Acta Limnologica Brasiliensia

Publication of the Brazilian Association of Limnology

Thematic Section:
Mini-Reviews in Applied Limnology
Acta Limnologica Brasiliensia, 2020, vol. 32, e204
https://doi.org/10.1590/S2179-975X2019
ISSN 2179-975X on-line version

Management of Pirarucu (*Arapaima gigas,* Teleostei, Osteoglossidae) in Sustainable Use Units as a proposal for the restoration of aquatic ecosystems

Manejo de Pirarucu (*Arapaima gigas*, Teleostei, Osteoglossidae) em Unidades de Uso Sustentável como proposta de recuperação de ecossistemas aquáticos

Eucilene Alves Santana[1]*, Edson Fontes de Oliveira[2], Nataluzo da Silva Balbino[3] and Helen Gurgel[4]

[1]Programa de Pós-Graduação em Geografia, Laboratório de Geografia, Ambiente e Saúde, Universidade de Brasília – UnB, Campus Universitário Darcy Ribeiro, ICC Norte, CEP 70904-970, Brasília, DF, Brasil

[2]Programa de Pós-Graduação em Engenharia Ambiental, Laboratório de Ecologia Teórica e Aplicada, Departamento de Engenharia Ambiental, Universidade Tecnológica Federal do Paraná – UTFPR, Campus de Londrina, Estrada dos Pioneiros, 3131, CEP 86036-370, Londrina, PR, Brasil

[3]Universidade de Brasília, Campus de Planaltina, Área Universitária 1, Vila Nossa Senhora de Fátima, CEP 73345-010, Planaltina, DF, Brasil

[4]Programa de Pós-Graduação em Geografia, Universidade de Brasília – UnB, Campus Universitário Darcy Ribeiro, Asa Norte, ICC Norte, CEP 70910-900, Brasília, DF, Brasil

*e-mail: eucilenealves2012@gmail.com

Cite as: Santana, E.A. et al. Management of Pirarucu (*Arapaima gigas*, Teleostei, Osteoglossidae) in Sustainable Use Units as a proposal for the restoration of aquatic ecosystems. *Acta Limnologica Brasiliensia*, 2020, vol. 32, e204

Abstract: Sustainable Use Units have been carrying out sustainable management since the 1990s in the State of Amazonas, leading to research on the influence of management plans on restoring ecosystems. We developed an integrative review and analyzed official documents, data from the Brazilian government and information obtained from fishermen on the Unini River Extractive Reserve. The review articles were analyzed qualitatively, and a X^2 test was used to verify differences in the distribution of proportions of pirarucu between the years after implementing the management. The management plan was the most cited as a solution to the environmental, social, and economic problems identified in the ecosystems. The data showed an increase in the numbers of pirarucu both in State of Amazonas and in the Unini River Reserve, reinforcing the perception of the community and fishermen. This suggests that when management plans are developed with the involvement of the local community, they present potential to restore ecosystems.

Keywords: rural populations; forests and waters; fishing environments; environmental planning.

Resumo: No Estado do Amazonas, Unidades de Uso Sustentável realizam manejo sustentável desde a década de 90, o que possibilita a pesquisa sobre a influência dos planos de manejo na restauração de ecossistemas. Desenvolvemos uma revisão integrativa e analisamos documentos oficiais, dados do governo brasileiro e informações obtidas com os pescadores da Reserva Extrativista Rio Unini. Os artigos de revisão foram analisados qualitativamente, e, para testar as diferenças na distribuição das proporções de pirarucus entre os anos após implantação do manejo, utilizamos o teste do X^2.

O plano de manejo foi o mais citado como solução aos problemas ambientais, sociais e econômicos identificados nos ecossistemas. Os dados mostraram aumento nos quantitativos de pirarucu tanto para o Estado do Amazonas como na Reserva Extrativista do rio Unini, em concordância com a percepção da comunidade e pescadores, sugerindo que planos de manejo, quando elaborados com o envolvimento da comunidade local, apresentam potencial na restauração de ecossistemas.

Palavras-chave: populações de campos; florestas e águas; ambientes de pesca; planejamento ambiental.

1. Introduction

In Brazil, the management of Conservation Units is developed in dialogue with the conservation and management of the ichthyofauna, as it includes social participation in the administration of protected areas, in the knowledge management and in the relationship between conservation and socioeconomic development (Polaz & Ribeiro, 2017). With the implementation of extractive reserves, one of the types of Conservation Unit Categories in Brazil, defined as the area used by traditional extractive populations, whose subsistence is based on extractivism, it is possible to increase the control of natural resources by local communities (Isaac-Nahum, 2006). A similar situation occurs in Sustainable Use Units (SUU), Indigenous Lands, or protected areas that have management permission through fishing agreements.

SUU, such as extractive reserves, originated as a form of criticism of the increasing deforestation occurring in Amazonia, with the purpose of covering different ecosystems or microenvironments in its territory and allowing the interaction between ecosystems in their multiple dimensions (Cunha, 2001).

An example of this is the case of the Amazon lowlands. Although more than half of the flooded habitats can provide feeding and breeding conditions for pirarucu (*Arapaima gigas*), they were intensely deforested (Castello et al., 2011; Renó et al., 2011), further intensifying the decline of fisheries in most of the Amazon (Castello & Stewart, 2010; Castello et al., 2013a). Deforestation with an impact on fishing is more typical in areas outside biological or extractive reserves (Castello et al., 2013b), justifying the creation of SUU.

The fishing resources are renewable, although also finite. A fishing extraction above a certain point may affect fish stocks and populations commercially and even biologically. This impact may increase even more with the occurrence of extreme phenomena such as large droughts (Oviedo & Crossa, 2013), climate change, alteration of river flows, sedimentation of rivers, which often result from human activities. This can affect not only the behavior of the pirarucu, the largest freshwater fish, but also its key role in its ecosystems, which is still largely unknown.

According to Queiroz (2000), some biological and ecological aspects of the pirarucu are that older fish can reach up to three meters in length and have a marked red color mainly on the back of the body, are piscivores when adults, and, due to gill atrophy, are forced to rise to the surface of the water to breathe in regular intervals, when they become easy prey for fishermen. Mobility is not a strong point of the species, which suggests that the main biological aspects of the species are closely related to physical and chemical aspects of its environment.

As for distribution, the family Osteoglossidae, subfamily Heterotidinae, is present in the Amazon Biome, and the species is known as "Paiche" in Peru and Colombia, "Arapaima" in Guyana and "Pirarucu" in Brazil, where it can be found in the lowlands of the Araguaia-Tocantins and Solimões-Amazonas (Queiroz, 2000).

In Brazil, this biome is the target of many large-scale economic activities that may have an impact on ecosystems, such as agriculture, mining, livestock, hydroelectric construction, and logging. Supression of riparian vegetation, river siltation and intense sport fishing are expected to interfere with the environmental quality of the lakes, the preservation of the riparian forest and the ecological interaction with the other species of fish in the lakes. The consequences could involve changes in the aquatic biota as a whole, leading to the loss of diversity in the system (Fidelis et al., 2008), including the removal of key species.

How is it possible to restore these ecosystems and guarantee their sustainable use by human populations? In Brazil, a strategy was adopted two decades ago. However, information regarding the results of this strategy is still restricted, due to the lack of geographic data monitoring information on the flooded areas of the managed lakes, and on the details of water and vegetation conditions of these managed lakes.

This mini-review aims to answer how the management plans used in the SUUs have contributed to the restoration of aquatic ecosystems and what are the existing gaps. We use the information available in the literature about the pirarucu management plan implemented since 2011 in the Unini River Extractive Reserve, as a case study.

2. Material and Methods

In order to search for articles, we used the following descriptors and their combinations in Portuguese and English: management plan; extractive reserve; aquatic organisms; ecosystem restoration; ecosystem evaluation; Unini River; Pirarucu; Arapaima. We used the database ScienceDirect® and the Google Scholar tool in the advanced search mode to have access to other databases.

The criteria for including the articles were: published in Portuguese, English or Spanish; articles in full that portrayed the theme of the review, and articles published and indexed at those databases in the last fifteen years. Articles that exclusively addressed marine or coastal environments or agroforestry management plans were excluded. The analysis of the articles was descriptive, allowing the observation, counting, description and classification of the data, in order to organize the knowledge produced on the topic.

For the case study, we analyzed the documents, data from the *Arapaima gigas* species that counts in the period from 2012 to 2017, the extractive fishery data (1994 to 2011) made available by Chico Mendes Institute for Biodiversity Conservation (ICMBio), and the information obtained in the field at the dry season in October 2018 during the management of the fishery with the fishermen of the communities of the River Unini Extractive Reserve.

To test whether there was a difference in the distribution of the proportion of young (budecos) and adult pirarucus from 2012 to 2017 obtained by the counting method adopted for the species (Castello, 2004), we chose the X^2 (chi-square) test, with a level of confidence of 5%, accepting that each years' groups are independent and the items of each group are counted randomly. We used the Epiinfo TM software version 1.4.3.

3. Results

3.1. Literature review

In the search using the keywords described in the methodology we obtained 59 articles available online, and only 12 directly presented the main environmental causes and their consequences to the continental aquatic ecosystems, as well as the use of management as a possible solution for the conservation and recovery of aquatic ecosystems (Table 1).

Among all the causes, the most cited are climate change, increased fishing effort and alteration in water resources. The environmental consequences are wide and vary according to the causes and ecosystems under analysis. Among the solutions, management was the most cited, and it could be conservationist, participatory, active or passive, proactive or reactive. Fishing agreements was also highlighted.

The articles also emphasized the importance of ecosystem monitoring as a way of predicting future scenarios, possible ecological consequences, determining how management practices should be implemented, as well as providing information on biology, population parameters and the effects of exploitation. They also pointed to the possibility of using modeling as a tool to help in the restoration (Table 1).

3.2. Case study: management of pirarucu

The shortage of vegetable resources, intensified by deforestation in the Amazonia biome, made fishing – which was previously secondary – a main source of food and income, leading to overexploitation of fish species. The piscivorous and carnivorous groups are the preferred targets of many commercial fisheries; however, these species of higher trophic levels and fairly large body sizes present greater vulnerability, and their recovery is not an easy task (Isaac et al., 2012).

This overexploitation is observed in the pirarucu extractive fishery between 1994 and 1995 in Brazil (>3,400 t/year) and in the State of Amazonas (2,122.00 t/year), but also in the impact of the following years, from 1996 to 2004, with a variation of 0.208 t/year to 0.71 t/year (Figure 1A). However, with the creation of SUU with management plans (12 in the State of Amazonas) between 1996 to 2007, and with the regulation of fisheries agreements through the Normative Instruction nº 29 of 2003 by Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) (Figure 1B), the extractive fishery of the species was expressive again from 2005 reaching 0.958 t/year.

The Unini River Extractive Reserve is one of the twelve SUUs with management plan. It encompasses approximately 99% of the Unini River basin (FVA, 2011), and was zoned into three sectors, of which the second is currently destined

Table 1. Summary of results in identifying the main environmental causes and consequences in aquatic ecosystems and solutions for recovery.

1. Reference: Mateus et al. (2017)	**Place of coverage:** Amazonas, Brazil
Environmental Causes and Consequences: Defaunation and climate change. The defaunation impacts the ecological structures and ecosystem functions/services, such as the patterns of species' evolution, the abundance, the ecology of biomes, the changes in nutrient cycles and water quality. In tropical freshwater ecosystems, the risk increases, since the number of endangered animals in these places is nine times higher than that of animals in marine ecosystems. **Solutions:** Development of well-planned local conservation management models and their execution as a strategy to face extinction and/or mitigate the process and face the environmental crisis.	
2. Reference: Medina & Barbosa (2016)	**Place of coverage:** Pará, Brazil
Environmental Causes and Consequences: Increased inventory pressure through the acquisition of equipment with higher capturing capacity or due to increase in time of work. **Solutions:** Fishing agreements or norms with clearly defined objectives.	
3. Reference: Vidal et al. (2015)	**Place of coverage:** Floodplain ecosystems in the central region of the Amazon Basin
Environmental Causes and Consequences: Increased fishing effort results in declining fish stocks, gradual decline in the average length of the captured species and successive elimination of larger specimens. **Solutions:** Projects for the management of natural resources in socio-economically and environmentally sustainable ways. Fishing agreements that limit access, season, type, and size of fishing gear used, or join these aspects together.	
4. Reference: Medeiros & Silva (2015)	**Place of coverage:** Marajó Island, Pará, Brazil
Environmental Causes and Consequences: Increased traffic in rivers and predatory exploitation leads to fish shortages. **Solutions:** The possibility of multiple activities with multi-purpose fishermen, or those who adapt to the seasonal conditions of the ecosystem performing other activities such as collecting wild products, developing small scale agriculture, jute farming, and some hunting as well as subsistence and commercial fishing.	
5. Reference: Oviedo & Crossa (2013)	**Place of coverage:** Acre, Brazil
Environmental Causes and Consequences: The closure, sedimentation and continuous silting of the lake due to the annual cycle of floods. Increased fishing efforts have led to changes in these ecosystems, directly affecting species such as the pirarucu due to their sedentary behavior. **Solutions:** Strategies that include technical norms of management, new methods of evaluation, the monitoring of the management with the effective participation of the fishermen in the elaboration of the management measures for preservation and conservation. As a shortcoming, the authors highlight the lack of knowledge about the potential of stocks due to lack of data and applied research.	
6. Reference: Figueiredo (2013)	**Place of coverage:** Amazonas, Brazil
Environmental Causes and Consequences: Climate change and large-scale fishing combined with artifices used in pirarucu fishing may affect biological communities. **Solutions**: Management of fishery resources with multilateral actions by the State and fishermen involving complex and multi-level socio-ecological management systems; the evolution of conventional fisheries management systems with the inclusion of social processes, opting for adaptive management, which should adjust to uncertainties and include different local, technical and scientific perspectives and knowledge, including the users in the problem-solving and decision making processes; increasing investment in the conservation and preservation of environments and the constant awareness raising in the communities about the importance of protecting their lakes and streams, as well as a greater presence of the organ monitoring the reserve. There is a lack of studies on the role played by the pirarucu in the ecosystem and the uncertainties regarding the size, composition and spatial distribution of fish stocks, their dynamics, and information on the populations, which interferes with the sustainable management.	
7. Reference: Kirsten et al. (2012)	**Place of coverage:** Mato Grosso, Brazil
Environmental Causes and Consequences: lack of management and of studies on the stocks' situation, together with the exploitation by other groups (tourists and indigenous fishermen) and the use of nets, has led to overexploitation, compromising local pirarucu stocks. **Solutions:** Deployment of management. The highlighted shortcomings were the lack of studies on fishing, ecology and conservation efforts of the species in the region and the absence of management plans.	
8. Reference: Lawler (2009)	**Place of coverage:** Aquatic ecosystems in general
Environmental Causes and Consequences: Climate change will cause the water temperature to rise and result in changes in the distribution of species including, for example, the potential loss of fish in the streams. **Solutions**: Increasing connectivity between reserves to help augment resilience by providing more opportunities for different locations in which species or communities can persist. Possessing reserves with a greater potential for possible habitat heterogeneity, which would help to respond to any future climatic scenario. Active or passive adaptive management are cited as a critical approach to deal with change, as it allows management of highly uncertain systems. Passive adaptive management involves the construction of a management strategy based on historical data and when new data is obtained, from the monitoring over time, this allows the inclusion of new strategies and assets by involving conscious experimentation, generally exploring the results of multiple strategies of this management. But barriers such as the lack of flexibility and the institutional capacity to perceive the risks of failures, the high degree of uncertainties, large temporal and long management scales, must be overcome.	

Table 1. Continued...

9. Reference: Erwin (2009)	**Place of coverage:** Aquatic ecosystems in general
Environmental Causes and Consequences: Global climate change coupled with a host of other pressures may result in increased spread of alien species and, consequently, greater pressure on the river basins. Generalized stress and spatial deviation can wipe out swamp areas, threatening the survival of species, the health of the natural systems, and the integrity of ecosystems.	
Solutions: Use of integrated modeling in the restoration of wetlands, in the adaptive management, and in plans at the level of mega river basins. The gaps to be overcome include the little discussion on wetland restoration and climate change, lack of monitoring, which is essential for the ecosystem management, as it intends to detect long-term changes in the ecosystem, provides insights on possible ecological consequences, and helps decision-makers to determine how management practices should be implemented.	
10. Reference: Palmer et al. (2008)	**Place of coverage:** Aquatic ecosystems in general
Environmental Causes and Consequences: Drastic changes in flow, increased demand for water related to economic and population growth, which may have effects even be greater than climate change on the water available to many rivers, leading to biodiversity loss.	
Solutions: Specific actions of restoration, rehabilitation, proactive and active management to improve the resilience of riparian ecosystems and minimize impacts.	
11. Reference: Bengtsson et al. (2003)	**Place of coverage:** Aquatic ecosystems in general
Environmental Causes and Consequences: Ecosystems are subject to both natural and man-induced disturbances at various spatial and temporal scales.	
Solutions: Recognize that not just nature, but humans are also part of the ecosystem, so reserves cannot be static, but are part of the management of the adaptive landscape. Although reserves are crucial for the short-term conservation of species and habitats, some of them have not incorporated long term and large-scale dynamics of ecosystems as parts of dynamic landscapes and it is necessary to reconsider how reserves are designed and managed in areas increasingly dominated by humans.	
12. Reference: Jungwirth et al. (2002)	**Place of coverage:** Aquatic ecosystems in general
Environmental Causes and Consequences: The intensive use and alteration of riverside landscapes by humans have led to drastic reductions in functional flood plains, loss of typical floodplain elements, alteration of hydrological and temperature regimes, impacting the reduction of biodiversity, spatial-temporal heterogeneity, functional processes and the diversity, density and biomass of species.	
Solutions: To have a political objective of maintaining or restoring the ecological integrity of the riverside landscapes; establish priorities of what must be preserved, mitigated and restored according to the ecological state of the water resource; incorporate new visions of the management of the floodplain that meet the needs of both humans and the natural systems. Use of hydrological, morphological and ecological conditions models to assist in the restoration of complex floodplain systems, as they predict and evaluate the effectiveness of restoration measures. The identified shortcomings are the lack of detailed information on functional relationships and processes in the landscape and catchment scale, which make it difficult to assess their ecological status.	

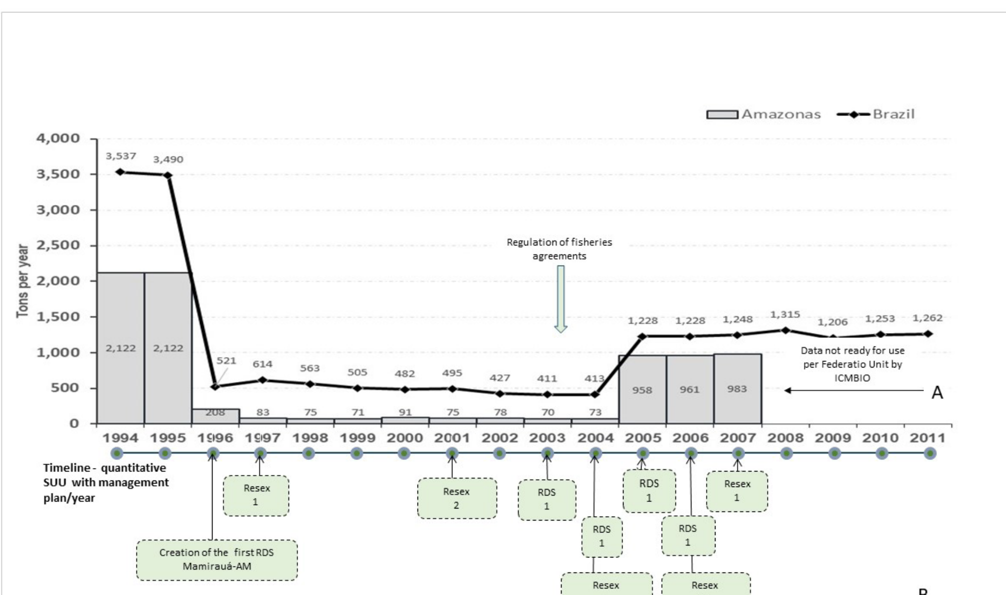

Figure 1. Demonstration in tons per year of the *Arapaima gigas* extractive fishery in Brazil and in the State of Amazonas (A) and the relationship with the timeline of the creation of Sustainable Use Units (SUU) with management plan in the state of Amazonas from 1994 to 2011 (B). Subtitle: Sustainable Development Reserve-RDS; Extractive Reserve-RESEX; Chico Mendes Institute of Conservation and Biodiversity- ICMBio.

Table 2. The chi-square test (X^2) and p values of the observed quantitative values of young (<1.5 cm length) and adults (>1.5 cm length) in the lakes, ressacas and paranã in sector 2 of the Unini River Resex, from 2012 to 2017.

Years under analysis	2012 2013	2012 2014	2012 2015	2012 2016	2012 2017	2013 2014	2013 2015	2013 2016	2013 2017	2014 2015	2014 2016	2014 2017	2015 2016	2015 2017	2016 2017
X^2	**7.1**	0.24	0.00	0.49	0.56	**10.60**	**8.14**	**4.39**	**4.35**	0.10	1.55	1.68	0.70	0.77	0.00
P value	**0.007**	0.625	0.924	0.482	0.454	**0.001**	**0.004**	**0.030**	**0.036**	0.685	0.210	0.190	0.406	0.380	0.970
Accepted	**H1**	H0	H0	H0	H0	**H1**	**H1**	**H1**	**H1**	H0	H0	H0	H0	H0	H0

Tested hypothesis: **H0**= There is no difference between the numbers of pirarucus (budecos and adults) counted annually in sector 2; **H1**= There are differences between the numbers of pirarucus counted annually in sector 2. Bold values presented ($p < 0.05$) and ($X^2 > 3.9$).

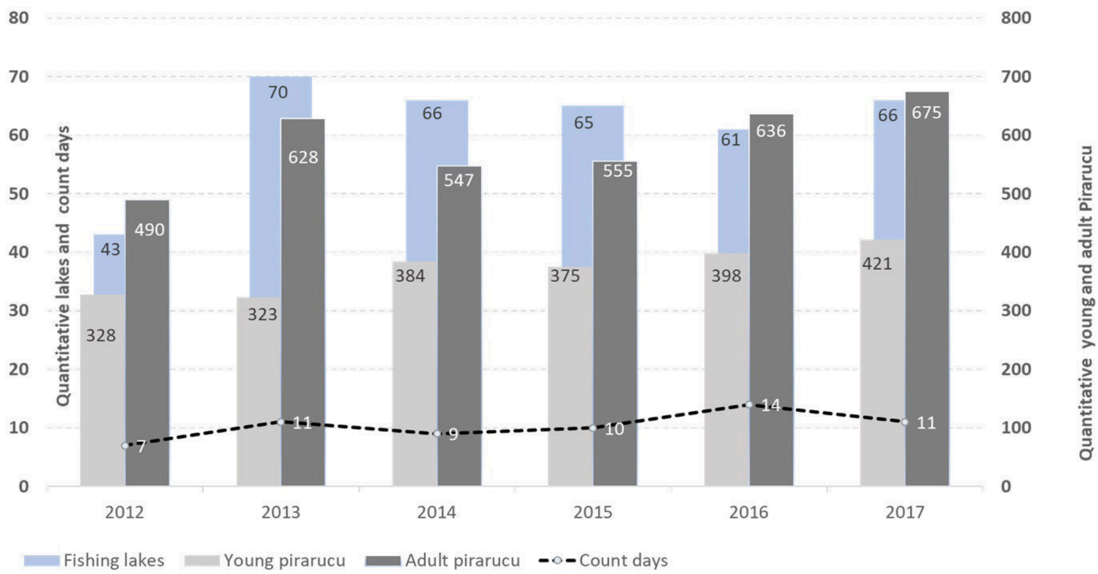

Figure 2. Demonstration of the count of young and adult pirarucu; fishing lakes and count days developed between 2012 and 2017 in sector 2 of the Unini River Resex, Amazonas, Brazil.

for participatory fishing management. Between the years 2012 and 2017, 75 types of environments of the lakes, ressaca[1], paranã[2] and furo[3] were mapped in sector 2 by the group of fishermen from the 10 communities present along the Unini River.

The creation of this Resex occurred due to illegal fishing, sport fishing done with small aircrafts without adequate monitoring, deforestation, uncontrolled fires, conflicts between communities regarding the overlapping of resource use (ICMBio, 2018), as well as the extraction of sand by mining companies since 2004 (ICMBio, 2014).

Since the creation of this SUU, in the perception of fishermen, residents and reports of the Fundação Vitória Amazônica (FVA), there has been a decrease in the number of socio-environmental conflicts in the lower Negro River, and a considerable increase in fish stocks. The pirarucu have been sighted in various places, even in the ports of their communities.

The data shows a variation in the number of days in the field (maximum 14 days and minimum of seven days) and in the number of fishing lakes (maximum 70 and minimum 43) during the counting of the species, which seems to reflect on the number of counted specimens (Figure 2).

However, the chi-square test showed significant differences ($p<0.05$) between the annual numbers of pirarucus counted in the year 2013 when compared to the other years (Table 2). The year 2013 is one of the years with the highest numbers of analyzed environments and a high number of days in the field, but the years 2016 and 2017 stood out in comparison with 2013 and presented higher values for both young and adult fish (Table 2).

In the participatory management plan, community surveillance is one of the activities planned with the objective of avoiding predatory exploitation and identifying who does not follow the rules established in the management plan. At Resex,

[1] Networks of water accumulation basins.

[2] Lakes which have direct connections to the river through canals.

[3] Connects a lake to a river or another lake.

there were records of emigration of former residents because they did not adapt to the surveillance and because they illegally exploited pirarucu and chelonians (Caldenhof, 2013), showing the importance of the activity for the very community which uses the resources.

4. Discussion

The different types of management were mentioned as some of the most plausible solutions, as strategies to confront species extinction, mitigate processes and minimize environmental crisis (Mateus et al., 2017) in the elaboration of conservation and preservation measures (Oviedo & Crossa, 2013). Moreover, as a possibility of dealing with climate change (Lawler, 2009), improving the resilience of riparian ecosystems, minimizing impacts (Palmer et al., 2008), and contributing to the recovery of the complex, structured and spatial units – if the interdependent relationship is maintained between the actors and factors, whether they are biotic, physical or socioeconomic (Berkes, 2009).

This situation is observed by the fishermen, who know the behavior of the species well, in relation to the increase of the fish stock. Hanazaki (2003) emphasizes the importance of considering local ecological knowledge, or traditional ecological, or ethnoecological knowledge. They are orally passed by these human populations living in or close to the ecosystems to be managed, and have important connections for the management based on local participation and sustainability principles.

When the management takes place in the environment as a whole, maintaining the ecosystemic focus ensures the conservation of the landscape with its components, serving as an effective means of conservation. We suggest that this situation is taking place in the Unini River basin with the creation of the Resex and the use of resource management. Although it is not restricted to the management of the ecosystem, this situation is also observed in the management of the pirarucu, because, according to Figueiredo (2013), it brings with it a power of conservation and organization of the use of several resources with gain for the conservation of the landscape and its components.

It was also validated by the authors Campos-Silva et al. (2019), who demonstrated in their studies along the Juruá River in the western Brazilian Amazon a recovery pattern of the pirarucu population through the use of management programs carried out by the ribeirinha community. This reaffirmed the data found in previous studies and Unini River Resex, that community-based shared management is a powerful tool for biodiversity conservation and local livelihoods.

Authors such as Jungwirth et al. (2002) recall that most of the world's 79 major floodplain ecosystems have been altered precisely by human activities, and restoring them requires knowledge that includes geomorphology, hydrology, landscape ecology, landscape planning, hydraulic engineering, aquatic and terrestrial ecology. Consequently, also requires the formation of interdisciplinary teams, which must be present in all phases of the planning, implementation, and evaluation process.

Restoration is not always possible, due to lack of logistical, financial, and human resources, availability of monitoring data and teams formed for this purpose in the country. This induces the reflection that, instead of trying to recreate ecosystems with properties characteristic of the past, the ecosystem's dynamic nature and the irreversibility of some changes that have occurred must be recognized.

However, from the possibility of using the traditional ecological knowledge in the elaboration and execution of management plans in these SUU, this instrument becomes a viable option not only for the conservation, but also for the recovery of ecosystems. These ecosystems must not be transformed, however, into island reserves, or an intensive management landscape administered to meet human goals disconnected from the natural process scales (Bengtsson et al., 2003).

Encompassing approximately 99% of the Unini River basin, the Unini Resex has allowed zoning almost all of its extension and a management shared by all the communities that live along the riverbank, meeting the proposal of using managements based on hydrographic basins. These have been identified as the most appropriate spatial management units in various parts of the world (Erwin, 2009). Thus, Unini Resex provides a unique opportunity to establish an integrated model of management for protected areas (FVA, 2011) and, together with two other Conservation Units (Jaú National Park and Amanã Sustainable Development Reserve), forms a network of protected areas with several ecosystems rather than isolated islands.

The oscillation observed in relation to the number of environments where the counting was performed suggests the perspective of a management plan that is not only participative, but also adaptive. According to Berkes (2009), the adaptive management plan allows integrating uncertainty into management strategies, emphasizing practices that encourage resilience, responding to and managing ecosystem feedbacks, rather than blocking them, and seeks to avoid ecological thresholds in scales that threaten the existence of social and economic activities.

This environmental oscillation, as observed in the field, is related to the richness of the environments and the complexity of the types of existing lakes (central, boca franca[4]), paraná, ressacas and holes, in a highly sinuous river like the Unini.

The pirarucu may exhibit sedentary behavior when the environment is in equilibrium (Oviedo & Crossa, 2013). This seems to reflect positively in the number of young and adult populations observed in the years 2016 and 2017. Another factor which influences this number is the carrying out of communitarian inspection actions by trained groups of fishermen from the different communities, inhibiting illegal fishing.

From the results, it is understood that even in a changed ecosystem, when it is transformed into a SUU, natural resources which were previously open to free access are now monitored, and their exploitation is guided by an instrument, the management plan. This situation was envisaged by Campos-Silva & Peres (2016) when comparing Arapaima fish stocks from managed and unmanaged areas on the Juruá River in the State of Amazonas, Brazil, finding a larger population of the species in community managed areas.

This instrument, initiated in SUU in the State of Amazonas, with its participative nature that avoids severe environmental modifications, becomes more efficient in the maintenance, allowing sustainable resource use (McGrath & Castello, 2015; Campos-Silva et al., 2019). Besides, it avoids the removal of key species, which is one of the major impacts on aquatic ecosystems. However, in Brazil, there is a need to strengthen these policies, which is visible for the absence of data and research that allow a better evaluation of their effectiveness.

Acknowledgements

We thank ICMBio for the field logistics, the fishermen team of the Unini River Resex, the LAGAS/UnB, the UnB/IRD JEAI-GITES projects, the LMI-Sentinela, the Post-Graduate Program in Geography-UNB and PPGEA-AP/LD/UTFPR. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

[4] A lake which has a permanent connection to the river in one of its extremities.

References

BENGTSSON, J., ANGELSTAM, P., ELMQVIST, T., EMANUELSSON, U., FOLKE, C., IHSE, M., MOBERG, F. and NYSTRÖM, M. Reserves, resilience and dynamic landscapes. *Ambio*, 2003, 32(6), 389-396. http://dx.doi.org/10.1579/0044-7447-32.6.389. PMid:14627367.

BERKES, F. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management*, 2009, 90(5), 1692-1702. http://dx.doi.org/10.1016/j.jenvman.2008.12.001. PMid:19110363.

CALDENHOF, S.B.L. *Mudanças sociais, conflitos e instituições na Amazônia: os casos do Parque Nacional do Jaú e da Reserva Extrativista do Rio Unini* (Tese de Doutorado em Ambiente e Sociedade). Campinas: Instituto de Filosofia e Ciências Humanas; Universidade Estadual de Campinas, 2013.

CAMPOS-SILVA, J.V. and PERES, C.A. Community-based management induces rapid recovery of a high-value tropical freshwater fishery. *Scientific Reports*, 2016, 6(34745), 1-13.

CAMPOS-SILVA, J.V., HAWES, J.E. and PERES, C.A. Population recovery, seasonal site fidelity, and daily activity of pirarucu (Arapaima spp.) in an Amazonian floodplain mosaic. *Freshwater Biology*, 2019, 64(7), 1255-1264. http://dx.doi.org/10.1111/fwb.13301.

CASTELLO, L. and STEWART, D.J. Assessing CITES non-detriment findings procedures for Arapaima in Brazil. *Journal of Applied Ichthyology*, 2010, 26(1), 49-56. http://dx.doi.org/10.1111/j.1439-0426.2009.01355.x.

CASTELLO, L., STEWART, D.J. and ARANTES, C.C. Modeling population dynamics and conservation of Arapaima in the Amazon. *Reviews in Fish Biology and Fisheries*, 2011, 21(3), 623-640. http://dx.doi.org/10.1007/s11160-010-9197-z.

CASTELLO, L., STEWART, D.J. and ARANTES, C.C. O que sabemos e precisamos fazer a respeito da conservação do pirarucu (Arapaima spp.) na Amazônia. In: E. S. A. FIGUEIREDO, org. *Biologia, conservação e manejo participativo de pirarucus na Pan-Amazônia*. Tefé, AM: IDSM, 2013a, pp. 17-32.

CASTELLO, L., ARANTES, C.C., SARMENTO, F. and MCGRATH, D.G.D.J. Recuperando a pesca do pirarucu no baixo Amazonas, Brasil. In: E. S. A. FIGUEIREDO, org. *Biologia, conservação e manejo participativo de pirarucus na Pan-Amazônia*. Tefé, AM: IDSM, 2013b, pp. 207-212.

CASTELLO, L.A. method to count pirarucu: fishers, assessment and management. *North American Journal* *of Fisheries Management*, 2004, 24(2), 379-389. http://dx.doi.org/10.1577/M02-024.1.

CUNHA, L.H. O. *Reservas Extrativistas: uma alternativa de produção e conservação da biodiversidade*. São Paulo: NUAPUB- USP, 2001. 42 p.

ERWIN, K.L. Wetlands and global climate change: the role of wetland restoration in a changing world. *Wetlands Ecology and Management*, 2009, 17(1), 71-84. http://dx.doi.org/10.1007/s11273-008-9119-1.

FIDELIS, L., NESSIMIAN, J.L. and HAMADA, N. Distribuição espacial de insetos aquáticos em igarapés de pequena ordem na Amazônia Central. *Acta Amazonica*, 2008, 38(1), 127-134. http://dx.doi.org/10.1590/S0044-59672008000100014.

FIGUEIREDO, E.S.A. *Biologia, conservação e manejo participativo de pirarucus na Pan-Amazônia*. Tefé, AM: IDSM, 2013.

FUNDAÇÃO VITÓRIA AMAZÔNICA – FVA. *Unini - o rio da sustentabilidade: bases socioambientais para a gestão da bacia do rio Unini e de suas unidades de conservação*. Manaus: Fundação Vitória Amazônica, 2011.

HANAZAKI, N. Comunidades, conservação e manejo: o papel do conhecimento ecológico local. *Biotemas*, 2003, 16(1), 23-47.

INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE – ICMBio. *Plano de Manejo Participativo da Reserva Extrativista do rio Unini, Amazonas, Brasil*. Novo Airão: ICMBio, 2014.

INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE – ICMBio. *Cartilha do Plano de Manejo participativo da reserva extrativista do rio Unini, Amazonas, Brasil*. Brasília: Ministério do Meio Ambiente, 2018.

ISAAC, V.J., FABRÉ, N.N., SILVA, C.O., RUFFINO, M.L. and SAINT-PAUL, U. Ecologia da Fauna Ictíica. In: V. S. BATISTA and V. J. ISAAC, orgs. *Peixes e pesca no Solimões-Amazonas: uma avaliação integrada*. Brasília: Ibama/ProVárzea, 2012, pp. 207-249.

ISAAC-NAHUM, V.J. Exploração e manejo dos recursos pesqueiros do litoral Amazônico: um desafio para o futuro. *Ciência e Cultura*, 2006, 8(3), 33-36.

JUNGWIRTH, M., MUHAR, S. and SCHMUTZ, S. Re-establishing and assessing ecological integrity in riverine landscapes. *Freshwater Biology*, 2002, 47(4), 867-887. http://dx.doi.org/10.1046/j.1365-2427.2002.00914.x.

KIRSTEN, I.F., PUERTA, L.R., MATEUS, L.A.F., CATELLA, A.C. and LIMA, E.S. A pesca do pirarucu (Arapaima sp.) na bacia do rio Araguaia em Mato Grosso – Brasil. *Boletim do Instituto de Pesca*, 2012, 38(2), 131-144.

LAWLER, J.J. Climate change adaptation strategies for resource management and conservation planning. *Annals of the New York Academy of Sciences*, 2009, 1162(1), 79-98. http://dx.doi.org/10.1111/j.1749-6632.2009.04147.x. PMid:19432646.

MATEUS, W. D., BALDOINO, M., ZACARIAS, E.F.J. and HIGUCHI, M.I.G. Amazônia no Antropoceno: o manejo como relação entre humanos e fauna silvestre. *Interações*, 2017, 19(3), 487-501.

MCGRATH, D. and CASTELLO, L. *Integrating fishers' ecological knowledge and the ecosystem based management of tropical inland fisheries: an Amazon case study*. Rome: FAO, 2015, pp. 127-148, FAO Fisheries and Aquaculture Technical Paper, vol. 591.

MEDEIROS, S.B.M. and SILVA, C.N. Organização social e uso dos recursos pesqueiros no estuário amazônico: estudo de caso no Município de Soure (PA). *InterEspaço*, 2015, 1(2), 31-42. http://dx.doi.org/10.18766/2446-6549/interespaco.v1n2p31-42.

MEDINA, G.S. and BARBOSA, C.W.S. A questão produtiva nas Reservas Extrativistas. *Novos Cadernos NAEA*, 2016, 19(2), 69-88. http://dx.doi.org/10.5801/ncn.v19i2.2318.

OVIEDO, A.F.P. and CROSSA, M.N. *Manejo do Pirarucu: Sustentabilidade nos lagos do Acre*. Brasília, DF, WWF-Brasil, 2013.

PALMER, M.A., REIDY LIERMANN, C.A., NILSSON, C., FLÖRKE, M., ALCAMO, J., LAKE, P.S. and BOND, N. Climate change and the world's river basins: anticipating management options. *Frontiers in Ecology and the Environment*, 2008, 6(2), 81-89. http://dx.doi.org/10.1890/060148.

POLAZ, C.N.M. and RIBEIRO, K.T. Conservação de peixes continentais e manejo de unidades de conservação. *Biodiversidade Brasileira*, 2017, 7(1), 1-3.

QUEIROZ, H.L.D. *Natural history and conservation of pirarucu, 'Arapaima gigas', at the Amazonian Várzea: red giants in muddy waters* (Doctoral Thesis of Philosophy). St Andrews: University of St Andrews, 2000.

RENÓ, V.F., NOVO, E.M.L.M., ALMEIDA-FILHO, R. and SUEMITSU, C. Mapeamento da Antiga Cobertura Vegetal de Várzea do Baixo Amazonas a Partir de Imagens Históricas (1975-1981) do Sensor MSS-Landsat. *Acta Amazonica*, 2011, 41(1), 47-56. http://dx.doi.org/10.1590/S0044-59672011000100006.

VIDAL, M.D., RASEIRA, M.B. and RUFFINO, M.L. Manejo participativo dos recursos naturais amazônicos - a experiência do ProVárzea. *Biota Amazônia*, 2015, 5(1), 53-60. http://dx.doi.org/10.18561/2179-5746/biotaamazonia.v5n1p53-60.

Received: 23 February 2019
Accepted: 20 May 2020

Associate Editors: André Megali Amado, Rafael Marques Almeida, Simone Jaqueline Cardoso, Joyce Andreia dos Santos.