduced predation, indicating promising natural alternatives for controlling these organisms (Júnior et al., 2011). In order to understand the potential damage caused by predators and implement effective control methods, it is essential to correctly identify the species involved (Hutchings, 1999; Carvalho; Vilarinho; Franchin, 2003).

Below is a summary of the main predator species that can impact freshwater fry farming, highlighting their modes of action, the damage they cause to aquaculture production and possible control and mitigation strategies (Table 2).

Table 2. Main predators of freshwater fry: origin, impacts and control strategies

Predator (common and scientific name)	**Interaction types**	**Cause of problems in fry**	**Possible solutions**
Great egret (*Ardea alba*); Great kingfisher (*Megaceryle torquata*).	Air and water.	Direct predation, Stress, inhibition of feeding, transmission of pathogens.	Roofing for ponds, scarecrows, reflective tapes, hanging nylon lines.
Bullfrog (*Lithobates catesbeianus*).	Land.	Direct consumption of fry, especially around the edges of ponds.	Fences around ponds, proper drainage, opulation control of larger fis
Dragonfly larvae (*Neuraeschna spp.*)	Aquatic.	Aggressive predation of larvae and fry, reduced survival rate.	Water filtration, proper liming, biological control e.g. *Melia azedarach* extract
Aquatic insects (*Belostoma spp., Notonecta spp.*)	Air and water.	Spot attacks, injection of digestive enzymes, localized mortality.	Use of fine mesh screens, egular drainage and cleaning biological control.
Otter (*Lontra longicaudis*); Water rat (*Nectomys squamipes*)	Land.	Predation, disease transmission, damage to infrastructure.	Electric or physical fencing, perimeter lighting, traps in access areas, dogs in the vicinity.

Source: Adapted from Watson and Shireman (1996), Carvalho; Vilarinho; Franchin, 2003, Júnior. et al. (2011), Sano et al. (2011), Domiciano (2015), Brasileiro et al. (2021).

Understanding the main predators that prey on fry in fish farming systems is essential for developing effective preventative strategies (Rezende and Bergamin, 2013. As shown in Table 2, the impacts of predation can directly compromise productivity, health and the economic viability of rearing, especially in the early stages of the rearing cycle. The adoption of integrated management measures, which take into account both the characteristics of predators and the conditions of the rearing environment, represents a sustainable and efficient approach to mitigating losses and increasing zootechnical safety (Silva et al., 2024). Prevention, continuous monitoring and the implementation of physical barriers, segregation by age or size, the use of screens and the provision of hiding places are recommended practices to reduce predation and ensure a higher survival rate of ornamental fry (Carvalho; Vilarinho; Franchin, 2003; Araujo, 2017; Pereira; Agostinho; Winemiller, 2017).

In summary, access to qualified information and technical knowledge is essential for success in fish farming (Carvalho; Vilarinho; Franchin, 2003; Sousa et al*.,* 2025). Understanding the biological characteristics of farmed species, as well as their nutritional requirements and specific management care, is fundamental to ensuring high zootechnical performance rates (Piedras and Pouyei, 2004; Corrêa and Silva, 2022). Identifying and controlling adverse factors, such as the presence of predators, is equally important, since these agents can significantly compromise the productivity and health of flocks (Silva et al., 2024).

CHAPTER 7

GENETIC OF THE AMAZONIAN ORNAMENTAL FISH

The Amazon region is home to one of the greatest fish biodiversities on the planet, with hundreds of commercially exploited ornamental fish species (Santos et al., 2023). In this context, hybridization and selective breeding have been used as strategies to meet market demands, promoting the development of exotic phenotypes and desirable characteristics, such as colors that are more vibrant, greater docility, and attractive morphological patterns. However, these practices have raised growing concerns about their ecological, genetic, economic, and sociocultural impacts in the Amazon (Santos et al., 2023).

From a genetic point of view, hybridization between different strains or species, even when conducted in controlled environments, poses a real risk of genetic introgression when hybrid individuals escape into natural environments. Genetic contamination can compromise the integrity of wild populations, affecting their evolutionary adaptability and resilience to environmental changes (Yamamoto et al., 2021). In addition, the reduction of genetic diversity in captive populations due to the selection of specific characteristics, such as coloration or behavior, can make them more susceptible to disease and reduce their reproductive viability in natural environments (Santos et al., 2023).

Ecologically, the impacts of selective breeding and the possible release of hybrids are not restricted to the genetic sphere. The accidental or deliberate introduction of hybrid ornamental fish can alter the structure of aquatic communities, promoting competition for resources with native species and, in some cases, even predation of local organisms (Waltrick, 2007). This dynamic can be observed in urban streams in Manaus, where ornamental fish farming has contributed to water eutrophication and a reduction in benthic biodiversity, according to an environmental assessment conducted by Waltrick (2007).

From an economic perspective, selective breeding adds value to the product by meeting specific demands of the international market, it can also shift the focus away from sustainable production based on the capture of native species. This shift poses a direct threat to the livelihoods of Amazonian riverine communities, whose income is linked to low-impact ornamental fishing (Santos et al., 2023). These communities, which possess extensive traditional ecological knowledge, often lack the infrastructure necessary to compete with industrial producers that operate with hybrid strains and artificial reproduction technologies.

Culturally, the progressive replacement of native species by laboratory-bred hybrids can lead to the loss of traditional knowledge about the behavior, habitat, and reproductive cycles of Amazonian species (Paes and Silva, 2021). This trend negatively affects the livelihoods and production systems of local populations, weakening the sociocultural ties that sustain the relationship between communities and Amazonian rivers (Yamamoto et al., 2021).

Selective breeding of ornamental fish has caused a significant reduction in the genetic diversity of several species, increasing their vulnerability to disease and hindering their adaptation to environmental changes. In tetras such as the neon tetra (*Paracheirodon innesi*) and the cardinal tetra (*Paracheirodon axelrodi*), a narrowing of the gene pool has been observed due to artificial selection (Santos et al., 2023). The same occurs with cichlids such as Discus fish (*Symphysodon* spp.) and Angelfish (*Pterophyllum scalare*), where aesthetic characteristics and resistance are prioritized, but which compromise genetic variability (Waltrick, 2007). A similar situation occurs with catfish and armored catfish, such as *Corydoras* spp., *Otocinclus* spp., and *Hypostomus* spp., whose selective breeding can weaken their ecological resilience (Yamamoto et al., 2021). Guppy (*Poecilia reticulata*), although exotic, pose an additional risk to Amazonian biodiversity due to their invasive potential and competition with native species (Yamamoto et al., 2021). Finally, species such as Apistogrammas (*Apistogramma* spp.) and silver arowana

(*Osteoglossum bicirrhosum*), when aesthetically modified through selective breeding, can cause ecological imbalances and see their natural adaptive capacity compromised (Waltrick, 2007).

Given this scenario, it is essential to adopt public policies and biosafety protocols that regulate the creation of hybrids and the release of ornamental species into the natural environment (BRASIL, 2021). The valorization of traditional ornamental fishing, combined with community management practices, may constitute a more sustainable alternative, both from an ecological and socioeconomic point of view, contributing to the conservation of Amazonian ichthyofauna and the strengthening of the communities that depend on it (Waltrick, 2007; Larcombe et al., 2024).

According to Lau et al. (2023), genetic characteristics such as pigmentation intensity, body shape and docility have a strong influence on the commercial value of ornamental fish. In addition to these aesthetic and behavioral attributes, resistance to diseases such as the microsporidian *Pseudoloma neurophilia*, bacterial sepses, nocardiosis, velvet disease and white spot disease represent a competitive differential, because just as in aquaculture, genetic improvement focused on health can add significant value to strains (Hwang et al., 2017; Gorgoglione et al., 2022; Larcombe et al., 2024). Therefore, the use of strategies and techniques associated with genetic improvement emerges as an essential tool to meet the demands of the sector, which not only prioritizes aesthetic and behavioral attributes, but also demands sanitary robustness (Plasus et al., 2022; Zhang et al., 2022; Patel et al., 2023).

In freshwater ornamental species, the creation and improvement of ornamental strains occurs through artificial selection, which combined with different crossing methods intensifies aesthetic characteristics and avoids problems due to inbreeding (Ramos and Gonçalves, 2019; Leite et al., 2022). Techniques such as *inbreeding* (crossing individuals with a high degree of kinship) accelerate the establishment of desired traits, while *line-breeding* (crossing individuals with a lower degree of kinship) and out-breeding (unrelated individuals) reduce inbreeding (Gjedrem, 2005; Alisha, 2024; Kwon et al., 2022).

The neon tetra (*Paracheirodon innesi*) is selected mainly for its vibrant coloration, with an emphasis on intensifying the red and blue colors (Kusumah et al., 2021). In the Discus fish (*Symphysodon* spp.), genetic selection is aimed at intensifying the colors, standardizing the shape of the fins and developing new patterns of spots and streaks. These advances have been achieved through selective breeding and inbreeding, which has resulted in more than 60 varieties currently available on the market (Figure 25), with production concentrated in

Malaysia, Vietnam, Indonesia and Thailand, the species' main global hubs (Livengood et al., 2010; Ng et al., 2024; Ji et al., 2024). The freshwater angelfish (*Pterophyllum scalare*), on the other hand, is mainly selected for its elongated fins and coloration patterns (Pandolfi et al., 2021).

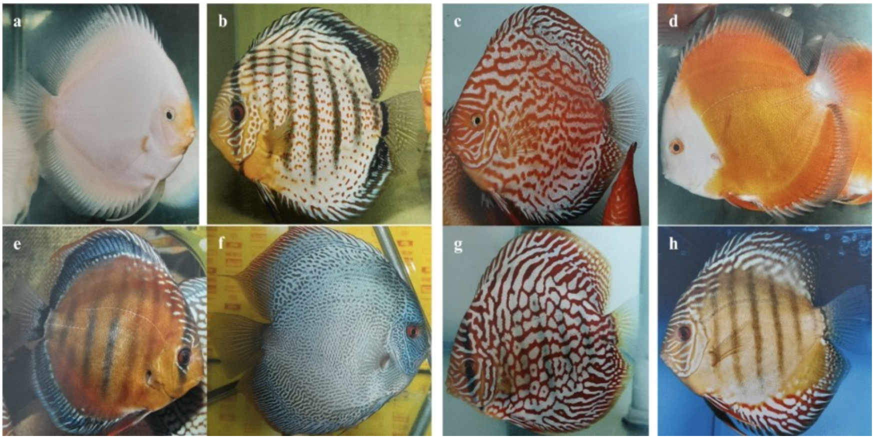


Figure 25. Varieties of adult Discus fish (*Symphysodon* spp.) (a) Discus Snow white; (b) Discus fish; (c) Transportation of animals to Manaus; (d) Fish kept in facilities in Manaus before international transportation. Source: Lau et al., 2023.

With the advance of genetic technologies, new tools have been consolidated as promising alternatives to enhance ornamental fish breeding, adding greater efficiency and precision to the process of creating new strains, as well as optimizing financial resources (Li et al., 2024; Lal et al., 2024). These tools include molecular markerassisted selection, which helps to understand which genes or genomic regions are associated with phenotypic characteristics of interest, such as coloration, fin pattern, disease resistance and growth rate (Martins et al., 2021; Wong et al., 2023).

In addition, predictive genomics, through genomic selection, has made it possible to estimate the genetic value of an animal based on large quantities of markers distributed throughout the genome, even before the expression of phenotypic characteristics (Chen et al., 2022; Oliveira and Kim, 2024). CRISPR-Cas9 technology has opened up new possibilities in the development of strains with desirable characteristics, although there are still ethical, regulatory and technical challenges (Zhang et al., 2023; Kumar et al., 2024). These technologies are paving the way for a new era in the production of aquatic organisms.

CHAPTER 8

FINAL CONSIDERATIONS

The Amazonian ornamental fish represents an invaluable treasure, not only for its beauty and biological diversity but also for its socioeconomic potential. For this sector to thrive sustainably, its expansion must occur under the pillar of sustainability, strategically integrating extractive fishing and aquaculture. Both models have their roles and, when well-managed, they complement each other, ensuring both the preservation of natural stocks and a continuous supply for the market.

To strengthen this production chain, collaboration is key. It's essential for large enterprises and small producers and fishermen to work together, sharing knowledge, infrastructure, and markets. Similarly, the union between aquaculture producers and extractive fishermen is vital. This synergy can optimize species supply, reduce pressure on wild stocks, and generate added value for all links in the chain.

Thus, the captive breeding emerges as a powerful and multifaceted tool. Besides being essential for large-scale production, meeting market demand and decreasing dependence on wild collection, it plays a fundamental role in conservation. Breeding species in controlled environments can serve as a genetic safeguard and, in the future, enable repopulation programs.

For all these efforts to materialize, the support of public authorities is non-negotiable. Governments, at their various levels, must act as facilitators, assisting with tax incentives, specific credit lines, technical training, and infrastructure, for both production and conservation. Furthermore, a favorable regulatory environment is also indispensable. The creation and implementation of inclusive laws adapted to the reality of this activity are crucial to formalize, guide, and incentivize sustainable practices. These laws must balance conservation with economic development, streamlining processes and offering legal security to those involved.

Finally, the health of the ecosystem and the animals must be a priority. The implementation of rigorous monitoring systems is fundamental to prevent the spread of diseases and non-native species between hydrographic basins, protecting Amazonian biodiversity. Additionally, the standardization of good management practices and the agile development of technological packages are essential to increase the productivity, quality, and sustainability of the activity, ensuring a prosperous future for Amazonian ornamental fish and the communities that depend on them.

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