Pirarucu: from its origins to commercial breeding

Pirarucu: das origens ao melhoramento comercial

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RESUMO
Por se tratar de um mercado com forte potencial e em expansão, alguns Estados brasileiros em parceria com entidades de proteção animal e instituições de ensino e pesquisa tem incentivado a criação de pirarucu em cativeiro, possibilitando assim, um monitoramento e preservação dos estoques naturais, consequentemente evitando-se assim a extinção da espécie. Descrito como pirarucu no Brasil e paiche no Peru, o Arapaima gigas é relatado como um dos maiores peixes dulcícolas do mundo possuindo rendimento de carcaça em cerca de 60% e do filé acima de 45%, sendo este tradicionalmente comercializado no mercado interno como produto salgado seco normalmente retratado como “bacalhau brasileiro”. Muito ainda deve ser feito para que se tenha o domínio total da criação em cativeiro do pirarucu, principalmente no que concerne à alimentação e reprodução do mesmo, contudo, trabalhos vêm sendo realizados visando alcançar tal intuito. Neste sentido, objetivou-se realizar uma revisão bibliográfica sobre o pirarucu visando elucidar o máximo sobre a respectiva espécie desde sua classificação, aspectos biológicos, método de obtenção e criação no Brasil.
Palavras-chave: Arapaima gigas; piscicultura; tanque escavado.

ABSTRACT
Because the captive breeding of pirarucu is a growing market segment with great potential, some Brazilian states in partnership with animal protection organizations and educational/research institutions have encouraged the activity, making it possible to monitor and preserve natural stocks and consequently prevent the extinction of the species. Commonly known as “pirarucu” in Brazil and “paiche” in Peru, Arapaima gigas is reported as one of the largest scaled freshwater fish in the world, with a carcass yield of around 60% and a filet yield of over 45%. The species is traditionally marketed in Brazil as a dry-salted food called “Brazilian cod”. Although much remains to be done for the captive breeding of pirarucu to be fully controlled, especially in terms of feeding and reproduction, research has been carried out with this purpose. In this scenario, the present literature review has been undertaken to elucidate the most information possible about the classification, biological aspects, production methods and breeding of pirarucu in Brazil.

Keywords: Arapaima gigas; earthen pond; fish farming.

1 INTRODUCTION
Known as “pirarucu” in Brazil and “paiche” in Peru, Arapaima gigas is considered one of the largest freshwater fish in the world, with common descriptions of the fish weighing an average of 125 kg. The species has been reported to reach up to around 200 kg in weight and 2 to 3 m in length, in nature (Imbiriba et al., 1996). Having received the title of “The giant of Amazonian waters” due to its importance, pirarucu has been known for several years abroad for its product, the salted filet, which is part of the European daily life (Ono et al., 2004).

In recent years, pirarucu, a red fish of the family Arapaimatidae and order Osteoglossiformes, has been the Amazonian species that most aroused the interest of Brazilian fish farmers. Apart from being widely characterized and studied in the scientific field, the species has also been a staple food for native populations since even before the country was discovered (Pereira-Filho and Roubach, 2013).

The species is described as a large-sized carnivorous and the largest scaled fish ever catalogued in the world, with a carcass yield of around 60% and a filet yield of over 45% (Ono et al., 2004). Pirarucu is usually marketed in Brazil as a dry-salted product popularly known as “Brazilian cod”, which has great economic and historic importance, mainly in the North region and in the northernmost area of the Central-West region (Nunes et al., 2012).

Formerly produced in extensive regimes due to ease of reproduction, the species is now farmed in intensive systems, for which it presents a number advantages, e.g., resistance to high stocking densities; easy adaptation to balanced feedstuffs and commercial feeds; rapid growth (around 7-10 kg) in the first year of farming, with a feed conversion of approximately 2:1 when only feed is used and up to 1.5:1 when supplemented with live fish (being a moderate carnivore); dual breathing (aerial and aquatic), which allows it to adapt and develop in water with low dissolved
oxygen contents such as still water with the presence of sediments and algae and no current; and high filet yield, which surpasses those achieved by most fish species cultured in Brazil (Brandão et al., 2008; Ono and Kehdi, 2013).

In this scenario, the present literature review has been undertaken to elucidate the most information possible about the classification, biological aspects, production methods and breeding of pirarucu in Brazil.

2 DEVELOPMENT

2.1 CLASSIFICATION AND BIOLOGICAL ASPECTS

Pirarucu is one of the earliest described fish species of the family Arapaimidae, whose line originated in the Jurassic period, even before the continental drift of Africa and South America. Because of its phylogenetic traits, skeleton and external morphology that are distinct from those of other species of fish from that time and even from its closest African relative, *Heterotis niloticus* (Lundberg and Chermoff, 1992), pirarucu is described as a live fossil of great importance for underpinning research contrasting it with the evolution of teleosts (Silva and Duncan, 2016).

Because it is a rather primitive species, pirarucu is often described as the freshwater dinosaur. It belongs to the class Actinopterygii, order Osteoglossiformes and family Arapaimidae, of which few species have been catalogued thus far. In the Amazon, the osteoglossids are formed by two genera and three species, namely, *Arapaima gigas*, *Osteoglossum bicirrhosum* and *O. ferreirai* (Imbiriba, 1996).

Studies conducted over more than 150 years have described pirarucu as a species of monotypic genus (Ferraris, 2003), *Arapaima gigas* (Schinz, in Cuvier, 1822). However, Cuvier and Valenciennes (1847) reported the presence of three species—*Arapaima agassizii*, *A. mapae* and *A. arapaima*—in a catalogue published by Günther (1868) as a synonym for *A. gigas*. On the other hand, recent studies confirm the existence of the species *A. agassizii* (Stewart, 2013a) as well as a new species from Central Amazon, thus totaling five species of pirarucu rather than one, as once thought (Stewart, 2013b).

Nevertheless, in Brazil, only the species *Arapaima gigas* had its geographic distribution determined, with the first occurrence reported in exploratory fishing operations near Santarém - PA, in the year 1787 (Stewart, 2013a).

The species is called “bodecos” in the Amazon region, “pirosca” in the state of Tocantins and “paiche” in Peru (Sousa et al., 2017). The name “pirarucu” originates from the Tupi language, where *pira* means fish and *urucu* comes from the “urucu” (annatto) tree (*Bixa orellana*). This description refers to the reddish color of its scales in the caudal-dorsal-anal fin portion, especially in males.
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(Ayala, 1999). Both the color intensity and the number of scales change over time, reaching their peak during the reproductive stage (Venturieri and Bernardino, 1999).

Pirarucu is a large species that inhabits the Amazonian rivers (warm water, between 24 and 31 ºC). It is characterized by being at the top of the food chain and by having a flattened head similar to that of catfish such as spotted sorubim; a long, cylindrical body; scales larger than those normally found in freshwater fish, which are commonly used as raw material in craftwork; and a bony tongue that is reused as sandpaper. Despite reaching up to 3 m in length and 200 kg in live weight (Nelson, 1994; Li and Wilson, 1996; Venturini and Bernardino, 1999; Gavis et al., 2006; Araripe et al., 2013), the typical pirarucu fished commercially in the Amazon weighs between 30 and 40 kg, generating an average carcass yield of approximately 57% (Imbiriba, 2001).

The respiratory system of the species consists of gills for aquatic breathing—performed only during the fingerling stage—and a modified swim bladder, which works as a lung during aerial breathing. This fact makes it impossible to transport the animal alive after it is fished or harvested, since it eventually suffocates on the way (Sousa and Val, 1990; Goulding et al., 2003). Furthermore, its reproductive apparatus in both females and males has a particularity that renders it anatomically unique: in females, only the left ovary is developed, whereas the male has a functional left testicle and an atrophied right testicle (Bard and Imbiriba, 1986).

2.2 ZOO TECHNICAL CHARACTERISTICS

Pirarucu is notably a species with a high growth rate. It is described as one of the earliest developing large-sized fish, which arouses the interest of producers in farming it on a large scale even though its weight gain does not accompany its longitudinal growth at the same rate. However, after reaching 750 cm, pirarucu starts to gain large amounts of mass, exhibiting good musculature upon attaining 1.50 m in length (Fontenele, 1948; Bard and Imbiriba, 1986).

There is controversy regarding the distribution of pirarucu, with some authors reporting it as present from the Amazon river in Brazil to the Orinoco river, Guyana, up to Ucayali river, in Peru, warranting more in-depth investigations about the area between Guyana and the French Guiana (Lüling, 1964). However, Bard and Imbiriba (1986) had already reported that there are no likely records of the presence of A. gigas in the Orinoco basin, but rather in the lower part of the Amazon river, where the fish reached the affluents, floodplain and igapó (blackwater-flooded) areas. Soares and Noronha (2007), in turn, stated that pirarucu is found in Brazil, Colombia, Guyana and Peru, but it remains to be determined whether it has reached Ecuador, since there are reports of native species that resemble it.

In Brazil, pirarucu is unanimously known to inhabit floodplain areas in the Amazon and Essequibo river basins as well as flooded forests, rivers, lakes and some coastal deltas. Its presence
is delimited by geographic barriers such as waterfalls and strong-current areas, as they impede its transit, making this species an excellent colonizer of environments with low or no current such as lakes (Queiroz and Sardinha, 1999; Castello, 2008a).

Described as a non-aggressive carnivorous species, pirarucu is normally characterized for attacking small detritivorous and omnivorous fish in nature, especially those of the family Loricaridae, among which are *Hypostomus plecostomus* (“cascudo”) and *Hoplosternum littorale* (“tamuatá” or “tamoatá”), as well as other items such as mollusks, crustaceans and insects. However, because pirarucu is mostly piscivorous, it is considered a top-end predator that helps to regulate the ecosystem in which it inhabits (Romero, 1961; Ono et al., 2004). Watson et al. (2013) conducted a study with pirarucu from Guyana and found the presence of nitrogen isotopes, demonstrating that it can be classified as omnivorous. Nonetheless, further studies must be developed to ascertain the extent of importance of pirarucu in its habitat and how positive or negative its influence can be.

Pirarucu is an ovuliparous monogamous fish (Monteiro, 2005) whose sexual maturation occurs from the 4th to the 5th year of life, when it reaches 1.60-1.85 m in length and 40-45 kg in weight (Lüling, 1964; Flores, 1980). During the dry season, the fish forms couples that last throughout their lifetime. Pirarucu is easily found in lakes, river beaches and some waterways during its reproduction period (Fontenele, 1948; Queiroz and Sardinha, 1999; Castello, 2008b).

At the beginning of the flood, when the water is around 1-m deep in regions on the margin of seedbank forests surrounded by lake, undertow and “paraná” (shallow branch with little water flow that rises only when the river floods) environments, males dig holes in the soil with an average diameter of 57 cm and an average depth of 16 cm. These will be the nest where the female gradually deposits the ovules, which are covered with the male’s sperm. Once fertilized, they are hatched by the female (Castello, 2008a; Castello, 2008b).

According to some researchers, the same couple can spawn several times in one year, depending solely on the weather, body conditions and feed availability (Lüling, 1964; Neves, 1995), and a pirarucu female is able to generate around 11,000 juveniles per spawn, which is below the average when compared to other productive species. However, these data are yet to be confirmed, especially in terms of fecundity (Bard and Imbiriba, 1986).

As soon as the eggs hatch, the male—whose color changes to black as a mechanism to hide and protect the offspring—migrates to flooded forests, where more food is available, e.g., fish seeking fruits and insects, which serve as food for the father; and insects and shrimps, for the offspring (Romero, 1961). Additionally, it is the father who teaches the pirarucu juvenile to perform aerial breathing, making itself present throughout the first three months of life of the offspring in flooded forests; following them when they have reached 30-50 cm in length towards “paraná” waterways;
and lastly migrating into lakes, where each follows their own path. Accordingly, if the pirarucu couple dies due to fishing or recurring fights, their entire offspring have high odds of also not surviving, which makes them highly vulnerable (Castello et al., 2013).

As previously mentioned, contrary to what it looks, as it is a large-sized animal of primitive origin, pirarucu grows fast and reproduces early as long as feed is available. Thus, under normal conditions in nature, it can reach 88 cm in length in its first year of life, 123 cm in the second year, 154 cm in the third year, 174 cm in the fourth year, and 188 cm in the fifth year of life (Isaac et al., 1993; Arantes et al., 2010).

According to the first historical records of pirarucu fishing in the Amazon region found in the literature, the activity began in the XVIII century, with *Arapaima gigas* having great importance among the fish landed at the ports of the region and being marketed mostly in the form of dry-salted fillets (Veríssimo, 1895). However, in the 1960s, its intensified fishing without any weight or size criteria culminated in pressure upon the pirarucu population in the rivers of the region, resulting in a drastic reduction of their number and in the appearance of clear signs of overexploitation (Veríssimo, 1895; Goulding, 1980; Val and Honczaryk, 1995; Isaac et al., 1996; Queiroz and Sardinha, 1999; Viana et al., 2007; Sousa et al., 2017).

In this scenario, governmental measures had to be established to regulate the fishing of pirarucu, thereby preventing its extinction. Some of the measures adopted at the time were: I - inclusion of the species in appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) as an endangered species whose sale was also restricted in both exports and imports; II - inclusion in the list of the International Union for Conservation of Nature (IUCN), in the category of species with insufficient data; and III - establishment of a minimum size for capture (150 cm) and a closed season for reproduction (December 1st to May 21st) (Ibama, 1991; Ibama, 1996; Sousa et al., 2017).

Additionally, since the end of the 1990s, riverside communities in the Amazon have put great effort into achieving a better management of pirarucu fishing and thus conserve it for future generations. This is the case of the Mamirauá Sustainable Development Reserve (RDSM), which conducts community monitoring of the species, establishing capture quotas for each fisherman; processing the salted fillet to reduce waste; and executing planned sales and control of natural stocks by counting the fish via observation at the time they perform aerial breathing (Viana et al., 2007; Sousa et al., 2017).

Despite the good results generated with projects like RDSM, which in 2011 achieved the production of 305 t of pirarucu in all areas managed by the Mamirauá Institute, which reported an increase in both production and number of fishermen registered in the period of 1999 to 2011.
(production of 3 t of pirarucu in 1999 and 42 to 961 fishermen), the current availability of pirarucu per extractive fishing operation does not meet the market demand, which grows daily (Amaral et al., 2011). Therefore, in addition to the maintenance of conservation-management strategies in nature, much research has been done on the captive breeding of pirarucu, which can be a viable alternative to meet the domestic and external market demands without compromising the native population (Monteiro, 2005).

2.3 CAPTIVE PRODUCTION

Considered a product of high commercial value, the filet is largely consumed in the northern region of the country and highly appreciated by exporters, which has raised the overfishing of pirarucu juveniles. This phenomenon has resulted in a reduction of its natural stock such that pirarucu is the only fish described as endangered by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Ibama, 1991; Ibama/Iara, 1995).

Because the captive breeding of pirarucu is a growing market segment with great potential, some Brazilian states in partnership with animal protection organizations and educational/research institutions have encouraged the activity, making it possible to monitor and preserve natural stocks and consequently prevent the extinction of the species (Brandão et al., 2008).

In this context, pirarucu has been strongly implied as one of the native species with enormous potential for commercial fish farming due to its particular production characteristics such as high market value; light-colored meat; mild taste and firm texture; excellent meat quality, without bones; low fat content; great acceptance by the population; hardiness for handling; adaptation to aerial breathing, which generates optimum tolerance to high ammonia levels in the water; and high growth rate, reaching up to around 10 kg in the first year of farming (Imbiriba et al., 1985; Bard and Imbiriba, 1986; Imbiriba, 1991; CArvalho and Nascimento, 1992; Imbiriba, 2001; Cavero et al., 2003; Cavero, 2011; Sousa et al., 2017; Lima et al., 2017).

Oliveira (1944) worked with pirarucu fingerlings from nature by exhaustively studying breeding methods, aiming to initiate and establish its commercial production in Brazil. In 1939, in the Emílio Goeldi Museum, located in Belém - PA, the researcher managed to produce adult specimens in captivity, 19 of which were introduced by Fontenele (1948) at the Fish Farming Station of Lima Campos in Icó - CE, in 1942. These fish were 1.20-m long and 3 years old, at the time. In 1944, they were first able to reproduce in captivity, thereby allowing, from that date, the effective commercial breeding of pirarucu in a closed-cycle farming system.

Today, the most common breeding approach for pirarucu in Brazil is the extensive system, whereby nurseries have different sizes, reaching yields of 1.7 to 11 t/ha/yr when the feed source used are low-cost fish described as foragers, e.g., piaba, matupiri, tamaatá, which reproduce naturally in
The intensive farming of pirarucu is subdivided into its life stages, namely, reproduction, with the choice of couples made by the fish themselves, which later proceed towards the so-called “pirarucu motels”, where each couple has their own nursery with a depth that enables the formation of nests; juvenile, which starts with the removal of the father’s protection until the feed-training phase and ends when the fish reaches around 10 to 20 cm in length; growth, the moment when most of the pirarucu are acquired by farmers, who work for the fish to adapt to our medium and develop, gaining up to around 0.5 to 1.0 kg in weight; and fattening, when the pirarucu is treated with a high-protein diet aiming at greater weight gain and feed conversion, ending at around 12 to 18 months of age, with a live weight between 10 and 13 kg (Lima et al., 2017).

Sousa et al. (2017) reported that the pirarucu farmed in Brazil is cultured in four main systems: net cages with dimensions between 18 and 32 m³; collapsible circular commercial-grade canvas tanks with varying dimensions, up to 10 m³ (in pirarucu breeding, farmers typically use those measuring 30 to 50 m³); earthen ponds, which are preferably rectangular, with dimensions ranging from 500 to 10,000 m², with a water depth of 1.0 to 1.5 m; and canvas-lined earthen ponds with dimensions between 300 and 500 m² and water depth of 1.00 to 1.20 m.

Lima et al. (2017) stressed that the captive breeding of pirarucu is based on three main segments: juvenile producers who master assisted reproduction; farmers with fish marketing goals who produce the fish from the growth to the fattening stages, representing the largest share in Brazil; and the fish processing industries, which are under expansion in the country. In 2017, the total industrial yield of pirarucu was 4,189,748 kg (BRL 46,422,000.00), with the North region producing the largest volume, 3,935,178 kg (BRL 42,395,000.00), followed by the Central-West region, which produced 100,840 kg, corresponding to BRL 1,706,000.00. The state of Rondônia was the biggest individual producer of the fish (3,471,264 kg), followed by Amazonas (108,733 kg) and then Mato Grosso (57,285 kg) (Ibge/Ppm, 2018).

Scientific data about fresh pirarucu are still sparse, considering that its fishing is still controlled by IBAMA (Brazilian Institute of Environment and Renewable Natural Resources) and there are few registered and licensed farms in the country. The existing results are typically from research done with the product dried and salted clandestinely. However, Oliveira et al. (2014) investigated 17 specimens of pirarucu from a commercial farm in the city of Manaus - AM, and found the following contents in the back and belly cuts, respectively: moisture - 79.51 and 77.88%, ash - 0.87 and 0.84%, lipids - 0.62 and 2.49%, protein - 17.56 and 16.10% and carbohydrate - 1.44 and...
2.69%; as well as a pH value of 6.79 and freshness of 6.65 mg N 100 g$^{-1}$ total volatile basic nitrogen (TVB-N).

3 CONCLUSION

Much remains to be done before the captive breeding of pirarucu can be fully controlled, especially in terms of feeding and reproduction. Research has, however, been undertaken with this purpose. This review has demonstrated the importance of pirarucu for the Brazilian fauna and society, where it has been part of the population’s diet since even before the country was discovered. Therefore, making information accessible about the said species and seeking partnerships to further promote research, increasing breeding efficiency, is of paramount importance so that *Arapaima gigas* can be appreciated by all without harming its existence in nature.

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