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Research Article

Distribution of arapaima (*Arapaima gigas*) (Pisces: Arapaimatidae) in Bolivia: implications in the control and management of a non-native population

Guido Miranda-Chumacero[1]*, Robert Wallace[1], Hailín Calderón[2], Gonzalo Calderón[2], Phil Willink[3], Marcelo Guerrero[2], Teddy M. Siles[1], Kantuta Lara[1] and Darío Chuqui[4]

1 *Wildlife Conservation Society (WCS), Greater Madidi-Tambopata Landscape Conservation Program, CP 3-35181 SM, La Paz, Bolivia*
2 *Centro de Investigación y Preservación de la Amazonía (CIPA), Univ. Amazónica de Pando (UAP), Av. 9 de Febrero # 001, Cobija, Bolivia*
3 *Field Museum, Department of Zoology, 1400 South Lakeshore Dr. Chicago, IL USA*
4 *Consejo Indígena del Pueblo Takana (CIPTA), Tumupasha, La Paz, Bolivia*

E-mail: gmiranda@wcs.org

**Corresponding author*

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Abstract

The introduction and establishment of arapaima (*Arapaima gigas*) in southeastern Peru and northwestern Bolivia is an example of a fish species that appears to be increasingly common and widespread in non-native portions of its range, but whose populations are on the decline within its native range. The arapaima is overfished and considered threatened throughout its native range in the Central Amazon. We gathered and examined data on the distribution of fish and wildlife in the Takana II Indigenous Territory in Bolivia, near the arapaima's reported initial invasion zone in Peru. Results confirmed the presence of arapaima in several water bodies where local people have also reported a strong decline in native fish populations. Further south in the Takana I Indigenous Territory, monitoring of fisheries by local communities (2002-2008), including observations on arapaima catches, indicate that until 2008 arapaima had not been reported in the area. However in 2009, there were reports of arapaima in the Undumo stream. Our results demonstrate that since the first presence of arapaima in Bolivia at the beginning of the 1980s, it has steadily expanded its distribution. We propose actions to mitigate this situation by managing and controlling populations of this invasive and endangered species, as well as improving income for indigenous communities.

Key words: introduction; community fisheries; endangered species; indigenous communities; Amazon

Introduction

Arapaima [*Arapaima gigas* (Schinz, 1822)], known as paiche in Bolivia and Peru and as pirarucú in Brazil, is one of the most emblematic species of the Amazon and the focus of numerous studies (Migdalaski 1957; Hrbek et al. 2005; Castello et al. 2009). This giant fish is native to the Central Amazon where it has long been over-exploited by humans as a source of food (Figure 1) (Hrbek et al. 2007). The arapaima was introduced into lagoons in the Madre de Dios region of Peru for aquaculture and during the late 1970s these fish or their progeny escaped into nearby streams during flood events (Wust 2001; Farrel and Azurduy 2006). Local people report that the introduction of arapaima has caused serious environmental impacts. In northern Bolivia, it may be causing a reduction of native fish populations, including many fish of high commercial value (Van Damme 2006).

Arapaima is an obligatory air breather. In some regions it has been reported to reach 4 meters in length and 200 kg in weight (Stone 2007). It is essentially piscivorous. Some studies on captivity report that individual arapaima consume more than 8% of their biomass per day (ie. ~7 kg for a 90 kg fish) (Padilla et al. 2004). The species reproduces at a round 1.5 m in length and exhibits parental care (Queiroz, 2000).

The natural distribution of *Arapaima gigas* covers a large portion of the Amazon River basin in Brazil and Peru (Reis et al. 2003; Rojas 2004; Franco 2005; Castello 2008a). Some of the most abundant populations are located in the center of the Solimões River in the Brazilian state of Amazonas (Queiroz and Champton 1999). Marginal distribution records are located close to Iquitos in Peru, the rivers Cuyabeno, Aguarico, Napo and Tiputuini in Ecuador, Leticia River in Colombia, the Tabatinga River, the mouth of the Amazon River near Belém, and the Amapá

Figure 1. *Arapaima gigas* with 2.41 m fished in the Takana indigenous territory by the local people (Photography: G. Alvarez).

region in Brazil, as well as in Guyana (Geay 1901; Migdalaski 1957; Jégu and Keith 1999; Castello 2001; Reis et al. 2003; Hrbek et al. 2005; E. Toral, pers. comm.) (Figure 2). The "cachuelas" (from the Portuguese *cachoeiras* meaning water rapids or small waterfalls) of the Madeira River are apparently a natural barrier to its dispersal further south, preventing the species reaching upstream areas within Bolivia.

History of introduction of arapaima in southeastern Peru

Live arapaimas were transferred (from a place close to Iquitos) for a fish-farming program in the Sandoval and Valencia lagoons (Peruvian side of the Madre de Dios River basin), close to the city of Puerto Maldonado in southeastern Peru, near the border of Bolivia (Wust 2001). These water bodies are part of the Madre de Dios basin in Peru, which is linked to the Beni River in Bolivia, a large river that flows northward into Brazil where it becomes the Madeira River, the largest major tributary of the western Amazon. According to people who participated in the activity, in 1979 about 1,000 arapaima fry were introduced into the Sandoval Lagoon (Roger Pinedo, pers. comm. 2010). The introduction occurred when the Madre de Dios River flooded and the rising water reached aquaculture ponds containing arapaima. As a result, the arapaima escaped into the broader watershed. By the mid 1980s, arapaima was reported outside the lagoons in Peru, and at the beginning of the 1990s the species was first reported in Bolivian waters. Subsequently, observations in Bolivia were more frequent, as well as reports of arapaima being caught by local fishermen (García 2006; Van Damme 2006).

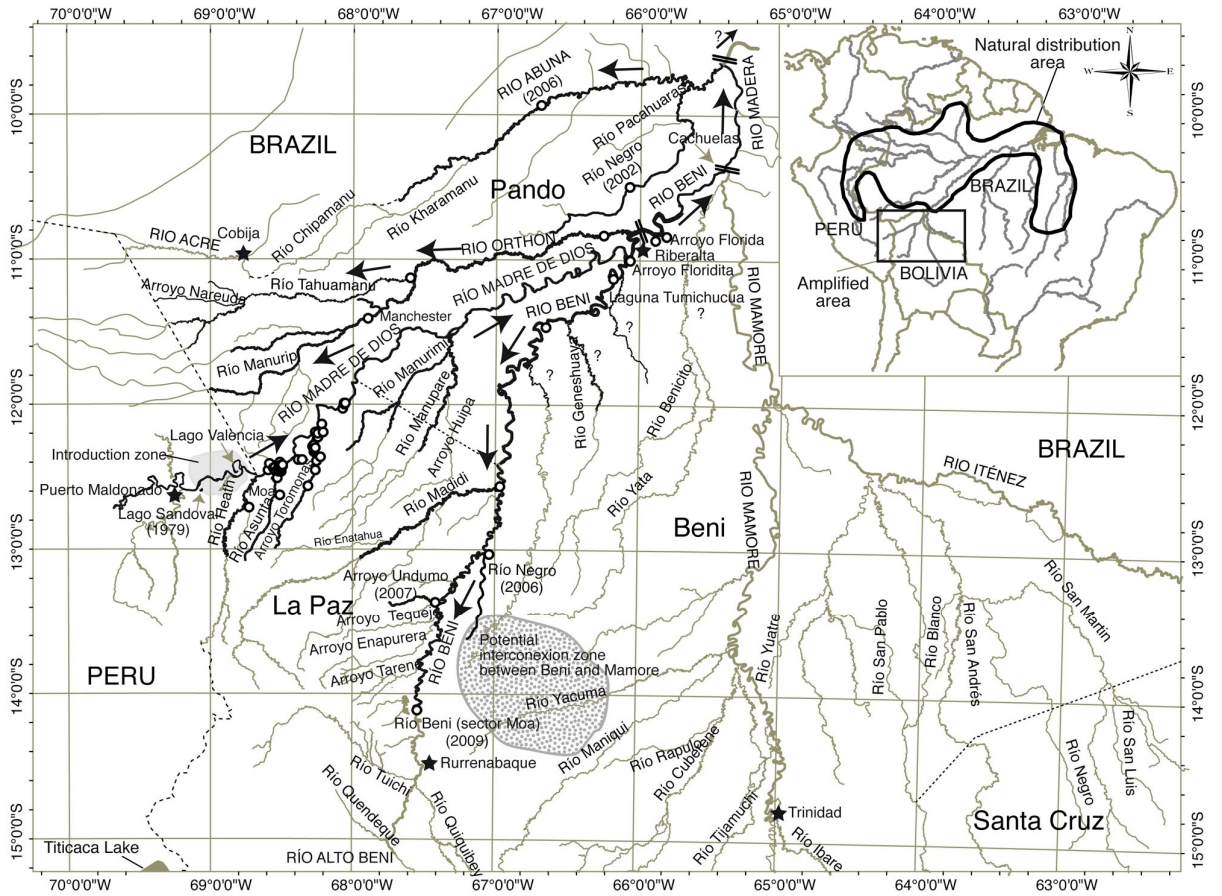

Figure 2. Map showing the known current distribution of *Arapaima gigas* in Bolivia. Dark lines show the rivers and streams where the species was confirmed. Black arrows show the direction of movement of arapaima. Open circles (o) show localities where Arapaima was reported and confirmed. The grey shadow polygon shows the introduction zone in southern Peru and the larger dashed shadow polygon shows the potential interconnection zone between two basins within Bolivia. Two parallel lines depict waterfalls or broken rapids. Question marks (?) show streams where arapaima may exist but have not yet been confirmed. Insert depicts map of central and northern South America showing the approximate natural distribution of *A. gigas*, after Hrbek et al. (2005).

Taxonomic status of the species

There has been recent discussion regarding the taxonomic status of the *Arapaima* and whether *Arapaima* consists of more than just *A. gigas* (Stewart et al. 2007; Castello et al. 2011). The strongest argument supporting this statement is that there is evidence of arapaima in certain populations having two rows of teeth in the lower jaw, while other populations only have one. Probably the species called *Arapaima gigas* is restricted to the Guyanas region (D. Steward and H. Ortega, pers. comm.). On the other hand, genetic studies of different populations of arapaima (Hrbek et al. 2005) have shown that genetic variability of the species throughout its distribution is very low. Discussion of the taxonomic status of the species is ongoing and so for the purpose of this study arapaima will be referred to as *Arapaima gigas*.

Conservation status of arapaima

In Brazil and Peru, a strong decline in natural arapaima populations occurred due to over fishing (Ferraris et al. 2003, Hrbek et al. 2007). Recent work showed that in certain areas of Peru and Brazil arapaima populations are now locally

extinct (Ruck 2005; Batista et al. 2007). Reintroduction initiatives have even taken place in some areas of Perú (Ormeño et al. 2010). Other management initiatives have started such as at the Reserva de Desenvolvimento Sustentável Mamirauá, where a successful arapaima management plan is in place (Queiroz and Champton 1999; Batista et al. 2007; Maccord et al. 2007; Castello et al. 2009). A considerable effort on the recovery of the species has also been put into fish farming (Rojas 2004; Franco 2005).

In spite of all of this, there are still legal and illegal markets for arapaima meat in the countries of its natural distribution. According to reports, between 1994 and 1996 approximately 440 tons of arapaima meat was sold in the lower Amazon (taking into account only those reported landings of arapaima from boats in Santarem and Manaus) (Ruffino 2004). Monitoring efforts around the Mamirauá Reserve area indicate high levels of illegal fishing (Paulo Roberto/IDSM, 2008 pers. comm.). Due to this situation and with the purpose of regulating the markets, *Arapaima gigas* has been listed as CITES Appendix II since 1975. This means that legal harvest of this species must be conducted with a specific management plan and their international commercialization is also under control. Currently in Brazil and Peru, additional strict regulations are being established regarding closed seasons for arapaima fishing, management plans and regional strategies, as well as tagging of individual arapaima that are captured (IBAMA Portaria nº 480, March 4th 1991; Castello et al. 2009).

This article documents the current distribution of arapaima in Bolivia, analyses implications for local human communities, identifies specific research actions for arapaima and its impact on native fish communities, and proposes specific control and management mechanisms to diminish the negative impacts caused by non-native arapaima in Bolivia.

Methods

Documentation of sites with confirmed arapaima reports in northern Bolivia

Using data from surveys of fish communities conducted by Wildlife Conservation Society (WCS) and Centro de Investigación y Preservación de la Amazonía (CIPA) in northern Bolivia, we identified all water bodies in the region considered to have valid records of arapaima presence either confirmed by direct observation by CIPA ichthyologists or by the capture of a specimen with gill nets in aquatic biodiversity surveys. Community fisheries monitoring programs provided the first observations and capture of arapaima in the Takana I and Takana II Indigenous Territories in La Paz, Pando, and Beni Departments. The main rivers in the area, Madre de Dios, Beni and Orthon, have many adjacent and connected water bodies such as old river meanders or oxbows that form suitable backwater habitat for arapaima.

Interviews

Between August and September 2005, 79 fishermen were interviewed from the El Tigre, Toromonas, La Asunta and Las Mercedes communities in the Takana II Indigenous Territory. The structured interviews formed part of a data gathering process regarding resource use by Takana communities as part of their development strategy production. In each interview, with the help of printed maps, questions were asked about the presence of arapaima in the wetlands, as well as other related information. Later, between July 2005 and August 2008, specific bi-monthly interviews about arapaima observations were conducted with 30 fishermen from the riverine communities of the Takana I Indigenous Territory. The interviews were carried out on groups of fishermen from the communities, and their answers were cross-referenced with the communities' fisheries data that had been recorded and updated since 2001 along the Beni River. Between August and September of 2008, we conducted interviews with people from the community of Tumichucua using maps of the area so that they could identify those water bodies in which they had observed arapaima.

Available published and unpublished information

For this study we collected a variety of available information, such as specific studies related to the development of fish management plans, population studies and land management plans (Sarmiento et al 2002; Van Damme 2006), newspaper articles (for example, Wust 2001) and unpublished information derived from general and personal communications from researchers and fishermen from the Beni River.

Georeferencing and systematization of the information

Each record gathered from the different information sources (studies, monitoring, surveys, interviews and publications) was centralized into a database of arapaima reports in Bolivia, which was then georeferenced using coordinates of the specific locations, or in some cases, the closest area to where the observation occurred, as specified in the reports. This allowed us to produce a map showing arapaima distribution in Bolivia.

Results

Current distribution in Bolivia

A total of 70 confirmed distribution points for arapaima in Bolivia have been registered. The distribution of the points includes streams, small rivers and lagoons connected to the main river basins of the Madre de Dios and Beni rivers. The points are distributed in the Bolivian departments of Pando with 21 points covering much of the department, La Paz in its extreme northern portion with 44 points, and Beni in its northern-central part with 5 points (Figure 2).

In Pando, arapaima has been reported in the Tahuamanu, Orthon, Manuripi, Negro and Abuná rivers. In La Paz, arapaima is found in the Madre de Dios, Beni and Heath rivers, and the Moa, Toromonas, Asunta, El Tigre, Madidi and Undumo streams. Finally, in Beni the species is found close to Riberalta, specifically in Florida and Ivón streams, Tumichucua Lake and the Negro River (Table 1).

A chronological analysis of arapaima reports in Bolivia demonstrates that the earliest records in the country are from the early 1990s and come from the Takana II Indigenous Territory, close to the border with Peru. Subsequently, in 1996-1997, arapaima were reported further downstream on the Madre de Dios River, close to the junction with the Beni river, in the Riberalta region (Ricardo Yamara, fisherman from Tumichucua, pers. comm.). Later, arapaima reports became increasingly common from those working the rivers in Pando, as well as the lower reaches of the Beni River. According to interviews with Takana fishermen, until 2006 the most southern record of the species was in the Negro River, a tributary of the Beni River, 490 km south of Riberalta and 330 km north of Rurrenabaque. By 2009, arapaima had reached the Undumo stream, 195 km from Rurrenabaque, where it was captured in the community of Carmen del Emero. Both the Negro River and the Undumo stream have very few natural barriers, such as waterfalls, preventing the dispersal of arapaima. In summary, arapaima has successfully invaded the Madre de Dios and Beni watersheds in less than 30 years.

Discussion

The arapaima advance

Since there are no natural geographical barriers in the upper part of the Beni River, such as the "cachuelas" in Madre de Dios, arapaima could potentially advance non-stop towards Rurrenabaque. The Negro River runs parallel to the Beni River and is between the Beni and Mamoré rivers (SNHN 1998). During periods of high water, such as have occurred recently in the Bolivian lowlands, there may have been an ephemeral connection between these river basins, providing a potential migration route for arapaima to the Mamoré River (Figure 2). There are also comments from local people along the Mamoré River that report the presence of "a giant fish artificially produced in Peru". Assuming that these observations are confirmed as arapaima, and considering that at the junction of the Beni and Madre de Dios rivers with the Mamoré River, there are some small cachuelas that may represent a barrier for arapaima, the flooding migration route is a persuasive hypothesis. However, it may also have been the case that arapaima were intentionally brought as ornamental fish or for fish culture to areas near Trinidad on the Mamore River, and later escaped to invade the broader basin. In addition, there are unconfirmed reports that in Riberalta and Guayaramerin juvenile arapaima have been introduced into the Iténez River basin on the border with Brazil (M. Jégu, pers. comm. December, 2008). Nevertheless, at the moment, there are no confirmed reports of the species in the Mamoré or Iténez rivers.

Current resulting distribution information on arapaima in Bolivia indicates the species has strong colonizing abilities despite initially being considered a sedentary species (Isaac et al. 1993; Queiroz 2000; Castello 2008a). The natural habitats for arapaima are mainly inundated

Table 1. Localities in the Amazon Basin of Bolivia where arapaima (*Arapaima gigas*) have been captured or otherwise documented (see Figure 2 for location of named water bodies).

Drainage	System	Name of Water Body	Latitude (South)	Longitude (West)	Information Source
Madre de Dios	Madre de Dios	Río Madre de Dios	-12.2305	-68.3723	TCO Takana II fishermen interviews
	Orthon	Río Tahuamanu	-11.1577	-67.6459	García (2006)
		Río Manuripi	-11.4082	-67.8967	García (2006)
		Río Orthon	-10.8311	-66.2524	García (2006)
		Arroyo El Tigre	-12.0296	-68.0721	TCO Takana II fishermen interviews
		Arroyo Toromonas	-12.2834	-68.2735	TCO Takana II fishermen interviews
		Arroyo Cachuela	-12.1386	-68.2188	TCO Takana II fishermen interviews
		Río Las Lloronas	-12.4552	-68.2639	TCO Takana II fishermen interviews
		Río Limón	-12.3286	-68.2734	TCO Takana II fishermen interviews
		Río Toco	-12.5638	-68.3096	TCO Takana II fishermen interviews
		Arroyo Remanso	-12.2925	-68.2827	TCO Takana II fishermen interviews
		Arroyo Ventarrón	-12.3831	-68.3561	TCO Takana II fishermen interviews
		Arroyo Asunta	-12.4377	-68.5031	TCO Takana II fishermen interviews
Beni	Beni	Río Beni	-11.0030	-66.0672	TCO Takana II fishermen interviews
		Madidi	-12.5635	-66.9668	Tumichucua lake and TCO Takana I fishermen
		Río Negro	-13.0318	-67.0402	TCO Takana I fishermen interviews
		Arroyo Florida	-10.9716	-65.9187	Tumichucua fishermen
		Arroyo Floridita	-11.0365	-65.8819	Tumichucua fishermen
		Arroyo El Prado	-10.8471	-65.8702	Tumichucua fishermen
		Arroyo Ivón	-11.1147	-66.1048	Tumichucua fishermen
		Laguna Tumichucua	-11.1290	-66.1829	Tumichucua fishermen,Miranda et al. (in prep)
Heath	Heath	Heath	-12.7124	-68.7285	TCO Takana II fishermen interviews
		Moa	-12.7184	-68.7575	Sarmiento et al. (2002)
Abuna	Abuna	Abuna	-9.8017	-65.5373	Calderón and Calderón (2007)
		Río Negro	-9.9019	-65.7051	Pereira et al. (2003)

várzea wetlands, river meanders, or old riverbeds. In their natural distribution each flooding event corresponds with the arapaima reproductive period, and lakes act as reservoirs for arapaima fry (Castello 2008b), serving as sources of arapaima to colonize other environments (Castello 2008a). In spite of the reported preferences of arapaima for slow waters such as lakes (Castello 2008a), in Bolivia, rivers are at least dispersal habitat, and indeed lateral migrations have been reported in native populations (Queiroz 2000; Castello 2008a). This has allowed the arapaima to cover larger areas during times when rivers flood and overflow the riparian forests, interconnecting rivers, lakes, and meanders.

The "cachuelas" of northern Bolivia have not hindered the downstream advance of arapaima, colonizing the lower part of the Beni and Abuná rivers. If populations of arapaima continued moving downstream through Bolivia, it is possible that they are now found in western Brazil. This expansion of an originally introduced population of unknown origin could cause further problems in defining the taxonomy of the genus.

The latest study on arapaima genetics shows that the Madre de Dios population has the lowest genetic variability (Hrbek et al. 2005). This finding may mean that arapaima can tolerate the effects of endogamy. The number of individuals that were freed accidentally into the Madre de Dios River is unknown, but it is assumed that they all came from fish farms and that the number of planted individuals was low (1,000 individuals in Sandoval lagoon according to local people). Nevertheless, considering arapaima constitutes much of the commercialized fish

in Riberalta (Van Damme 2006), it is clear that the number of individuals has multiplied.

Social and economic implications

Fishermen in the Takana II Indigenous Territory have reported arapaima in most of the water bodies in the territory. The fishermen also note the negative effect arapaima have had on populations of other fish species. In Riberalta, up to 85 percent of commercial fish in the market is arapaima (Van Damme 2006), suggesting that while arapaima populations have increased so has arapaima fishing, in turn causing a general change in fishery catches. The presence of arapaima has also caused conflicts between indigenous communities and other local fishermen, since arapaima move between lakes and lagoons inside indigenous territories, inhabiting areas that are owned by the communities. It is important to note that fishing techniques employed by local fishermen today have not been modified to capture the largest individuals of arapaima, and this may help to maintain very large arapaima individuals in the invasion area.

Threatened vs. Invasive: Effects on local fish fauna

Some of the main reasons used to justify introduction of various fish species around the world have been for aesthetics, recreation and aquaculture (Allan and Flecker 1993). According to Vázquez and Aragón (2002) one of the main obstacles to establishing solid theories about biological invasions is poor knowledge about the ecology of the species and the impact it may have on the new ecosystem. Since arapaima is one of the most emblematic species of the Amazon, a reasonable body of studies exist, making this invasive species relatively well understood. Due to a high commercial value, the arapaima has been subject to strong fishing pressure that has drastically reduced its native populations in Brazil and Peru where national management plans are being developed for sustainable use (Ferraris 2003; Del Aguila 2002).

The successful invasion of non-native populations of arapaima is particularly intriguing due to its general fragile conservation status within its native range. It is a threatened species inside its natural area of distribution, while in Bolivia it is considered one of the main threats to native fish diversity. According to local fishermen in parts of Bolivia, fishery catches have dropped in areas where arapaima have been reported and the species is blamed for changes in the structure and composition of native fish communities (Miranda et al., unpulb. data). However, scientific evidence to support many of the conclusions regarding impacts is absent. Consequently, there is a need for further study to provide information necessary to develop adequate national policies for managing arapaima in Bolivia.

In general, biological invasions are complex processes that involve several phases (Garcia-Berthou 2007), which in this case can be interpreted as: a) transporting the organism to a new region (from Iquitos to the Madre de Dios River basin, in the case of arapaima), b) introduction of individual arapaima into the wetlands (Valencia and Sandoval lakes near the Madre de Dios River in the case of the arapaima), c) establishment and dispersal (arapaima is now found all along the Madre de Dios River and rivers near by), and d) integration or impact (change in the composition of fishery catch by fishermen, in the case of Bolivia). Some non-native fish species introduced to new aquatic environments have shown great colonizing and adaptation capacity (Coblentz 1990). These species are considered responsible for some degree of change in the systems in which they have been introduced, but there have been few studies to quantify their effects (Rodriguez 2001). This lack of information is a common factor in the majority of cases worldwide (Vázquez and Argón 2002; Garcia-Berthou 2007). In the case of arapaima, although in its natural distribution area it is a threatened species with particular habitat needs; its introduction into new water bodies in southern Amazonia has however transformed it into a real threat to local fish fauna.

All that is known about the impact of arapaima on fish communities is limited to an intentional introduction to control piranha proliferation in lakes in the southeastern Brazil. Although this strategy was successful, it also drastically reduced the number of native fish species in these water bodies (Oliveira 1944; Fontenele 1948; Helder Quiroz and Kelven Lopes, pers. comm.). If this is confirmed to be the situation in Bolivia, it may be one of the few cases in which a single threatened species can threaten other fish species with local extinction.

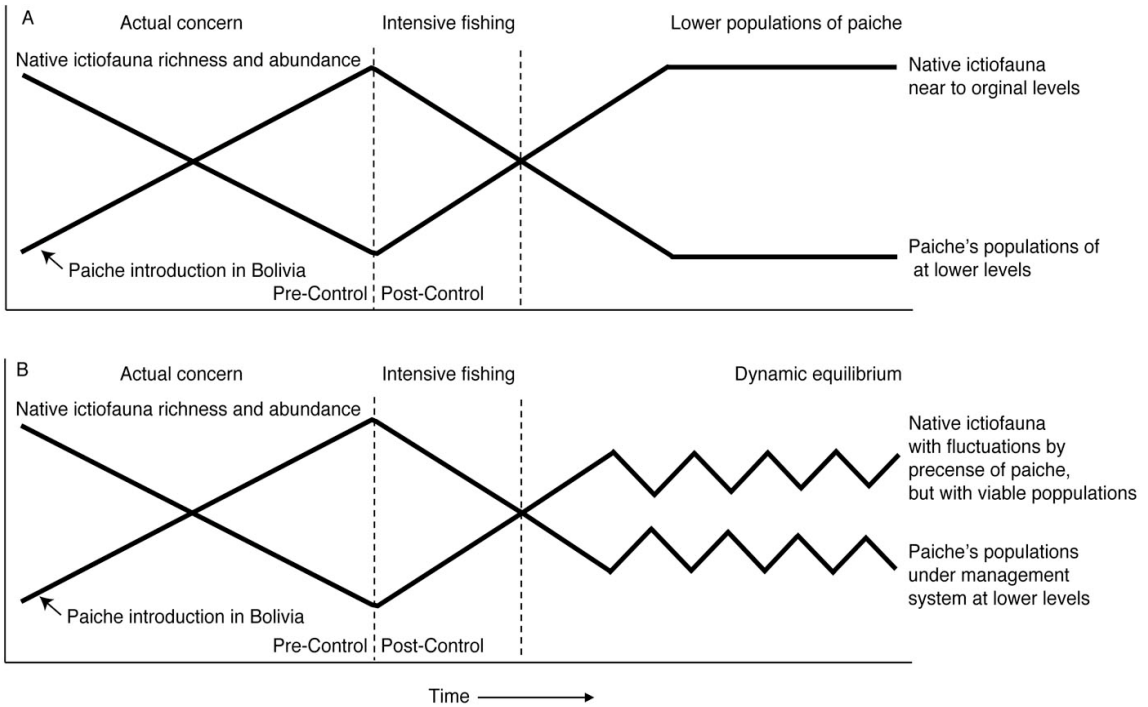

Figure 3. Suggested models of harvest and control of non-native populations of arapaima in the western Amazon drainages of Bolivia.

Management and control

The presence of arapaima in Amazonian Bolivian rivers is a real concern and management to control the species is required, at least to maintain it at a level where native fish populations adapt to the presence of this voracious species. Preliminary studies about its diet show that its feeding habits in Bolivia are more diverse than in its natural distribution area (CIPA, unpublished information), involving the consumption of a wide variety of prey items, including several species of fish, birds, reptiles (turtles and small caimans) and even small mammals.

One management possibility is to reduce arapaima populations to a low level and thereafter maintain this level by sustainable harvesting, since paradoxically this large fish is a valuable economic resource and hence maybe beneficial for many fishing communities (Van Damme 2006; Wiefels 2006). Intensifying arapaima fishing could also help the recovery of other commercial fish species since the majority of fishing effort would be directed towards arapaima. The majority of riverine communities have reduced access to basic services and a community-based management initiative could become a sustainable management model for a non-native species, endangered across its natural distribution, which threatens native species. Intensified fishing methods need to specifically target arapaima, especially the largest individuals that are currently under fished. Otherwise all fishes, including arapaima and native fishes, will be over-fished.

At least two potential scenarios for the arapaima in Bolivia should be considered: a) the impact of arapaima on native fish populations strongly reduces richness and composition of the native fish fauna, therefore drastically affecting all local fish, or b) there is a more dynamic balance of fish communities between seasons of the year making it possible for the wetlands to renew to a degree and the presence of arapaima has a more limited affect on the richness and abundance of local fish species (Figure 3).

Based on one of these alternatives, a control system will have to be planned in order to a)

reduce arapaima populations to the minimum possible, or b) maintain these populations to a degree where there is balance between the presence of local fish species and the long-term management of arapaima considering both environmental and human needs.

In conclusion not all invasive species can be considered "bad" *per se*. Nevertheless, even a charismatic and endangered species such as the arapaima, can transform into a big and serious threat to aquatic biodiversity after human induced introduction.

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