BOLETIM DO INSTITUTO DE PESCA
Scientific Article

Methods applied to the management of invasive pirarucu in protected areas in the Amazon Basin

Thales Quintão Chagas[1], Celso Costa Santos Júnior[1], Lidiane França da Silva Tomasoni[1], Thaylla Araújo dos Santos[2], Chirlaine Alves Ribeiro Varão[3], Marcos Garcia da Silva[3], Rodrigo Rios Barreto[3], Evandro de Jesus Tavares de Souza[3], Raniere Garcez Costa Sousa[4]*

[1]Instituto Chico Mendes de Conservação da Biodiversidade – Porto Velho (RO), Brazil.
[2]Ministério Público de Rondônia – Porto Velho (RO), Brazil.
[3]Secretaria de Estado do Desenvolvimento Ambiental – Porto Velho (RO), Brazil.
[4]Universidade Federal de Rondônia – Departamento de Geografia – Porto Velho (RO), Brazil.
*Corresponding author: ranieregarcez@unir.br

ABSTRACT

The pirarucu (*Arapaima gigas*) is native to the Amazon basin, but in Rondônia, Brazil, it occurs naturally only in the far north. For multiple reasons, it has become an invasive alien species in this biome and in other Brazilian states, with reported impacts on biodiversity and the food security of riverine populations. This study developed a management technique for the control/eradication of invasive pirarucu, based on the sustainable management of native pirarucu in Mamirauá, Amazonas, Brazil. After adaptation, eradication management was implemented and validated with riverine communities of the Cautário River. Between 2022 and 2024, 126 residents were trained as managers to monitor populations and conduct managed fisheries under the supervision of environmental agencies. The process also structured a production chain for commercializing invasive pirarucu. In total, 633 pirarucu were captured, generating R$ 302,916.54 (US$ 58,417.20) for local communities. Thus, invasive pirarucu management can reduce its populations and provide supplementary income to riverine communities, strengthening local bioeconomy and governance initiatives. Continued fishing and systematic population monitoring in the coming years are necessary to evaluate management effectiveness and deepen investigations into invasions and socio-environmental impacts in protected Amazonian areas.

Keywords: Invasive alien species; Biodiversity loss; Bioeconomy.

Método aplicado ao manejo e à bioeconomia do pirarucu invasor em áreas protegidas na bacia amazônica

RESUMO

O pirarucu (*Arapaima gigas*) é nativo da bacia amazônica, mas, em Rondônia, Brasil, ocorre naturalmente apenas no extremo norte. Por múltiplas causas, tornou-se espécie exótica invasora nesse bioma e em outros estados brasileiros, com impactos relatados sobre a biodiversidade e a segurança alimentar de populações ribeirinhas. Este estudo desenvolveu uma técnica de manejo para controle/erradicação do pirarucu invasor, baseada no manejo sustentável do pirarucu nativo de Mamirauá, Amazonas, Brasil. Após adaptação, o manejo de erradicação foi implantado e validado com comunidades ribeirinhas do Rio Cautário. Entre 2022 e 2024, 126 moradores foram habilitados como manejadores para monitorar populações e realizar pescarias manejadas sob supervisão de órgãos ambientais. O processo também estruturou uma cadeia produtiva para comercialização do pirarucu invasor. Ao todo, 633 pirarucus foram capturados, gerando R$ 302.916,54 (US$ 58.417,20) para as comunidades locais. Assim, o manejo do pirarucu invasor pode reduzir suas populações e oferecer renda complementar às comunidades ribeirinhas, fortalecendo iniciativas locais de bioeconomia e governança. A continuidade da pesca e do monitoramento nos próximos anos é necessária para avaliar a eficácia do manejo e aprofundar as investigações sobre invasões e impactos socioambientais em áreas protegidas amazônicas.

Palavras-chave: Espécie exótica invasora; Perda de biodiversidade; Bioeconomia.

Received: July 28, 2025 | **Approved:** March 24, 2026
Section editor: Welber Senteio Smith

INTRODUCTION

Brazil has a megadiverse fauna and flora and is home to between 15 and 20% of the planet's biodiversity (Machado et al., 2008; Pedreira, 2023). Such natural wealth is related to its environmental heterogeneity and results in essential ecosystem services for the maintenance of life (Costanza, 2000). However, such services are threatened because of anthropogenic actions that alter natural dynamics around the world (Priya et al., 2023).

Faced with the expansion of the global population and the resulting environmental impacts, protected areas (PAs) are among the main instruments used for the conservation of sociobiodiversity (Gillingham et al., 2024). Brazil has one of the largest and most complex systems of conservation units (CUs) in the world (Brasil, 2000), but it faces difficulties in effectively managing these areas (Soares-Filho et al., 2023).

The CUs are divided into groups that either offer integral protection and or are areas of sustainable use; the conditions of the use of their natural resources are respectively characterized as either indirect or direct (Brasil, 2000). Consequently, there are different interpretations of the possibility of using the territories, the forms of management and the pressures they are subjected to (Ribeiro et al., 2024).

One of the pressures corresponds to invasive alien species (IAS), which occur outside their natural geographical areas, and these species are among the most significant causes for the reduction of biodiversity and the promotion of ecosystem imbalances (Pocock et al., 2024; Pratzer et al., 2024). In Amazon, the problem of IAS is linked to threats such as climate emergencies, habitat fragmentation, deforestation and illegal mining, which results in the low effectiveness of protection of such PAs due to anthropogenic pressures (Santos et al., 2024), mainly in CUs and indigenous lands (ILs).

In aquatic ecosystems, the consequences of biological invasions can irreversibly degrade the biotic composition, which compromises the dynamics of these populations (Portz et al., 2011). Such processes can be potentiated by climate change, which increases the randomness of events of extreme drought and flooding, thereby favoring the dispersion of native and exotic species (Simberloff & Vitule, 2014).

Studies indicate that such impacts can be perceived in the same biome, if the target species does not occur naturally in its entirety (Catâneo, 2019). An example of this is the pirarucu (*Arapaima gigas*), which despite being a fish that is native to the Amazon basin, does not occur naturally in the whole basin (Doria et al., 2020).

As it is a large species, its size limits its dispersion through waterfalls and other geomorphological formations (Simberloff & Vitule, 2014). Additionally, some studies have linked invasions by *A. gigas* to fish farms, due to the precariousness of some establishments or the lack of biosecurity and containment, which have resulted in escapes from production areas (Méndez et al., 2012; Pereira et al., 2022).

These invasions are aggravated by intentional introductions linked to sport fishing, biopiracy and incidents in the ornamental trade (Castaldelli et al., 2013), which have already made possible the presence of pirarucu in other ecosystems in South America and other continents, such as Europe and Asia (Pereira et al., 2022).

As a result, the emergence of complex environmental problems related to fisheries management is inevitable. While managers in most of the Amazon basin make efforts to keep the pirarucu free from the threat of extinction, a threat it has previously suffered (Castello et al., 2011), the need arises to eradicate the species in the invaded ecosystems (Doria et al., 2020; Marková et al., 2020).

Therefore, in case of omission in the adequate management of the species, in both scenarios (native or invasive), the threat extends to the other species in the ecosystem (Castaldelli et al., 2013). This is due to the pirarucu being able to shape ecosystems, especially because of the adaptive advantages it has, such as parental care, respiratory physiology, large body size, and high reproductive fitness (Castello et al., 2013; Lima & Batista, 2012).

In the state of Rondônia, Brazil, the invasion by the pirarucu has been occurring for more than 40 years (Catâneo et al., 2022; Pereira et al., 2022; Brito-Pereira et al., 2026a). Although it is not a recent invasion, the distribution of the species and negative impacts have progressed in the last decade due to the flooding of rivers and changes in the landscape caused by hydroelectric projects (Johnson et al., 2008; Lima Junior et al., 2018).

Studies indicate losses in the environmental, economic, and social spheres (Catâneo et al., 2022). Although the management of the eradication of IAS is the most appropriate ecological measure, there are no validated methods and techniques for eradicating pirarucu. It is worth noting that due to the complexity of eradicating pirarucu, inadequate management can result in other socio-environmental disorders (Sampaio & Schmidt, 2013).

Therefore, this study aimed to develop methodologies for the management of the control/eradication of invasive *A. gigas* to be performed by traditional riverine communities in PAs and CUs. As a basis for the study, the sustainable management of pirarucu was used, since it has been developed over more than 25 years in the Mamirauá and Amanã sustainable development reserves in the state of Amazonas, Brazil (Castello et al., 2013).

It was assumed that with the appropriate adaptations, the

procedures that have already been consolidated could contribute to organizing the appropriate management strategies to reduce invasive populations and consequently strengthen the natural dynamics of native species of these disturbed environments.

MATERIALS AND METHODS

Study area

The study was carried out between 2022 and 2024 along with the traditional extractive communities of the Cautário River microbasin (Fig. 1), a tributary of the Guaporé River that divides the state and federal extractive reserves of the Cautário River. The state area is managed by the State Secretariat for Environmental Development (SEDAM), and the federal area is managed by the Chico Mendes Institute for Biodiversity Conservation (ICMBio), covering respectively the municipalities of Costa Marques and Guajará-Mirim, in the state of Rondônia.

The extractivists are from eight communities, namely: Ouro Fino, Ilha, Canindé, Vitória Régia, Laranjal, Águas Claras, Meia Dois, and Cajueiro. In the units, there are approximately 420 residents who have income that originates from fishing, subsistence agriculture, and sustainable exploitation of Brazil nuts (*Bertholletia excelsa*), latex (*Hevea brasiliensis*) extraction, açaí (*Euterpe oleracea*) production, cassava (*Manihot esculenta*) flour production, among other activities (SEDAM, 2016).

The Cautário River originates in the Uru-eu-wau-wau indigenous land and drains an area of approximately 8,823.290 km^2 (Pedlowski et al., 1999). The regional vegetation consists of open ombrophilous forest and cerrado enclaves (Dias, 2014). Running in a winding and narrow channel, the river is between 30 and 100 m wide and up to 15 m deep (ICMBio, 2016).

The region is rich in blackwater-flooded forests (*igapós*) during periods of higher rainfall (Ikeziri et al., 2008) and has sandy-clayey soil, which incorporates sediments at the time of greater

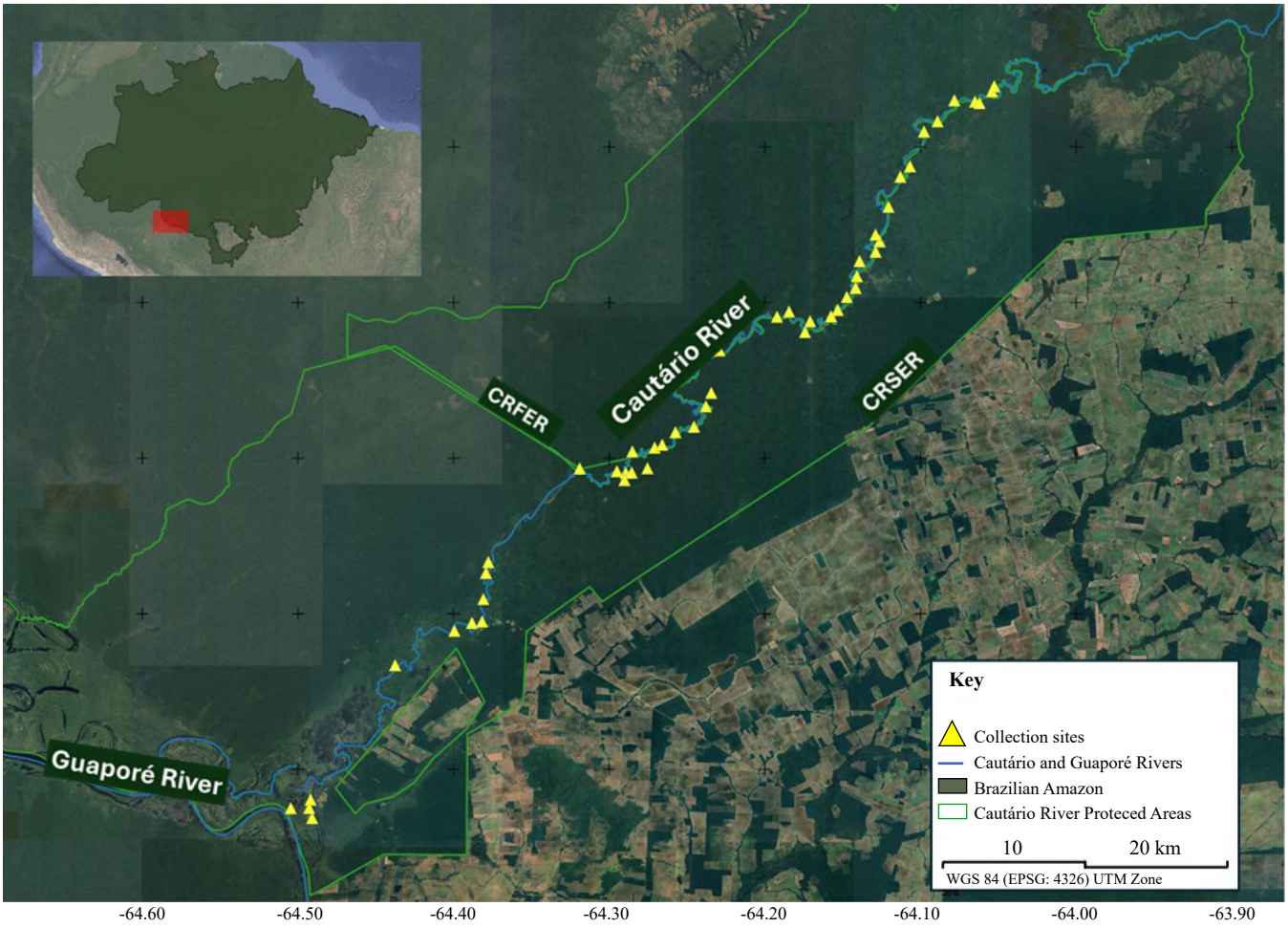

Figure 1. Delimitation of the Cautário River state and federal extractive reserves and the location of the Cautário River in the state of Rondônia, Brazil. Where: CRFER = Cautário River Federal Extractive Reserve; CRSER = Cautário River State Extractive Reserve.

current, resulting in an increase in its turbidity (SEDAM, 2016). The climate is tropical hot and humid, with an annual average of 24°C and an average rainfall of 1,250 ± 398 mm (Rondônia, 2024).

Experimental design

As a basis, the study used the sustainable management of pirarucu, developed in the CUs of the state of Amazonas, in the Mamirauá and Amanã sustainable development reserves (Gonçalves & Figueiredo, 2013). There, efforts have been made to increase the populations of native pirarucu that, because of predatory fishing, have had their populations reduced over the years (Amaral et al., 2013).

In the context of the study, the target species is considered invasive in the basins of the Mamoré and Guaporé rivers, which is why experts have recommended its eradication (Doria et al., 2020). Thus, adjustments to sustainable management were proposed to develop the control/eradication of the species, to mitigate the negative impacts on native species.

In Amazonas, the sustainable management of pirarucu is understood as a macroprocess, structured in several stages: organization, zoning, protection, counting, fishing, sale, and evaluation (Amaral et al., 2013). So, as to adapt the management to the reality of southern Rondonia, the zoning stage was replaced by mapping, and protection was excluded.

In addition, the fishing quota of one management system was increased in the other from up to 30% of adult pirarucu to up to 100% of the pirarucu—young and adults—, since in Rondônia eradication is sought via the management of invasive animals (Table 1).

Table 1. Structure and macrophases of sustainable management employed in Amazonas state, Brazil, and the proposed eradication management of invasive pirarucu carried out in Rondônia, Brazil.

Stages	Sustainable management		Eradication management	
1	Organization		Organization	
2	Zoning	Maintenance Sale Breeding	Mapping	Eradication management
3	Protection		Not applied	
4	Counting		Counting	
5	Fishing	Up to 30% of the adults	Fishing	Up to 100% of young and adults
6	Sale		Sale	
7	Evaluation		Evaluation	

Technical and community training

Following the premises of the management in Amazonas state, multidisciplinary groups of professionals from different areas of knowledge were trained to conduct technical activities with traditional extractive communities. Thus, during the three years of the study, workshops were held for researchers, analysts, and environmental technicians.

Likewise, training and improvement workshops were offered to the extractivist communities. For both technical and community audiences, the content related to the managers' training was the same, varying only the form of approach and the level of depth in the topics (Dos Santos, 2018).

The contents were structured in the axes:

- Fundamental concepts;
- Biology and ecology of *A. gigas*;
- Sustainable management;
- Proposals for eradication management.

Theoretical and practical modules were carried out, making use of audiovisual resources and carrying out activities aimed at the execution of management activities (Fig. 2).

Mapping and characterization of managed environments

In the community capacity building workshop, the RESEX Riverine dwellers defined sampling points to be monitored. In a systematic and participatory manner, they discussed and elected points of known or unknown occurrence of the pirarucu in the Cautário River. Information was organized using mind maps (Fig. 3).

Satellite images from the Google Earth Pro software were presented to the community members to confirm the sampling points to be monitored. In addition, via the images, we obtained

Figure 2. Theoretical and practical dynamics of pirarucu counting: (a) didactic material/model representing the managed ecosystems; (b) pirarucu counting activities performed *in loco*.

Figure 3. Mind maps for the definition of sample points to be monitored. (a) Registering of points suggested by the community. (b) Discussion on the logistics for accessing the environments to be monitored.

information on the geographic coordinates—centroid, the shape (elliptical lakes, oxbows or long, narrow lakes), length, width and area in hectares.

Population counting and monitoring of invasive pirarucu

To perform population monitoring of the pirarucu, the counting method was used (Silva et al., 2013), which is widely used in the Pan-Amazon. The method consists of quantifying the frequency of times that animals move to the surface to carry out gas exchange, a behavior known locally as "*boiada*" (Amaral et al., 2013).

For this, pairs of counters were positioned at the sampling points to visualize an area equivalent to 1 hectare. For 20 minutes, the *boiadas* were quantified, and the pirarucu were classified as young (≤ 149 cm) or adults (≥ 150 cm) (Silva et al., 2013). The environments had their depth measured by means of a rope.

Managed fishing and collection of biological material

The captures occurred only in the Cautário River and in lakes located in the Cautário River State Extractive Reserve, because, during the study, the capture of pirarucu in the federal CU was still subject to specific regulations. For the capture of the pirarucu, nets, lines, and hooks with floats were used. Seven gillnets were used—with multifilament No. 80 line and a mesh size ≥ 28 cm between opposite knots and a height of 3 m—, to reduce the chances of catching native fish species. These gillnets were set, and the techniques of waiting, encirclement, and herding were employed.

The nets were checked every 30 min, and any native animals accidentally caught were released. The lines used were ≥ 0.80 mm, and the hooks were suitable for large fish. When equipped with the floats, made of a polyethylene terephthalate (PET) bottle, the baits (pieces of fish) were at a depth of 80 cm. Fresh baits were used, mainly from the fish species *Hoplias malabaricus* and *Sebastiania commersoniana*. Fishing was not carried out using harpoons, jigging spears or other types of equipment that pierce fish in order to avoid contamination of the fish.

After capture, the pirarucu were subjected to euthanasia using the cerebral concussion technique (CONCEA, 2013), followed by the sectioning of the branchial artery, quickly and

irreversibly interrupting the blood circulation and functioning of the vital organs.

The total length (cm) and gross biomass (kg) of each fish were measured. Subsequently, the fish were eviscerated, according to the Manual of Good Handling Practices of Pirarucu (Conceição et al., 2018), at which time the sexing of animals was carried out. After being eviscerated, the animals had their biomass measured again, for the calculation of their commercial value. After pre-processing, the animals were cooled in cold rooms with ice, using 2 kg of ice/1 kg of pirarucu. The animals received identification tags, and the length of time out of the water was recorded.

The sampling effort of the catches was calculated based on Eq. 1, corresponding to the catch per unit of effort (CPUE) (Dantas et al., 2022):

$$CPUE = kg/fishers/day \quad (1)$$

where CPUE is the catch per unit of effort, expressed as kilograms of pirarucu captured per fisher per day; kg is the total commercial biomass captured; fishers is the number of fishers involved in each fishing event; and day is the number of effective fishing days. This index standardized catch productivity among fishing events.

Good handling practices of pirarucu

To avoid contamination during the pre-processing, the handlers were trained in good handling practices according to the manual (Conceição et al., 2018). It focused on aspects of hygiene, use of personal protective equipment, and preventive sanitary measures to ensure high quality fish for trade and consumption.

Documentary requirements for pirarucu eradication management

Managing animals within CUs requires the submission of various documents, aligned with the management guidelines of these areas and existing regulations. Initially, the invasive Pirarucu Eradication Management Project was submitted to relevant environmental agencies, requesting authorizations to carry out the studies and other management actions.

To define the agreements and procedures with the community, a set of procedures was drawn up. In addition, the community involved in fishing and trade of the animals submitted their general fishing records to the Ministry of Fisheries and Aquaculture.

Through the legal entity representing the extractivists, the Association of Extractivists of the Guaporé Valley, invoices were issued for the transport of fish from the CU to the processing enterprise (cold storage facility).

Data analysis

All the data were subjected to descriptive analysis to establish mean values and standard deviation, in addition to absolute and relative frequency. The data of the counts were submitted to the Shapiro-Wilk's normality test and the Bartlett's test to evaluate homoscedasticity.

Because they assumed a non-parametric profile, the data were submitted to the Friedman's test, with Dunn's post-test (5% confidence). This analysis was carried out to investigate whether there was a population reduction of managed pirarucu, based on the counts carried out over the years. Statistical analyses were performed, and graphical plots were created using GraphPad Prism software (version 10).

RESULTS

Two government technicians participated in the course "Shared management of fisheries resources with a focus on participatory management of pirarucu (*A. gigas*) in floodplain environments", 2022 edition, offered by the Mamirauá Sustainable Development Institute, in Tefé, Amazonas. After this, adjustments to the conservation management were proposed.

The sustainable management stages were reduced from seven to six (Table 1). To do this, the "protection" step was deleted, and the "zoning" step was replaced by the "mapping" step. Thus, all mapped environments were considered suitable for the eradication management of pirarucu.

With the new method, the technicians/environmental agents acted as multipliers, training six new technicians in 2022, 12 in 2023, and 40 in 2024. They worked in the training of extractivists/riverine dwellers, qualifying 40 managers in 2022, 35 in 2023 and 51 in 2024, totaling 126 managers, a number equivalent to 30% of the community. For each year, the community training sessions totaled 16 hours.

During participatory mapping, 55 sampling points were identified for conducting the pirarucu count. Among the mapped points, 48 were targets of the counts over the three years of study. The number of pirarucu was estimated at 925 (543 young and 382 adult specimens) in 2022, 863 (497 young and 366 adult specimens) in 2023 and 679 (361 young and 318 adult specimens) in 2024 (Fig. 4), totaling 2,467 pirarucu.

There were no significant differences in the quantity of pirarucu counted between the years monitored (Friedman; $p = 0.2650$). However, compared to the first year, there was a 6.71 and 26.6% reduction in the amount of pirarucu in the second and in the third year of study, respectively. The counts were carried out at the beginning of the dry season, between July and August.

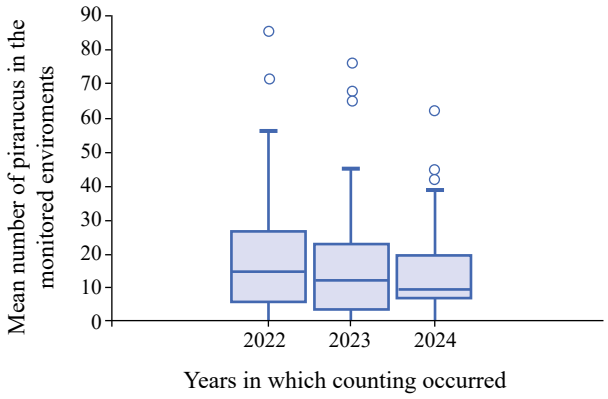

Figure 4. Count for population monitoring of invasive pirarucu in the Cautário River basin.

Regarding the format of the sampling points, 41.66% (n = 20) were of elliptical type, 35.41% (n = 17) were oxbows, and 22.91% (n = 11) were long, narrow lakes. Of these, 75% (n = 36) maintain a direct connection with the bed of the Cautário River and 25% (n = 12) lose this connection in the dry months, forming central lakes.

The depth of the sampled sites varied between 2.16 ± 0.87 m. Regarding the size (hectares) of the points, the value of 80.1 ± 1.99 ha was recorded, with the environments averaging 347.65 ± 229.19 m in length and 50.85 ± 26.89 m in width.

Using the mapping of pirarucu hotspots, the captures were programmed. For this, five groups of extractivists were trained on good handling practices of pirarucu—two groups in 2022, one in 2023 and two in 2024. Each class trained an average of 26 managers.

For the fisheries, the managers were subdivided into groups: fishing; pre-processing; data collection; and transport, logistics, and chilling of the fish. The possession of the general fishing registry identification was a governing factor for participating in the fishing team.

During the three years of the study, 633 pirarucu were captured, corresponding to 35,098 kg (55.45 ± 31.97) of crude biomass. Considering the biomass of the eviscerated animals, a total of 31,560 kg (49.86 ± 22.30) was sold. The average length of the animals corresponded to 172.85 ± 26.66 cm. A total of 320 (50.55%) females and 313 (49.44%) males were captured. The mean time exposure of the animals to air (moment of capture until their packaging in boxes with ice) was 31.47 ± 25.09 min.

In the first year, 146 (23%) pirarucu were caught, in the second 67 (10%), and in the third 420 (67%). In the first year of the study, the animals were marketed per kg at R$ 8 (US$ 1.58). In the other ones, the animals were marketed at R$ 10 (US$ 1.93). Therefore, there was a gross income of R$ 302,916.54 (US$ 58,417.20) from the control of the invasive pirarucu.

Considering the sampling effort related to catches, 64 effective fishing days were spent, with the average daily catch varying around 9 ± 7 fish/day. In addition, the CPUE of the catches was calculated at 54.84. This effort was able to capture 15.78% of the animals counted in the first year, 7.76% in the second one and 61.86% in the third one.

During managed fishing operations, bycatch was recorded. The technical team carried out monitoring, identification, and handling activities for incidentally captured species (Brito-Pereira et al., 2026b), and it was possible to record fish species (*Pseudoplatystoma tigrinum*, *Oxydoras niger*, *Colossoma macropomum*, *Melanosuchus niger*, *Phractocephalus hemioliopterus*, *Cichla* sp., *Patratygon* sp.), and other animals such as turtles (*Podocnemis unifilis*, *Podocnemis expansa*) and alligators (*Caiman crocodilus*). No accidental deaths of animals were recorded during the fisheries.

DISCUSSION

When it comes to biological invasions, the most appropriate measure from an ecological point of view is the eradication management of IAS (Doria et al., 2020). However, actions that effectively culminated in the eradication of the targets are practically nonexistent (Leão et al., 2011), and control attempts have increasing costs over time.

The complexity of the management of IAS is directly related to their ecology (Zenni et al., 2016). Thus, aspects such as dispersal, reproductive cycles, responses to environmental and climatic events, trophic level and behavior totally change the way species are managed (Sanguinetti et al., 2014). Management techniques that proved efficient for terrestrial species may not be used for aquatic species, due to the difficulties of detection in their natural environments, which represents challenges linked to population monitoring and, consequently, in the way the target species respond to management actions (Marangon et al., 2023). Because of this, there is a need for the use of adaptive management, by which, via monitoring of control actions, it is possible to improve decision-making with the knowledge that is obtained (Sampaio & Schmidt, 2013).

Nowadays, more investments are made in favor of efficient technologies for the early detection of environmental degradation, focusing on the effective control of such degradation (Olímpio & Zanella, 2012). One example of this are the Brasil Mais or Mapbiomas platforms for monitoring environmental degradation or the fire panel for detecting fire events (Nogueira, 2023). These have several methodologies for detecting and scaling degradation, directing actions of the government and contributing to more assertive decision-making. However,

when compared to the IAS, there are few initiatives that represent the actions aimed at early detection and coping with the degradation caused by them.

Such a problem is even more serious when it comes to aquatic species in natural ecosystems, since the mapping and monitoring of their populations tend to be even more difficult, especially in Amazon, due to its continental dimensions (Marangon et al., 2023; Sampaio & Schmidt, 2013). In this context, the extractive communities of Rondônia have already reported the deleterious effects of the emergence and growth of the invasive pirarucu population (Catâneo et al., 2022; SEDAM, 2022). However, because it is an unprecedented case in Rondônia and Brazil, the actions of the government have become bureaucratic and uncertain regarding the management of the case, especially in CUs.

As a result of predatory exploitation, in the past, the native populations of pirarucu were reduced to the point of being considered threatened with extinction (Castello et al., 2011). Since then, conservation actions have sought to restore natural stocks, both through sustainable management systems and by increasing rigidity in fishing standards (Castello et al., 2011). Another strategy adopted was the expansion of rearing of pirarucu in fish farms (Méndez et al., 2012; Pelicice et al., 2014). However, the technique has been replicated in various parts of the planet, including outside its zone of natural occurrence on several continents (Pereira et al., 2022).

Among the main causes of the invasion of pirarucu in natural ecosystems, scientists have already highlighted the precariousness of anti-escape barriers in farming systems and overflow caused by floods (Catâneo et al., 2022). Such reports have already occurred in several states of Brazil (Doria et al., 2020; Farias et al., 2019; Pereira et al., 2022), Bolivia, Peru (Doria et al., 2020; Miranda-Chumacero et al., 2012), and India (Raj et al., 2021).

In this context, the invasion by pirarucu has been known about in Rondônia for at least 40 years (Catâneo et al., 2022). However, government management to solve the problem is incipient (Sampaio & Schmidt, 2013), mainly due to the lack of protocols and or public policies related to decision-making.

Meanwhile, one of the main problems that has been reported by riverine communities is reduced food security, which has been caused by the decrease in fish that are traditionally consumed by these communities (Catâneo et al., 2022; SEDAM, 2022). Interestingly, although the meat of the pirarucu is popular in several states of Brazil and in other countries, most of the riverine communities of the invaded sites in Rondônia do not consume this type of fish (Catâneo et al., 2022). It is believed that this is due to cultural factors, which have strengthened the population increase of the species as an IAS.

As such, similar losses have already been reported in the form of the loss of biodiversity and extinction of endemic species in environments in which the pirarucu is not native (Gozlan et al., 2010; Vitule et al., 2009). The impacts linked to their invasion are usually due to the adaptive advantages and functional characteristics the pirarucu possesses over native species. For example, the pirarucu is a hardy fish, with a generalist diet (Queiroz, 2000; Brito-Pereira et al., 2026a) and is of a large size, which culminates in a high predation rate, associated with the lack of natural non-human predators (Carvalho et al., 2017).

Therefore, the occurrence of the species as an IAS in protected areas represents risks to the original purposes of the areas (Sampaio & Schmidt, 2013). Furthermore, the impacts extend to traditional riverine communities and the professional fishing community, as these areas are nurseries of biodiversity and function as sources for the replenishment of rivers in which commercial fishing occurs.

Studies have reported that among 20 species predated by pirarucu, including in CUs, 15 were of commercial interest (Pereira et al., 2022; Brito-Pereira et al., 2026b). This scenario is reinforced by the notes made by professional fishers from the Guaporé and Mamoré River basins, who with their empirical observations and fishing landing data, confirm the gradual reduction of fishing resources over the past 20 years (Catâneo et al., 2022).

According to Miranda-Chumacero (2012) and Van Damme et al. (2011), these observations are similar to those recorded in Bolivia, where the pirarucu is also classified as a biological invader. In Bolivia, its occurrence is already considered one of the main threats to aquatic ecosystems, due to the relationship it presents with the reduction in the availability of fishery resources (Doria et al., 2020), and this reflects in changes in the composition and structure of the icthyic assemblies (Miranda-Chumacero et al., 2012), which in the medium and long term, causes impacts on the entire trophic chain of invaded ecosystems (Carvalho et al., 2017).

In response to community demands, the present study proposed to adapt the management method of pirarucu consolidated in the Amazon, so that with the appropriate adaptations, it would be able to organize communities to face the environmental problem generated by the pirarucu invasion. From the adaptations, consistent methodologies were applied so that the community could have access to technical and scientific knowledge to act in the mission of minimizing the impacts of this invasive species. Thus, associating traditional knowledge with scientific knowledge, the community members were fundamental in the planning of management actions and were the protagonists in the capture and data collection from the managed animals, as well as local ecosystems data.

During the study, more than 630 pirarucu were caught, with a total length ranging between 104 and 232 cm. Such data corroborate the findings of Pereira et al. (2022), who also in Rondônia, captured 137 invasive pirarucu, with sizes ranging between 40 and 213 cm, suggesting that the animals have adapted to new environments and are achieving success in the colonization process.

The capture effort of the present work resulted in the removal of more than 35 tons of invasive pirarucu from the Cautário River, which represents one of the ways to reduce the animals' population. However, it is essential to highlight that the priority cause of the actions of the eradication management of pirarucu is the mitigation of the pressure imposed by invasive fish on native species, since the pirarucu does not only feed on fish (Carvalho et al., 2017).

To exploit the bioeconomic potential they have, one of the consequences of the management that is recognized by the State is the generation of income for the participating communities. In the first years, the management generated more than R$ 300,000 (US$ 58,417.20) for the extractivists and riverine communities involved, which brings about an improvement in their quality of life through the generation of income within the communities in which they live.

Protected areas are under constant pressure because of environmental crimes of the most diverse types. As a result, the generation of lawful income in the CUs may represent the reinforcement of strategies for the protection of the territory (Aracaty e Silva, 2022), since the community members act socially in the defense of their environmental resources (Mendonça & Santos, 2024).

One of the pillars used in the management of pirarucu is the participatory action of communities throughout the process (Santos & Nunes Filho, 2016). Thus, associating traditional knowledge with scientific knowledge was fundamental for the fulfillment of the stages that make up the management and to establish a relationship of trust with the communities.

From the counts, the results showed no significant difference for the numbers of pirarucu between the years monitored. However, there is a trend towards a reduction in the number of pirarucu between the years, of 6.71% in the second year and 26.6% in the third one. This represents a decrease in the number of fish counted, which may be associated with a reduction in the population of animals, since annual counts were carried out in the same ecosystems. Thus, it is considered that the first three years of management served to initiate the formative process of the communities in favor of the beginning of animal control. Moreover, the experience gained by the managers, associated with the increase in CPUE, tends to generate more severe impacts on the fish stocks of the managed pirarucu. As a result, it is necessary to continue the fishing of the invasive pirarucu in the coming years, considering the training of more community members and recycling the knowledge of experienced community members.

As such, a few more years of management are necessary, so that more robust evaluations of their effectiveness can be carried out. Furthermore, it is essential to defend better working conditions and greater market value for the pirarucu from the control/eradication management in the Cautário River RESEX, especially due to the conservationist aspect linked to this initiative.

CONCLUSION

This study demonstrates that the adaptation of participatory *A. gigas* management, originally developed for conservation purposes, can be redirected toward the control of invasive populations in protected areas of the Cautário River basin. The experience brought together technical knowledge, local ecological knowledge, community organization and institutional support, allowing riverine communities to take an active role in the monitoring, capture, and commercialization of invasive pirarucu. Between 2022 and 2024, the process resulted in the training of 126 community members, the mapping of 55 sampling points, the capture of 633 individuals and the commercialization of more than 31 tons of eviscerated biomass, generating R$ 302,916.54 in gross income for local communities. Although the population counts did not differ statistically among the years evaluated, the reduction observed in the number of individuals counted suggests a possible response to the management effort, which should be interpreted with caution and assessed through continued monitoring.

Beyond the numerical results, the method proved relevant because it addressed an environmental problem without disregarding the people who live with its consequences. By transforming the control of an invasive species into an organized, legal and community-based activity, the initiative strengthened local participation, contributed to supplementary income and created practical conditions for reducing pressure on native fish assemblages. The continuity of this strategy, however, remains essential. Longer monitoring periods, recurring training, improved working conditions, fairer market values and sustained institutional support will be necessary to evaluate its effectiveness more robustly and to consolidate it as an adaptive management model for invasive aquatic species in Amazonian protected areas.

ETHICAL APPROVAL AND ENVIRONMENTAL PERMITS

The management project was submitted to the relevant environmental agencies (SEDAM and Brazilian Institute of Environment and Renewable Natural Resources), which provided the environmental authorizations for research (SEDAM-CUC no. 156031 and no. 12/2023-CGFau/DBFlo), in addition to the authorization for fish sales (Environmental Licensing and Monitoring Coordination Office no. 156031). The project was also submitted to the Ethics Committee for Animal Use of the Universidade Federal de Rondônia and approved under the certificate number 003-2024-A.

CONFLICT OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT

All data relevant to the study are included in the article.

AUTHORS' CONTRIBUTION

Conceptualization: Chagas, T.Q., Sousa, R.G.C.; **Supervision:** Chagas, T.Q., Santos Júnior, C.C., Tomasoni, L.F.S., Santos, T.A., Souza, E.J.T., Sousa, R.G.C.; **Writing – review & editing:** Chagas, T.Q.; **Validation:** Chagas, T.Q., Sousa, R.G.C.; **Investigation:** Varão, C.A.R., Silva, M.G., Barreto, R.R.; **Final approval:** Sousa, R.G.C.

FUNDING

Fundação de Amparo ao Desenvolvimento das Ações Científicas e Tecnológicas e a Pesquisa do Estado de Rondônia

Grants no: 0012.000492/2023-07; 0012.000162/2025-75.

DECLARATION OF USE OF ARTIFICIAL INTELLIGENCE TOOLS

The authors declare that no artificial intelligence tools were used in the preparation of this manuscript.

ACKNOWLEDGMENTS

The authors would like to thank the traditional communities of the Extractive Reserve of the Cautário River for their fundamental support during field activities and experimental fisheries. They also thank Secretaria de Estado do Desenvolvimento Ambiental and Instituto Chico Mendes de Conservação da Biodiversidade for the logistical and operational support granted to the project.

REFERENCES

Amaral, E., Torres, A. C., & Peralta, N. (2013). A avaliação participativa como ferramenta para tomadas de decisão em processos de manejo de pirarucu (*Arapaima gigas*). In: Figueiredo, E. S. A. (ed.), *Biologia, conservação e manejo participativo de pirarucus na Pan-Amazônia* (pp. 213-236). Instituto de Desenvolvimento Sustentável Mamirauá. Retrieved from https://mamiraua.org.br/wp-content/uploads/2025/11/Biologia-conservacao-e-manejo-participativo-de-pirarucus.pdf

Aracaty e Silva, M. L., Lucas, M. M. B. L., & Pinto, L. M. D. R. B. (2022). Startups da floresta, negócios de impacto e a sustentabilidade na Amazônia. *Informe Gepec*, 26(2), 30-49. https://doi.org/10.48075/igepec.v26i2.28223

Brasil (2000). *Lei n. 9.985, de 18/08/2000. Regulamenta o art. 225, § 1o, incisos I, II, III e VII da Constituição Federal, institui o Sistema Nacional de Unidades de Conservação da Natureza e dá outras providências*. Ministério do Meio Ambiente, Sistema Nacional de Unidades de Conservação da Natureza. Retrieved from https://www.planalto.gov.br/ccivil_03/leis/l9985.htm

Brito-Pereira, S. B., Oliveira, N. S., Fernandes, F. H., Lima, S. A. O., Chagas, T. Q., Meante, R. E. X., Beltrão, B., & Sousa, R. G. C. (2026a). Analysis of the stomach contents of Arapaima gigas in the Cautário River Basin, Rondônia, Brazil. Boletim do Instituto de Pesca, 52, e978. https://doi.org/10.20950/1678-2305/bip.2026.52.e978

Brito-Pereira, S. B., Silva, E. F. O., Pereira, S. B., Varão, C. A. R., Barreto, R. R., Chagas, T. Q., Gonzaga-Junior, M. A., & Sousa, R. G. C. (2026b). Composition of the bycatch associated with Arapaima gigas fisheries in lotic and lentic environments of the Cautário River basin, Rondônia, Brazil. Boletim do Instituto de Pesca, 52, e1014. https://doi.org/10.20950/1678-2305/bip.2026.52.e1014

Carvalho, F., Power, M., Forsberg, B. R., Castello, L., Martins, E. G., & Freitas, C. E. C. (2017). Trophic ecology of Arapaima sp. in a ria lake-river-floodplain transition zone of the Amazon. Ecology of Freshwater Fish, 27(1), 237-246. https://doi.org/10.1111/eff.12341

Castaldelli, G., Pluchinotta, A., Milardi, M., Lanzoni, M., Giari, L., Rossi, R., & Fano, E. A. (2013). Introduction of exotic fish species and decline of native species in the lower Po basin, north-eastern Italy. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 23(3), 405-417. https://doi.org/10.1002/aqc.2345

Castello, L., Stewart, D. J., & Arantes, C. C. (2011). Modeling population dynamics and conservation of arapaima in the Amazon. *Reviews in Fish Biology and Fisheries*, 21, 623-640. https://doi.org/10.1007/s11160-010-9197-z

Castello, L., Stewart, D. J., & Arantes, C. C. (2013). O que sabemos e precisamos fazer a respeito da conservação do pirarucu (*Arapaima* spp.) na Amazônia. In: Figueiredo, E. S. A. (org.), *Biologia, conservação e manejo participativo de pirarucus na Pan-Amazônia* (pp. 17-32). Instituto de Desenvolvimento Sustentável Mamirauá. Retrieved from https://www.researchgate.net/publication/280683192_O_que_sabemos_e_precisamos_fazer_a_respeito_da_conservacao_do_pirarucu_Arapaima_spp_na_Amazonia

Catâneo, D. T. B. D. S. (2019). *A invasão do pirarucu* Arapaima gigas *Schinz, 1822 na bacia do rio Madeira: histórico de introdução, determinação genética e manejo* [dissertation]. Fundação Universidade Federal de Rondônia. https://ri.unir.br/jspui/handle/123456789/2989

Catâneo, D. T. B. D. S., Ximenes, A. M., Garcia-Davila, C. R., Van Damme, P. A., Pagotto, R. D. C., Vitule, J. R. S., Hrbek, T., Farias, I. P., & Doria, C. R. C. (2022). Elucidating a history of invasion: population genetics of pirarucu (*Arapaima gigas*, Actinopterygii, Arapaimidae) in the Madeira River. *Hydrobiologia*, 849(16), 3617-3632. https://doi.org/10.1007/s10750-022-04977-8

Conceição, R. M., Marinho, J. C., Batista, J. S., Lima, A. C., Gonçalves, A. C. T., Gomes, M. C., Nunes, E. S. C. L., Moraes, C. M., Lima, B. M., Chagas, I. C. C., Bezerra, C. A. C., Silva, R. B., Souza, D. O. B., Souza, N. B., Batalha, Y. S., & Lopes, R. D. (2018). *Boas práticas de manipulação do pirarucu*. Instituto Mamirauá. Retrieved from https://mamiraua.org.br/wp-content/uploads/2025/11/Boas-praticas-de-manipulacao-do-pirarucu.pdf

Conselho Nacional de Controle de Experimentação Animal (CONCEA) (2013). *Resolução Normativa n. 13*. Institui a Diretriz da Prática de Eutanásia do Conselho Nacional de Controle de Experimentação Animal. Ministério da Ciência, Tecnologia e Inovação. Retrieved from https://antigo.mctic.gov.br/mctic/export/sites/institucional/institucional/concea/arquivos/legislacao/resolucoes_normativas/Resolucao-Normativa-CONCEA-n-13-de-20.09.2013-D.O.U.-de-26.09.2012-Secao-I-Pag.-5.pdf

Costanza, R. (2000). Social goals and the valuation of ecosystem services. *Ecosystems*, 3(1), 4-10. Retrieved from https://www.jstor.org/stable/3658660

Dantas, D. D. F., Raseira, M. B., Polaz, C. N. M., & Lopes, U. (2022). *Estratégia integrada de monitoramento aquático continental na Amazônia:* Programa Nacional de Monitoramento da Biodiversidade do ICMBio (Monitora) – subprograma Aquático Continental. ICMBio. Retrieved from https://www.gov.br/icmbio/pt-br/assuntos/monitoramento/conteudo/Materiais-de-Apoio/estrategiaintegradademonitoramentoaquaticocontinentalamazonicointernet16082022.pdf

Dias, R. D. S. (2014). *Reserva extrativista estadual do rio Cautário-RO: o manejo florestal como uso sustentável no território* [dissertation]. Fundação Universidade Federal de Rondônia. Retrieved from https://ri.unir.br/jspui/bitstream/123456789/2022/1/3686_rosalina_dos_santos_dias_2012.pdf

Doria, C. D. C., Catâneo, D. T. B. S., Torrente-Vilara, G., & Vitule, G. R. S. (2020). Is there a future for artisanal fishing in the amazon? The case of *Arapaima gigas*. *Management of Biological Invasions*, 11(1), 1-8. https://doi.org/10.3391/mbi.2020.11.1.01

Dos Santos, A. L. (2018). A educação ambiental através da linguagem midiática verbal e não verbal. *Revista Acadêmica Licencia & Acturas*, 6(1), 86-94. https://ojs.licenciaeacturas.com.br/index.php/ojs/article/download/211/193/43

Farias, I. P., Willis, S., Leão, A., Verba, J. T., Crossa, M., Foresti, F., Porto-Foresti, F., Sampaio, I., & Hrbek, T. (2019). The largest fish in the world's biggest river: Genetic connectivity and conservation of *Arapaima gigas* in the Amazon and Araguaia-Tocantins drainages. *PLoS One*, 14(8), e0220882. https://doi.org/10.1371/journal.pone.0220882

Gillingham, P. K., Britton, J. R., Jones, G., Miller-Rushing, A., Stafford, R., & Slater, H. (2024). Climate change adaptation for biodiversity in protected areas: An overview of actions. *Biological Conservation*, 289, 110375. https://doi.org/10.1016/j.biocon.2023.110375

Gonçalves, A. C., & Figueiredo, E. S. A. (2013). O manejo participativo de pirarucu (*Arapaima gigas*) nas Reservas de Desenvolvimento Sustentável Mamirauá. In: Figueiredo, E. S. A. (org.), *Biologia, conservação e manejo participativo de pirarucus na Pan-Amazônia* (p. 267-277). Instituto de Desenvolvimento Sustentável Mamirauá.

Gozlan, R. E., Britton, J. R., Cowx, I., & Copp, G. H. (2010). Current knowledge on non-native freshwater fish introductions. *Journal of Fish Biology*, 76(4), 751-786. https://doi.org/10.1111/j.1095-8649.2010.02566.x

Ikeziri, A. A. S. L., Queiroz, L. J., Doria, C. R. C., Fávaro, L. F., Araújo, T. R., & Torrente-Vilara, G. (2008). Estrutura populacional e abundância do apapá-amarelo, Pellona castelnaeana (Valenciennes, 1847) (Clupeiformes, Pristigasteridae), na Reserva Extrativista do rio Cautário, Rondônia. *Revista Brasileira de Zoociências*, 10(1), 41-50. Retrieved from https://periodicos.ufjf.br/index.php/zoociencias/article/view/24084

Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) (2016). *Plano de Manejo da Reserva Extrativista Federal do Rio Cautário*. Ministério do Meio Ambiente e Mudança do Clima, Instituto Chico Mendes de Conservação da Biodiversidade, NGI ICMBio Cautário-Guaporé. Retrieved from https://www.gov.br/icmbio/pt-br/assuntos/biodiversidade/unidade-de-conservacao/unidades-de-biomas/amazonia/lista-de-ucs/resex-do-rio-do-cautario/plano_de_manejo_resex_cautario.pdf

Johnson, P. T., Olden, J. D., & Vander Zanden, M. J. (2008). Dam invaders: impoundments facilitate biological invasions into freshwaters. *Frontiers in Ecology and the Environment*, 6(7), 357-363. https://doi.org/10.1890/070156

Leão, T. C. C., Almeida, W. R., Dechoum, M. S., & Ziller, S. R. (2011). *Espécies exóticas invasoras no nordeste do Brasil: contextualização, manejo e políticas públicas*. Centro de Pesquisas Ambientais do Nordeste, Instituto Hórus de Desenvolvimento e Conservação Ambiental. Retrieved from https://www.esalq.usp.br/lcb/lerf/divulgacao/recomendados/outros/leao2011.pdf

Lima, L. G. D., & Batista, V. D. S. (2012). Estudos etnoictiológicos sobre o pirarucu *Arapaima gigas* na Amazônia Central. *Acta Amazonica*, 42(3), 337-344. https://doi.org/10.1590/S0044-59672012000300005

Lima Junior, D. P., Magalhães, A. L. B., Pelicice, F. M., Vitule, J. R. S., Azevedo-Santos, V. M., Orsi, M. L., Simberloff, D., & Agostinho, A. A. (2018). Aquaculture expansion in Brazilian freshwaters against the Aichi Biodiversity Targets. *Ambio*, 47, 427-440. https://doi.org/10.1007/s13280-017-1001-z

Machado, A. B. M., Drummond, G. M., & Paglia, A. P. (2008). *Livro vermelho da fauna brasileira ameaçada de extinção*. Ministério do Meio Ambiente, Fundação Biodiversitas. Retrieved from https://biodiversitas.org.br/wp-content/uploads/2025/12/Livro-Vermelho-BR-Vol-I.pdf

Marangon, G. M. C., Galvão, A., Guimarães, T. C. S., & Marini, M. M. G. (2023). Espécies exóticas invasoras nos planos de ação nacional para a conservação das espécies ameaçadas de extinção. *Biodiversidade Brasileira*, 13(4), 1-14. https://doi.org/10.37002/biodiversidadebrasileira.v13i4.2275

Marková, J., Jerikho, R., Wardiatno, Y., Kamal, M. M., Magalhães, A. L. B., Bohatá, L., Kalous, L., & Patoka, J. (2020). Conservation paradox of giant arapaima *Arapaima gigas* (Schinz, 1822) (Pisces: Arapaimidae): endangered in its native range in Brazil and invasive in Indonesia. *Knowledge & Management of Aquatic Ecosystems*, 421(47), 1-10. https://doi.org/10.1051/kmae/2020039

Méndez, C. C., López, G. R., Carvajal-Vallejos, F. M., Peredo, R. S., Wojchiechowski, J. M., & Van Damme, P. (2012). *Cadena de valor del pescado en el norte amazónico de Bolivia: contribución de especies nativas y de una especie introducida (el paiche-* Arapaima gigas*)*. Investigación ambiental/Fundación PIEB. Retrieved from https://idl-bnc-idrc.dspacedirect.org/bitstreams/f51266e1-2d3e-4a50-8969-2f2079ec223b/download

Mendonça, T. C. M., & Santos, R. D. O. (2024). A "casa" é minha: perspectivas e significados da "casa" na Rede Nhandereko de Turismo de Base Comunitária. *Revista Latino-Americana de Turismologia*, 1-12. https://doi.org/10.5281/zenodo.13830284

Miranda-Chumacero, G., Wallace, R., Calderón, H., Calderón, G., Willink, P., Guerrero, M., Siles, T. M., Lara, K., & Chuqui, D. (2012). Distribution of arapaima (*Arapaima gigas*) (Pisces: Arapaimatidae) in Bolivia: implications in the control and management of a non-native population. *BioInvasions Record*, 1(2), 129-138. https://doi.org/10.3391/bir.2012.1.2.09

Nogueira, E. M. (2023). Atuação do Censipam na proteção, conservação e desenvolvimento sustentável da Amazônia Legal e Amazônia Azul. *Diálogos Soberania e Clima*, 2(8), 64-72. Retrieved from https://soberaniaeclima.org.br/wp-content/uploads/2023/08/06-Atuacao-do-Censipam-na-protecao-conservacao-e-desenvolvimento-sustentavel-%E2%80%94-Edileuza-de-Melo-Nogueira.pdf

Olímpio, J. L. S., & Zanella, M. E. (2012). Emprego das tecnologias da geoinformação na determinação das vulnerabilidades natural e ambiental do município de Fortaleza/CE. *Revista Brasileira de Cartografia*, 64(1), 1-12. https://doi.org/10.14393/rbcv64n1-43772

Pedlowski, M., Dale, V., & Matricardi, E. (1999). A criação de áreas protegidas e os limites da conservação ambiental em Rondônia. *Ambiente & Sociedade*, (5), 93-107. https://doi.org/10.1590/S1414-753X1999000200008

Pedreira, B. C. C. G. (2023). *A relação entre as interferências antrópicas e os serviços ecossistêmicos*. Retrieved from https://www.sidalc.net/search/Record/dig-alice-doc-1154596/Description

Pelicice, F. M., Vitule, J. R. S., Lima Junior, D. P., Orsi, M. L., & Agostinho, A. A. (2014). A serious new threat to Brazilian freshwater ecosystems: the naturalization of nonnative fish by decree. *Conservation Letters*, 7(1), 55-60. https://doi.org/10.1111/conl.12029

Pereira, L. S., Barbosa, J. M., & Sousa, R. G. C. (2022). The Amazonian Arapaima changes its status from threatened species to an invader of earth's freshwater ecosystems. *Acta of Fisheries and Aquatic Resources*, 10(2), 97-107. http://doi.org/10.46732/actafish.2022.10.2.97-107

Pocock, M. J., Adriaens, T., Bertolino, S., Eschen, R., Essl, F., Hulme, P. E., Jeschke, J. M., Roy, H. E., Teixeira, H., & Groot, M. (2024). Citizen science is a vital partnership for invasive alien species management and research. *IScience*, 27(1), 108623. https://doi.org/10.1016/j.isci.2023.108623

Portz, L., Manzolli, R. P., Saldanha, D. L., & Correa, I. C. S. (2011). Dispersão de espécie exótica no Parque Nacional da Lagoa do Peixe e seu entorno. *Revista Brasileira de Geografia Física*, 4(1), 33-44. https://doi.org/10.26848/rbgf.v4i1.232694

Pratzer, M., Meyfroidt, P., Antongiovanni, M., Aragon, R., Baldi, G., Czaplicki Cabezas, S., de la Vega-Leinert, C. A., Dhyani, S., Diepart, J.-C., Fernandez, P. D., Garnett, S. T., Gavier Pizarro, G. I., Kalam, T., Koulgi, P., le Polain de Waroux, Y., Marinaro, S., Mastrangelo, M., ... & Kuemmerle, T. (2024). An actor-centered, scalable land system typology for addressing biodiversity loss in the world's tropical dry woodlands. *Global Environmental Change*, 86, 102849. https://doi.org/10.1016/j.gloenvcha.2024.102849

Priya, A. K., Muruganandam, M., Rajamanickam, S., Sivarethinamohan, S., Gaddam, M. K. R., Velusamy, P., Gomathi, R., Ravindiran, G., Gurugubelli, T. R., & Muniasamy, S. K. (2023). Impact of climate change and anthropogenic activities on aquatic ecosystem–A review. *Environmental Research*, 238(part 2), 117233. https://doi.org/10.1016/j.envres.2023.117233

Queiroz, H. L. D. (2000). *Natural history and conservation of pirarucu, Arapaima gigas, at the Amazonian Várzea: red giants in muddy waters* (doctoral dissertation). University of St Andrews. https://hdl.handle.net/10023/2818

Raj, S., Prakash, P., Reghunath, R., Tharian, J. C., Raghavan, R., & Kumar, A. B. (2021). Distribution of alien invasive species in aquatic ecosystems of the southern Western Ghats, India. *Aquatic Ecosystem Health & Management*, 24(2), 64-75. https://doi.org/10.14321/aehm.024.02.10

Ribeiro, R. E., Corrêa, R. S., & Couto Júnior, A. F. (2024). Criminological analysis of green delicts in the Federal District of Brazil. *Fronteira: Journal of Social, Technological and Environmental Science*, 13(1), 200-212. https://periodicos.unievangelica.edu.br/index.php/fronteiras/article/view/6999/5143

Rondônia (2024). *Boletim Diário de Monitoramento de Eventos Hidrológicos Críticos do Estado de Rondônia*. Secretaria de Estado do Desenvolvimento Ambiental. Retrieved from https://www.sedam.ro.gov.br/post/cogeo-boletim-diario-2024

Sampaio, A. B., & Schmidt, I. B. (2013). Espécies exóticas invasoras em unidades de conservação federais do Brasil. *Biodiversidade Brasileira*, 3(2), 32-49. https://doi.org/10.37002/biodiversidadebrasileira.v3i2.351

Sanguinetti, J., Buria, L., Malmierca, L., Valenzuela, A. E., Núñez, C., Pastore, H., Chauchard, L., Ferreyra, N., Massaccesi, G., Gallo, E., & Chehébar, C. (2014). Manejo de especies exóticas invasoras en Patagonia, Argentina: Priorización, logros y desafíos de integración entre ciencia y gestión identificados desde la Administración de Parques Nacionales. *Ecología Austral*, 24(2), 183-192. Retrieved from https://www.scielo.org.ar/scielo.php?pid=S1667-782X2014000200007&script=sci_arttext

Santos, F., Rabelo, S. A., Lehmann, D., Lemos, P. F., Reis, M. L., Marini Filho, O. J., Carvalho Júnior, E., Borges, M. C., Silvius, K. M., & Felizardo, S. P. S. (2024). Programa Monitora e a amostragem em contraste: narrativas da implementação em uma floresta nacional na Amazônia. *Biodiversidade Brasileira*, 14(3), 105-120. https://doi.org/10.37002/biodiversidadebrasileira.v14i3.2541

Santos, K. C. C., & Nunes Filho, M. S. (2016). A sustentabilidade ambiental e os conhecimentos tradicionais no manejo do pirarucu na Amazônia. *Revista de Direito e Sustentabilidade*, 2(1), 242-258. https://doi.org/10.26668/IndexLawJournals/2525-9687/2016.v2i1.1041

Secretaria de Estado do Desenvolvimento Ambiental (SEDAM) (2016). *Plano de Manejo da Reserva Extrativista Estadual do Rio Cautário*. Secretaria de Estado do Desenvolvimento Ambiental, Coordenadoria de Unidades de Conservação. Retrieved from https://www.gov.br/icmbio/pt-br/assuntos/biodiversidade/unidade-de-conservacao/unidades-de-biomas/amazonia/lista-de-ucs/resex-do-rio-do-cautario/plano_de_manejo_resex_cautario.pdf

Secretaria de Estado do Desenvolvimento Ambiental (SEDAM) (2022). Manejo do pirarucu na Resex Rio Cautário em Costa Marques será destacado pela Sedam na COP-27. Governo do Estado de Rondônia. Retrieved from https://rondonia.ro.gov.br/manejo-do-pirarucu-na-resex-rio-cautario-em-costa-marques-sera-destacado-pela-sedam-na-cop-27/

Silva, R. B. D., Gonçalves, A. C. T., & Marinho, J. C. (2013). *Contagem e censo populacional de Pirarucu*. Instituto de Desenvolvimento Sustentável Mamirauá. Retrieved from https://transforma.fbb.org.br/storage/socialtecnologies/80/files/Contagem%20de%20Pirarucu.pdf

Simberloff, D., & Vitule, J. R. (2014). A call for an end to calls for the end of invasion biology. *Oikos*, 123(4), 408-413. https://doi.org/10.1111/j.1600-0706.2013.01228.x

Soares-Filho, B. S., Oliveira, U., Ferreira, M. N., Marques, F. F. C., Oliveira, A. R., Silva, F. R., & Börner, J. (2023). Contribution of the Amazon protected areas program to forest conservation. *Biological Conservation*, 279, 109928. https://doi.org/10.1016/j.biocon.2023.109928

Van Damme, P., Carvajal-Vallejos, F. M., Carpio, J. M. (eds.) (2011). *Los peces y delfines de la amazonía boliviana: hábitats, potencialidades y amenazas*. Editorial INIA. Retrieved from https://www.editorial-inia.com/wp-content/uploads/2021/06/Van-Damme-et-al_2011_Los-peces-y-delfines-de-la-Amazonia-boliviana.pdf

Vitule, J. R. S. (2009). Introduction of fishes in Brazilian continental ecosystems: Review, comments and suggestions for actions against the almost invisible enemy. *Neotropical Biology and Conservation*, 4(2), 111-122. https://revistas.unisinos.br/index.php/neotropical/article/view/5123/2375

Zenni, R. D., Dechoum, M. S., & Ziller, S. R. (2016). Dez anos do informe brasileiro sobre espécies exóticas invasoras: avanços, lacunas e direções futuras. *Biotemas*, 29(1), 133-153. https://doi.org/10.5007/2175-7925.2016v29n1p133