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# Environmental Assessment and Aquatic Biodiversity Conservation of Amazonian Savannas, Marajó Island, Brazil

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## 1. Introduction

Marajó Island is located in the mouth of the Amazon River, the World's largest river, at its interface with the Atlantic Ocean (Goulding et al., 2003). Marajó is the World's largest riverine island (Cruz, 1987), with a total area of approximately fifty thousand square kilometers (Fig. 1). In addition to the Amazon, the island is also influenced by the Tocantins River and other small rivers of the south (Barthem & Schwassmann, 1994; UNEP, 2004).

The island is surrounded by sandy-clayey beaches, and encompasses a hydrographic system (rivers, channels, and creeks) which both drains and floods the *terra firme* forest and *várzeas* (swamps) (Marques-Aguiar et al., 2002). In addition to these forest ecosystems, the island's lakes, lagoons, beaches, rivers, and mangroves contribute to its diversity of habitats and organisms (Marques-Aguiar et al., 2002; Montag et al., 2009; Almeida et al., 2009). This diversity of habitats influences the richness of the region's fauna, including its fish, and plays an important role in habitat preferences and use (Lowe-McConnell, 1999; Carrier et al., 2004). Most of these environments are heavily influenced by the inundation cycle of the estuarine region, which Junk (1997) characterizes as a polymodal cycle of low amplitude, but highly predictable flood pulses, influenced primarily by the local tides.

The climate of Marajó Island can be characterized by two categories of the Köppen classification system – Af (humid tropical, with mean precipitation in the driest month at least 60 mm) and Am, tropical monsoon, with excessive rainfall between February and May. During this period, two-thirds of the island are completely flooded (Cardoso & Pereira, 2002; Lima et al., 2005; Fig. 1). Annual precipitation on Marajó Island ranges between 2500 mm and 4000 mm, with a mean temperature of around 27°C, and relative humidity of 81% to 94%. Rainfall is distributed in two distinct periods, with a marked rainy season between January and June, and a dry season, between September and November.

Despite this rigorous hydrological regime, the vegetation covering the part of the island that is flooded annually is referred to as a savanna (or flooded grassland; Fig. 2), which is known for the diversity and abundance of its fishery resources (Barthem & Fabré, 2003; Montag et al., 2009; Schaan, 2010). While the term savanna is more associated with specific floristic characteristics, comparable with those of the savannas of central Brazil (Eiten, 1972; Ratter et

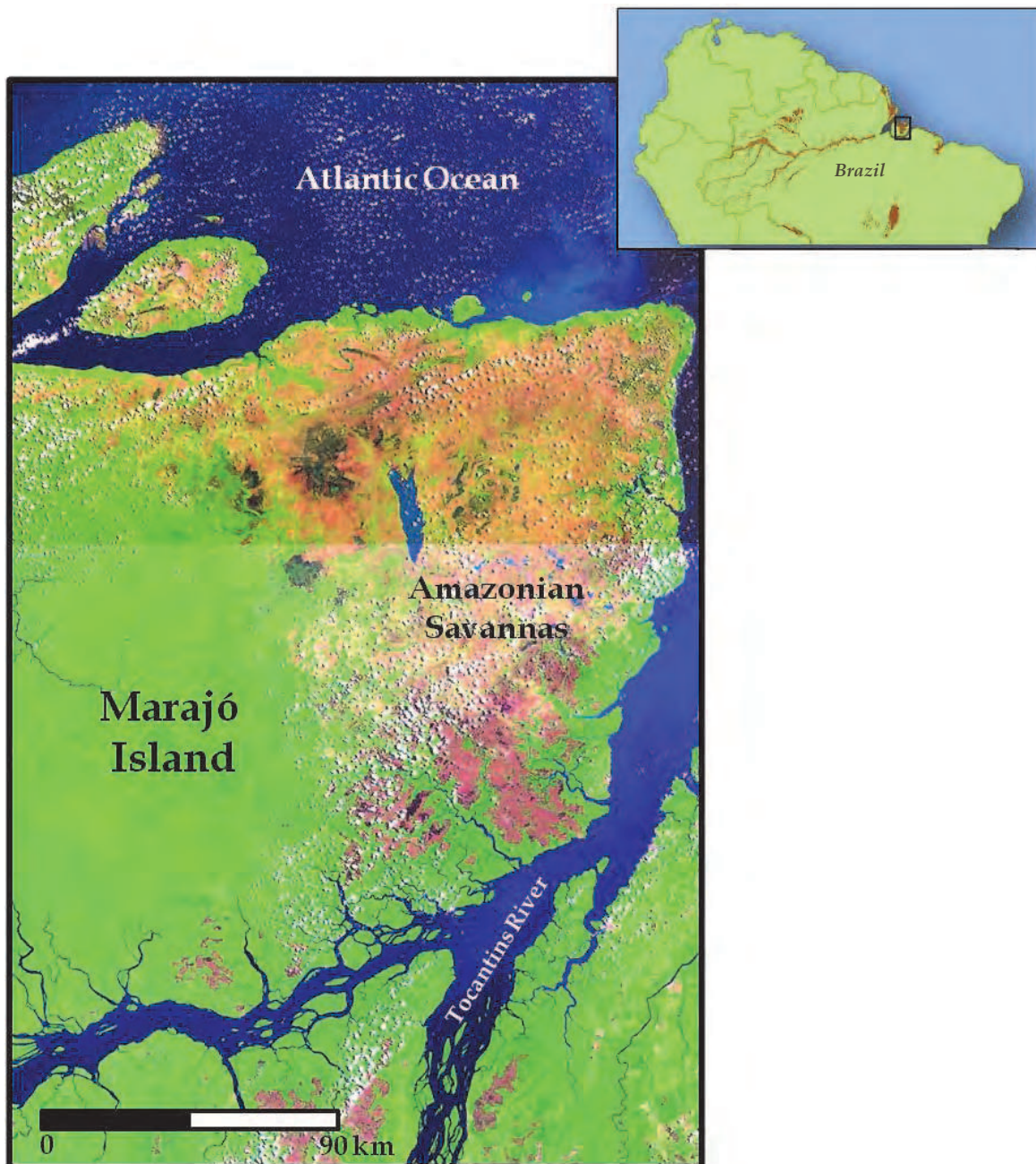


Fig. 1. LandSat Image (2001) of Marajó Island in the Eastern Amazon. The eastern of the island shows the seasonally-flooded savannas (shaded pink).

al., 1997; Sanaiotti et al., 1997; Ribeiro & Walter, 1998, Barbosa et al., 2007), Harris (1980) and Schaen (2010) recognize the flooded grasslands of Marajó Island as a typical example of seasonally-flooded savanna, more typical of the Amazonian *várzeas*, given the duration of the flooding period. However, there are also important differences, especially in the dynamics of inundation. While the Marajó grasslands are inundated by rainwater, the floodplains of the lower Amazon basin are encroached by rising river levels (Sombroek, 1966). The influence of oceanic tides is an additional factor contributing to the unique ecology of the Marajó savannas (Moran, 1995), demanding specific adaptive responses from the living organisms that inhabit this environment.



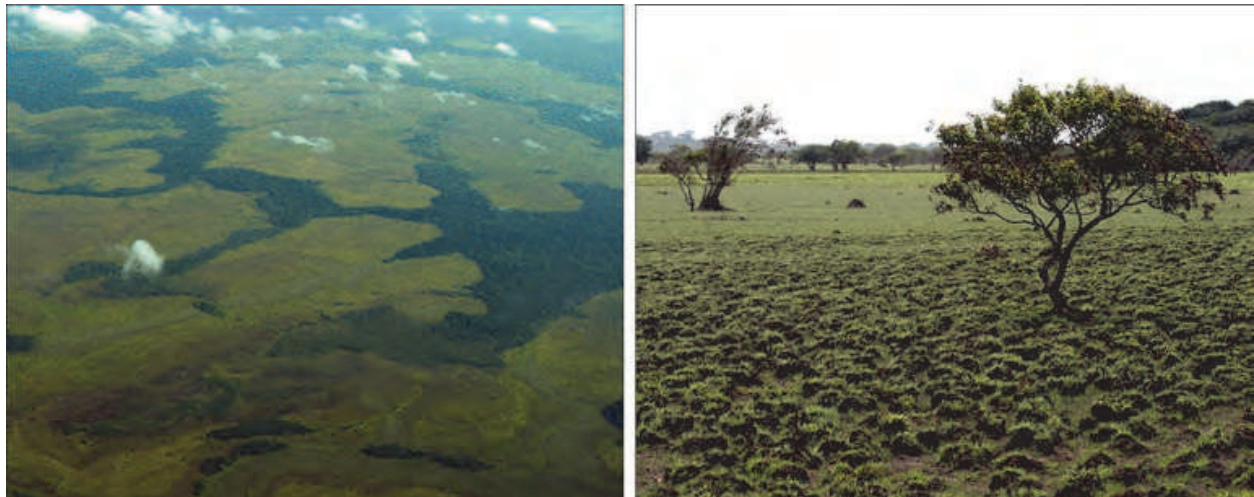


Fig. 2. Aerial view of the Marajó landscape, with the savannas or grassland in lighter green (left fig.); a typical scenario of the savannas in the Marajó Island during the dry season (right fig.). Photo by Miguel von Behr.

Humans have occupied Marajó Island for at least the past five to seven thousand years (Simões, 1981; Roosevelt et al., 1991). These first inhabitants probably subsisted on game, fish, and small-scale agriculture (Schaan, 2010), although, as in the present day, this activity would have been limited by the low fertility of the local soils and their inadequate drainage. However, these soils are appropriate for a number of native palm species, such as the buriti (*Mauritia flexuosa* L.), also known locally as miriti, and the açaí (*Euterpe oleracea* Mart.). These two plants provide the raw material on which much of the local economy is based. The buriti supplies a fiber used for the production of artifacts and household items, while the fruit of the açaí is the principal source of nutrients for much of the island's riverside population (Schaan, 2010). A third plant species, the wild nutmeg, *Virola surinamensis* (Rol.) Warb. provides the raw material for the local plywood industry (Homma et al., 1998), which is the principal source of income for many of the island's municipalities (Lima et al., 2005). Ranching, in particular of water buffalo, is another important source of income for the local inhabitants (Lima et al., 2005; Fig. 3). According to data from the Brazilian Institute for Geography and Statistics, IBGE (Barbosa, 2005), the Marajó stocks represent approximately one quarter of all the buffalo raised in Brazil. However, traditional ranching on the island has declined in recent years due to competition from cattle ranchers from southern Pará, who produce a more marketable product (Schaan, 2010).

These economic activities, which are developed without conservation management guidelines, have contributed to the progressive degradation of the island's ecosystems. The shipping of açaí in motorized vessels also contributes to the contamination of the local rivers with oil and plastics, while the production of beef and pork leads to the silting up of bodies of water (Schaan, 2010). A number of authors have associated these anthropogenic impacts with the decline in the numbers of fish and species, and the abundance of fishery stocks (Ackermann, 1963; Smith, 2001, 2002). These stocks have also suffered direct impacts from overfishing, the use of gillnets of illegal mesh size, and the discarding of catches of inadequate size or low market value (Hilbert, 1952; Barthem & Goulding, 2007).



Fig. 3. The ranching of water buffaloes is an important source of income for the local inhabitants. Photo by Miguel von Behr.

Despite the unique features and ecological importance of Marajó Island in the local context, it has not been included in the environmental and hydrological management programs that have been developed for the Amazon region (Lima et al., 2005). One of the reasons for this is probably the lack of information on the region's fauna. Given this preoccupying scenario, this chapter focuses on the ecological evaluation of the fish diversity of the flooded savannas of Marajó Island in Brazil. The historical and biological aspects of the local ichthyofauna are analyzed, and the threats to this fauna are examined. The challenges for the implementation of effective conservation and management of one of the Amazon region's most important natural resources – its fish – are also discussed.

## 2. What do we know?

### 2.1 The fishes

Despite having one of the richest ichthyofaunas found anywhere on the planet (Reis et al., 2003), our scientific knowledge of the diversity of the fish of Marajó Island is restricted to just two studies, Boulenger (1897) and Montag et al. (2009), more than one hundred years apart. In the more recent study, Montag et al. (2009) revised the data available from fieldwork conducted between 2003 and 2005 in the municipalities of Chaves, Muaná, and Ponta de Pedras. Additional data were obtained from the ichthyological collections of the Goeldi Museum (MPEG) and the Museum of Zoology of São Paulo University (MZUSP) in Brazil, as well as international institutions, such as the Swedish Natural History Museum (NMR) and the Florida State Museum (UF, USA). Most of the specimens available in these collections were obtained during the 1980s and 1990s in the municipalities of Cachoeira do Arari, Muaná, Ponta de Pedras, Salvaterra, Santa Cruz do Arari, and Soure (Montag et al., 2009). This study was part of the PROBIO Marajó project entitled "Ecological Evaluation

and Selection of Priority Areas for the Conservation of the Amazonian Savannas of the Marajó Archipelago in the Brazilian State of Pará”, which was financed by the Program for Biodiversity Research (PPBio) and the Brazilian Environment Ministry (MMA), through the Goeldi Museum in Belém.

A total of 254 fish species were recorded from the flooded savannas of Marajó Island, including the first documentation of eight families for this region – Cetopsidae, Ctenoluciidae, Paralichthyidae, Poeciliidae, Polycentridae, Rivulidae, and Trichomycteridae (Montag et al., 2009; see Appendix 1). However, the bootstrap estimate of the region’s total species richness was approximately 310 (Fig. 4), which represents an additional 50 species that may potentially be catalogued on Marajó Island.

Of these 254 species, 44 (17% of the total) are commercially important as food species, while 46 (18%) are targeted by the ornamental fish market. In fact, the marshlands of Marajó Island represent one of the most important fishing grounds of the lower Amazon basin (Barthem & Fabr , 2003).

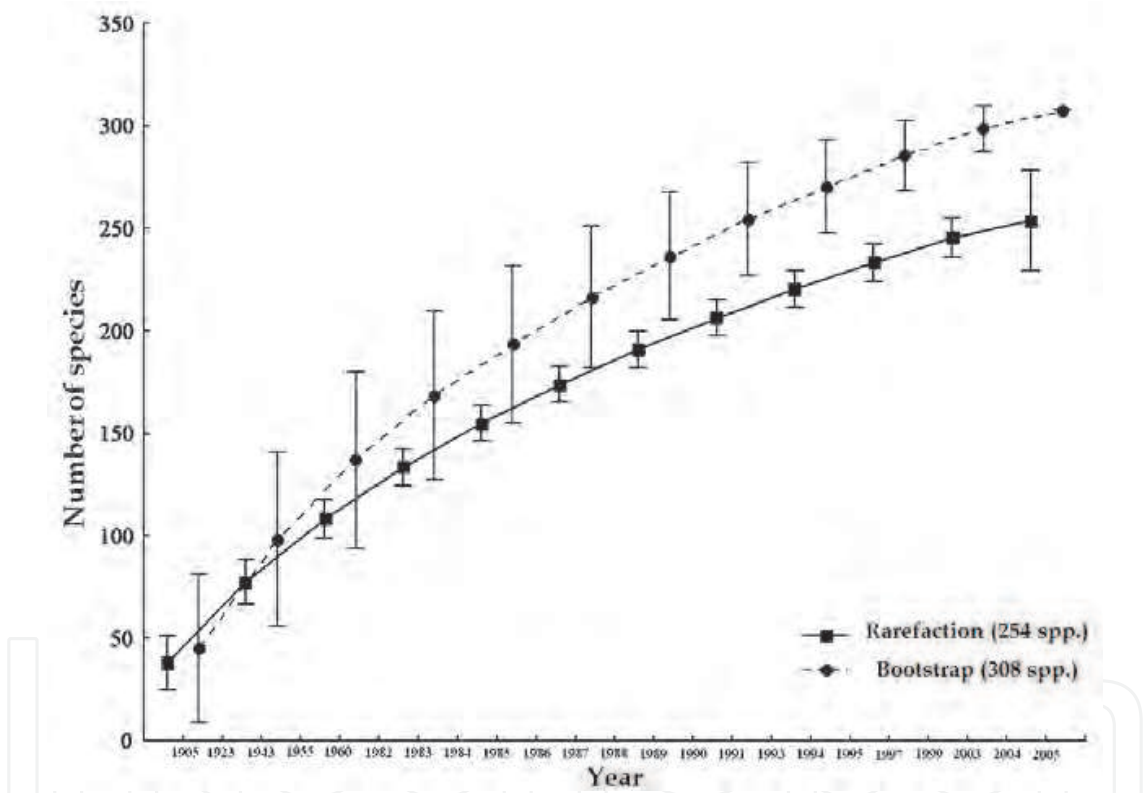


Fig. 4. Species accumulations curve for the number of fish species recorded in the Maraj  savannas using the rarefaction technique and the species richness estimated by Bootstrap analysis for the data available for the period between 1905 and 2005. Source: Montag et al. (2009).

The principal species targeted by commercial fisheries include the tamuat  or brown hoplo (*Hoplosternum littorale*), thraira (*Hoplias malabaricus*), cangati or driftwood catfish (*Trachelyopterus galeatus*) and aracu or headstanders (family Anostomidae). The island’s most popular ornamental fish include lebiasinids, caracids of the genera *Hemigrammus* and *Hyphessobrycon*, dwarf cichlids of the genera *Apistogramma*, *Crenicichla* and *Geophagus*, cascudos or plecos of the Loricariidae family, and stingrays of the genus *Potamotrygon*.



Until now, few endemic species have been recorded from the flooded savannas of Marajó Island, although this may be at least partly related to the deficiency of conclusive systematic and taxonomic studies for many species groups. One case in point here is swamp eel, *Synbranchus lampreia* Favorito, Zanata and Assumpção (2005), which is known only from the Goiapi River on Marajó Island. Given the gaps in our knowledge of the region's ichthyofauna and the unreliability of the taxonomic arrangements of most groups, Montag et al. (2009) proposed that the island should be considered among the regions with the highest priority for both biological inventories and the implementation of protected areas, based on well-defined empirical criteria.

## 2.2 Environmental patterns

The savannas of Marajó Island are seasonally flooded by rain, forming a complex system of temporary or permanent lakes and swamps. The aquatic biodiversity of this region is adapted to the extreme conditions of drought and flood, together with high temperatures associated and low levels of dissolved oxygen (Almeida et al., 2009). The most common fish species found in these lakes and swamps are well adapted to the extremes of oxygen depletion (Kramer et al., 1978), such as the temporary development of a dermal lip protuberance for surface respiration (Winemiller, 1989) or permanent accessory respiratory organs, like the swimbladder of the pirarucu (*Arapaima gigas*) (Greenwood & Liem, 1984), and the vascularization of the posterior intestine in the tamuatá or brown hoplo (*Hoplosternum littorale*) (Persaud et al., 2006) or the oral mucosa in the poraquê or electric eel *Electrophorus electricus* as cited by Johansen et al. (1968).

The reproduction of these fish species is synchronized with the flood pulse. The electric eel (*Electrophorus electricus*) spawns during the late dry season, between September and December (Assunção & Schwassmann, 1995), while *Hoplosternum littorale* spawns at the beginning of the rainy season, i.e. January and February (Oliveira, 2000). This species builds nests in the flooded vegetation and presents parental care. For many fishes the environmental characteristics is an important factor for species distribution, and this is also applied for potamotrigonids stingrays. However, according to Almeida et al. (2009) the distribution of the stingray *Potamotrygon motoro* is related to body size, with the largest specimens being found in the center of the island, and the smaller individuals in peripheral areas.

Fishery activities are also synchronized with the flood pulse (Welcomme, 1979). The body of water expands during the rainy season, dispersing the fish populations over the floodplain, reducing fishery productivity. By contrast, during the dry season, the fish are restricted to isolated pools or shallow channels, facilitating their capture. Overall, 90% of the island's commercial catch is based on four species, with *Hoplosternum littorale* accounting for approximately two-thirds of total fishery production (Barthem & Goulding, 2007). Fishery activities are based on cast- and gillnetting. Gillnets are employed either in a fixed manner, or as a seine, which is drawn towards a beach or a second gillnet, which acts as a barrier. Hooks and harpoons are also used by artisanal fishermen (Albuquerque & Barthem, 2008).

## 2.3 Pattern and process

The flood pulse is the main ecological factor that determines the productivity and biological processes of the aquatic environments of the Amazon Basin (Junk et al., 1989; Junk & Wantzen, 2004). The flood pulse of the central portion of Marajó Island is determined basically by local precipitation levels, while water levels in marginal areas are determined primarily by tidal cycles.

Data on precipitation and water levels are available from the website of the Brazilian National Waters Agency (Agência Nacional de Águas, or ANA). Rainfall is more intense during the first half of the year, between January and June, reaching a peak normally in March. The precipitation is not distributed homogeneously, and tends to be higher in the eastern and western portions of the island, and lower in its center (Lima et al., 2005). The highest precipitation – 200 mm in a single day – was recorded in the east of the island, the part closest to the Atlantic Ocean (Soure). The lowest precipitation rates coincide with the area of savanna, with the lowest values being recorded in September, when the monthly maximum is less than 100 mm (Cachoeira do Arari) (Fig. 5). The center of the island is flat and shallow, and the rainfall floods the savannas between March and May, forming permanent or temporary lakes and swamps (Fig. 6). In subsequent months, the local rivers drain off this water to coastal areas.

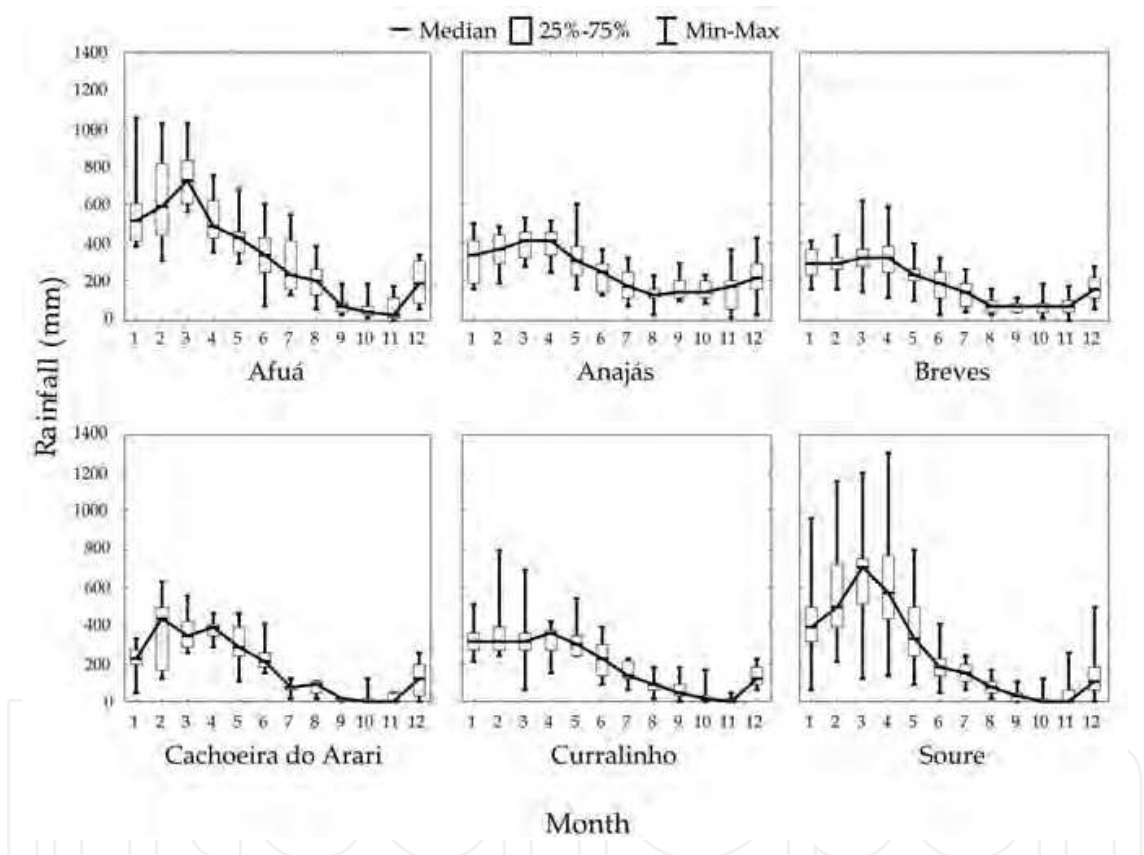


Fig. 5. Median monthly precipitation at different localities on Marajó Island (Source: Brazilian National Waters Agency - ANA).

The tidal surge moves upstream into the Amazon from east to west, when it is deformed, delayed and amortized. The high tide increases the level of the river and dams or inverts its flow, which returns to normal during the ebb tide (Kosuth et al., 1999). Rivers can be classified in three categories, according to the predominant hydrological force, i.e. river flow, tide or a combination of the two effects (Volker, 1966). The rivers of Marajó Island may be classified in all three categories. The rivers in the center of the island are affected only by local rainfall, while those on the coast are dominated by the tides, and those in intermediate areas are affected by a combination of these processes. The proximity of the ocean results in an



increased intrusion of brackish water during the second half of the year, raising salinity levels near the coast and in the small rivers in the east of the island (Barthem & Schwassmann, 1994).

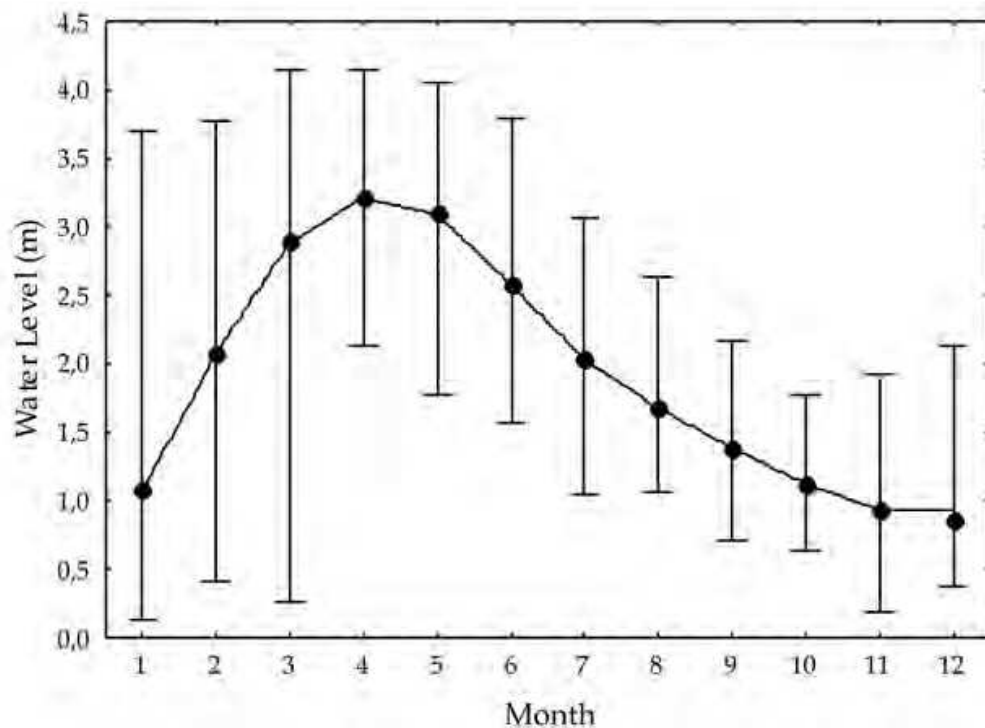


Fig. 6. Monthly variation in the water of the Cachoeira do Arari River, in the center of Marajó Island.

### 3. What are the threats to local biodiversity?

Throughout its recent history, the Amazon basin has been subjected to a series of rapid processes of environmental degradation, which have had negative consequences for the local biota. On a broad scale, the principal economic activities that have contributed to this process have traditionally been cattle ranching and agriculture. However, logging and the harvesting of forest products, such as fruits, oils, latex, game, and fish, have also contributed to the depletion of natural resources. On Marajó Island, these processes have been typical of those observed in the rest of the Amazon basin. First occupied by Europeans in the 17th century, Marajó Island was involved in the principal economic cycles of the Amazon basin. During the colonial period, the island's principal economic activities were large-scale (by the standards of the period) cattle ranching, and the production of sugar, tobacco, and cotton in plantations established primarily in coastal locations (Teixeira, 1953; Miranda Neto, 1968). During this period, the trampling of the grasslands by the cattle already contributed to a decline in local fishery productivity (Brasil, 1990). Following a period of decadence, and the rubber boom at the turn of the twentieth century, ranching began to grow on Marajó Island in the 1920s, although it is currently in decline once again. Currently, ranching on the island is based on its herd of water buffalo, which arrived at the end of the 19th century, when animals of the Carabao breed, originally from the Philippines (see Fig. 3). However, the weight of these animals results in hoofprints of up to 10 cm in

depth (Santos, 2006) which, together with their habit of excavating holes in which they cool themselves during the dry season, provoke significant alterations in the structure of the superficial soil layers and the composition of the vegetation, which favor erosive processes (Dias, 1999; Fig. 7). In addition, the compaction of the soil creates an environment unfavorable for plant growth, reducing the productivity and longevity of forage species (Imhoff et al., 2000).



Fig. 7. Water buffaloes cooling themselves during the dry season, which provokes significant alterations in the structure of the superficial soil layers and changes in the composition of the vegetation. Photo by Miguel von Behr.

Buffalo ranching also contributes with the nitrogen enrichment of water bodies through urine and feces, resulting in high turbidity and reduced oxygen levels. These alterations of hydrological resources may also affect the abundance and quality of fishery resources, as well as increasing the potential for the transmission of water-borne diseases. This process also affects the local biodiversity through the destruction of the vegetation, in which many species seek refuge when breeding (Bernardi, 2005).

Most of the economic activities developed on Marajó Island provoke some form of impact on the local biota. Activities that result in deforestation, such as ranching, agriculture, and unregulated logging, result in the loss of riparian vegetation and the silting up of river beds (Goulding et al., 2003). The extraction of fruit-producing lumber species and the commercial exploitation of the palm-heart and fruit of the açaí result in a reduction in the abundance of fruit for many frugivorous animals, including fish (Barthem, 2001). While commercial fisheries are an extremely profitable activity in eastern Amazonia, they have been exerting increasing pressure on local fish stocks. Species such as the pirarucu *Arapaima gigas* and the tamuatá *Hoplosternum littorale* are being overfished, but are marketed prominently in the Ver-o-Peso market in Belém, the capital of the Brazilian state of Pará (Fig. 8). Commercial fishing by so-called “ice boats” (equipped with icebox), in particular in *várzea* lakes and

other sheltered areas of the estuary (bays, channels, and creeks), threatens the reproduction of commercial species, and thus their stocks over the long term (Goulding et al., 2003; UNEP, 2004). The negative consequences of this process may eventually throughout the local ecosystem in a cascade effect.



Fig. 8. The tamuatá *Hoplosternum littorale* are being marketed prominently in the Ver-o-Peso market in Belém, the capital of the Brazilian state of Pará. Read up on the broad “Large tamuatá from Marajó Island”.

In addition to these impacts on the physical-chemical characteristics of the water and the vegetation, the compaction of the soil threatens the survival of the fish species that inhabit these seasonally-flooded habitats, such as the South American lungfish (*Lepidosiren paradoxa*), which may asphyxiate during the estivation period. During the dry season, the lungfish bury themselves in the humid soil of the savannas, covering themselves in mucous, which is produced in the tegument in large quantities to protect the animal from dehydration. They are also able to reduce their metabolism and body temperature in a process of estivation. There is an opening in the upper part of the mucous “cocoon”, which allows the fish to breathe atmospheric air. The lungfish may remain in this state for many months, until the following rainy season, when more favorable conditions arise (Mesquita-Saad et al., 2002; Kramer et al., 1978).

In contrast with the fluctuations of the ranching industry, the harvesting of natural plant and animal resources has always been the mainstay of the economy of Marajó Island. The commercial exploitation of the fruit and palm-heart of the açai, and fish stocks, constitute the most important economic activities for the local communities of the Amazon estuary (Brasil, 1990).



The native vegetation of Marajó Island has been modified by a combination of ranching, fires, and direct anthropogenic impacts (see Prance & Shaller 1982). Barthem (2001) considered the Marajó savannas to be the most threatened environment of the whole of the Amazon basin in terms of the conservation status of its ichthyofauna. In addition to these other anthropogenic pressures, this environment is being further threatened by the possible introduction of a new variety of rice developed specifically for the conditions on Marajó Island by EMBRAPA, the agricultural research agency of the Brazilian government.

One of the most dramatic anthropogenic impacts on the aquatic biota of the island's savannas was probably caused by the digging of the Tartaruga canal at the end of the 19th century. This canal crossed the savanna in a north-south direction for approximately 25 km, and was originally conceived as a means of reducing the time necessary to navigate between Macapá and Belém, the two principal cities on the Amazon estuary (Teixeira, 1953). The canal provoked the relatively rapid draining of the water accumulated in the savannas at the end of the rainy season (Ackermann, 1963), accentuating the effects of the dry season on the aquatic biota and many terrestrial animals.

In addition to all these threats to the local biodiversity, a large number of other projects are currently being planned or are under development in the Marajó region. One of these is the construction of a new canal, with the same objective of the Tartaruga canal, which is to reduce navigation time between Macapá and Belém. In addition to the intrinsic physical effects of the increase in the river-borne traffic, the degradation of aquatic habitats and the reduction or elimination of feeding resources will affect the plant and animal communities directly (Bucher et al., 1993).

The region has also been regional initiatives for the development of economic activities, including tourism, industrial fisheries, industrialized pineapple plantations, palm-heart processing plants, and cattle ranching. The Pará state government, through its Science, Technology, and Environment ministry (SECTAM), has implemented technical and scientific cooperation agreements, and other institutional covenants, with the aim of elaborating environmental management strategies for the sustainable development of all the island's municipalities which have instated official policies for the protection of the environment. Up to now, agreements have been signed with ten municipalities – Afuá, Anajás, Breves, Cachoeira do Arari, Chaves, Curralinho, Muaná, Ponta de Pedras, Salvaterra, and Soure.

Eleven of the 16 municipalities of Marajó Island have already obtained the seal of tourism quality from the Brazilian Tourism Agency (EMBRATUR), and are among the “flagships” of the tourism development program of the Pará State Tourism Company (PARATUR, 2001). The Marajó region is also included as a main hub in the Amazon Basin Ecotourism Development Program (PROECOTUR), a federal program administered by the Environment Ministry (MMA) through its secretary for Amazonian affairs, with financial support from the Inter-American Development Bank (BID). This program aims to promote the expansion of ecotourism in the Brazilian Amazon region, as one of the principal strategies for the sustainable development of the nine states had make up the region.

#### **4. What do we still need to know?**

The first step towards the effective mitigation of any of the environmental impacts affecting the biodiversity of the flooded grasslands of Marajó Island is the consolidation of our

knowledge of the ecological processes that underpin this unique system. However, few data are available in the literature on the status and integrity of local habitats and biodiversity, even in the case of the ichthyofauna, which is of direct interest to local human populations.

The 254 fish species already recorded on Marajó Island represent only 12% of the total diversity of the Amazon basin. Most of the records collated by Montag et al. (2009) were derived from sites located in the eastern portion of the island, and represent a relatively reduced sampling effort, considering its total area. Furthermore, the western portion of the island, with its many channels and tidal creeks, appears to be a more propitious environment for a high diversity of fish species. This part of the island is probably inhabited by a number of endemic species that are typical of the brackish estuarine and coastal systems that extend along the northern coast of South America, between the mouth of the Orinoco River in Venezuela and São Marcos Bay, in the Brazilian state of Maranhão.

The Amazon estuary is a unique, but still poorly-studied environment inhabited by both freshwater and marine fish species, many of which fundamental to both the regional and the national fishery industries (Barthem, 2001). The estuary and the adjacent vegetation constitute an extremely important nursery for the local ichthyofauna, providing both refuges and rich feeding resources for the juveniles of an ample variety of species. Many of these species also move through the flooded forest, where they eat fruits and seeds, and thus play an important role in the dispersal of the seeds of many *várzea* plant species (Gottsberger, 1978; Goulding, 1980; Kubitzki & Ziburski, 1994; Correa et al., 2007; Pollux, 2011).

As mentioned above, insufficient information is available on the composition of the region's ichthyofauna and the biology of the species that make up this fauna. At the present time, it is essential to conduct more definitive surveys, and to evaluate the status of populations and their long-term viability in both time and space, especially in the case of migratory species and/or those with an ample geographic range. In addition, understanding the basic functioning of the Amazonian ecosystems affected by seasonal flooding will be fundamentally important for the development of effective conservation strategies for the ichthyofauna of Marajó Island (Roberts, 1993).

## 5. Challenges: Applying what we already know

The destruction and degradation of the rivers and creeks of the flooded savannas of Marajó Island, combined with the overfishing throughout the estuarine region, are the principal threats to the integrity of the local ichthyofauna. To be effective, any conservation strategy must take into consideration the complex life cycles of different species, and their specific habitat requirements. Given this, population-level studies will be essential for the understanding of the ecological niche of each species, so that more effective conservation strategies can be developed. Data on the habitat use of these species will also be essential for the development of effective *in situ* conservation strategies for target species.

In a wider context, the strategies applied to the conservation of species of special interest – such as the pirarucu or freshwater stingrays – will undoubtedly also favor most of the other species that share the same habitat or have similar niches. Unfortunately, far too few data are currently available for any such process to be systematic and dependable, although the identification of the key species and habitats may nevertheless provide an adequate baseline for the development of effective public policies for the conservation of the aquatic biodiversity of Marajó Island.

One of the greatest challenges in the Amazon today is to integrate the exploitation of natural resources by the local human communities with the conservation of the biota. To achieve this, the economic, social, and ecological benefits of managed ecosystems must be understood by the local residents if there is to be any possibility of the sustainable use of resources. In the specific case of the savannas of Marajó Island, the understanding by residents and managers of the benefits of the conservation of these habitats for the maintenance or even the improvement of fishery stocks, will be essential for the success of any conservation efforts.

An important step towards the integration of local populations in any conservation scheme is the understanding of conservation initiatives, however minor or incipient, developed by the local populations themselves. However, conservation strategies should be diversified on both a local and regional scales due to the complexity of anthropogenic impacts and their differential effects on different trophic levels of ecosystems. Integrated conservation initiatives involving governments, non-governmental organizations, and in particular, the active participation of local populations, should be given the highest priority.

In addition to the integrated management of natural resources, the creation of protected areas has been an important practical conservation strategy in Brazil. In fact, the whole of Marajó Island is located within a single state conservation unit, the Marajós Archipelago Environmental Protection Area, or Marajó EPA. Considered to be the largest state EPA in Brazil (MMA, 2007), this unit was created by article 13, paragraph 2 of the Pará state constitution, decreed on October 5th, 1989. However, this category of protected area is highly flexible in terms of the exploitation of natural resources and definitely does not guarantee the maintenance of the ecological functions of the local ecosystems over the long term.

The Marajó EPA was created as part of the ecological-economic zoning of the state of Pará, with the objectives of conserving the region's biodiversity, development and improvement of the quality of life of the island's population, the preservation of endangered species and representative areas of the local ecosystems, and the establishment of scientific, environmental education, and ecotourism projects. However, up to now, no management plan or administration program has been developed for this protected area.

An alternative proposal for the more effective conservation of the fauna and flora of Marajó Island would be the creation of a biosphere reserve. Biosphere reserves are areas of terrestrial and/or marine-coastal ecosystems recognized by the Man and the Biosphere Program (MaB), which was created in the 1970s by UNESCO, the United Nations Educational, Scientific and Cultural Organization. This program supports the development of a balanced relationship between people and nature, and determines that areas of special environmental and human value be recognized (designated) as biosphere reserves by the international coordinating council of the MaB program, at the request of the interested state. Following this recognition, the area of the reserve comes under the exclusive sovereignty of the state within which it is located.

## 6. Conclusions

The considerable lacunas in our current knowledge of the ichthyofauna of the region of Marajó Island indicate the need for more thorough, complementary surveys of the flooded grasslands (savannas) of the eastern portion of the island, studied by Montag et al. (2009), as well as new inventories of the western portion of the island. The anthropogenic impacts observed on local fish stocks, together with the dependence of local communities on the



fishery resources of the Amazon estuary combine to make this region a priority for scientific studies of the aquatic biota and associated environments.

There is still a long way to go before the conservation of the aquatic biodiversity of Marajó Island can be assured and the maintenance of fishery stocks guaranteed over the long term. In both cases, management strategies must be well diversified. As part of this process, it will be the responsibility of the region's researchers to undertake scientific studies of local diversity (taxonomic revision with the identification of species and cataloguing of specimens), the relationships between species and the physical environment, spatial distribution of species, and the identification of possible endemics and key species for conservation. These studies will provide a theoretical and empirical database for the systematic development of public policies that integrate authorities, administrators, and local residents in the quest for the effective conservation and management of the natural resources of the aquatic environments of Marajó Island over the long term.

## Appendix 1

Fish species of the savannas of Marajó Island, Pará, Brazil. Modified from Montag et al. (2009).

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### Fish species from Marajó Island

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#### **BELONIFORMES: Belonidae**

*Potamorhaphis guianensis* (Jardine, 1843)

*Potamorhaphis* sp.

#### **CHARACIFORMES: Acestrorhynchidae**

*Acestrorhynchus altus* Menezes, 1969

*Acestrorhynchus* cf. *altus* Menezes, 1969

*Acestrorhynchus falcatus* (Bloch 1794)

*Acestrorhynchus falcistrotris* (Cuvier, 1819)

*Acestrorhynchus microlepis* (Schomburgk, 1841)

*Acestrorhynchus* sp.

#### **Anostomidae**

*Leporinus affinis* Günther, 1864

*Leporinus fasciatus* (Bloch, 1794)

*Leporinus friderici* (Bloch, 1794)

*Leporinus* sp.

*Rhytiodus microlepis* Kner, 1858

*Schizodon fasciatus* Spix and Agassiz, 1829

*Schizodon* sp.

*Schizodon vittatus* (Valenciennes, 1850)

#### **Characidae**

*Astyanax bimaculatus* (Linnaeus, 1758)

*Bryconops alburnoides* Kner, 1858

*Bryconops caudomaculatus* (Günther, 1864)

*Bryconops giacopinii* (Fernández-Yepez, 1950)

*Bryconops* sp.

*Charax pauciradiatus* (Günther, 1864)

*Cheirodon* sp.

*Hemigrammus bellottii* (Steindachner, 1882)

*Hemigrammus levis* Durbin, 1908  
*Hemigrammus ocellifer* (Steindachner, 1882)  
*Hemigrammus rhodostomus* Ahl, 1924  
*Hemigrammus* sp.  
*Hemigrammus unilineatus* (Gill, 1858)  
*Hyphessobrycon heterorhabdus* (Ulrey, 1894)  
*Hyphessobrycon* sp.  
*Metynnis luna* Cope, 1878  
*Metynnis* sp.  
*Moenkhausia collettii* (Steindachner, 1882)  
*Moenkhausia lepidura* (Kner, 1858)  
*Moenkhausia pyrophthalma* Costa, 1994  
*Moenkhausia* sp.  
*Paragoniates alburnus* Steindachner, 1876  
*Phenacogaster* sp.  
*Poptella* sp.  
*Pristella maxillaris* (Ulrey, 1894)  
*Pristobrycon aureus* (Spix and Agassiz, 1829)  
*Pristobrycon calmoni* (Steindachner, 1908)  
*Pygocentrus nattereri* Kner, 1858  
*Roeboides myersii* Gill, 1870  
*Roeboides* sp.  
*Serrasalmus elongatus* Kner, 1858  
*Serrasalmus rhombeus* (Linnaeus, 1766)  
*Serrasalmus* sp.  
*Triportheus* aff. *angulatus* (Spix and Agassiz, 1829)  
*Triportheus albus* Cope, 1872  
*Triportheus angulatus* (Spix and Agassiz, 1829)  
*Triportheus elongatus* (Günther, 1864)  
*Triportheus* sp.

#### **Crenuchidae**

*Crenuchus spilurus* Günther, 1863  
*Microcharacidium* sp.

#### **Ctenoluciidae**

*Boulengerella lucius* (Cuvier, 1816)

#### **Curimatidae**

*Curimata inornata* Vari, 1989  
*Curimata* sp.1  
*Curimata* sp.2  
*Curimatopsis* sp.

#### **Erythrinidae**

*Erythrinus erythrinus* (Bloch and Schneider, 1801)  
*Hoplerythrinus unitaeniatus* (Spix and Agassiz)  
*Hoplias malabaricus* (Bloch, 1794)  
*Hoplias* sp.

#### **Gasteropelecidae**

*Carnegiella* sp.

*Carnegiella strigata* (Günther, 1864)  
*Gasteropelecus sternicla* (Linnaeus, 1758)  
*Thoracocharax stellatus* (Kner, 1858)

#### **Hemiodontidae**

*Hemiodus unimaculatus* (Bloch, 1794)

#### **Lebiasinidae**

*Copella arnoldi* (Regan, 1912)  
*Copella nattereri* (Steindachner, 1876)  
*Nannostomus eques* Steindachner, 1876  
*Nannostomus nittidus* Wetziman, 1978  
*Pyrrhulina filamentosa* Valenciennes, 1847

#### **CLUPEIFORMES: Engraulididae**

*Anchovia* sp.  
*Anchovia surinamensis* (Bleeker, 1866)  
*Lycengraulis batesii* (Günther, 1868)  
*Lycengraulis* sp.  
*Pterengraulis atherinoides* (Linnaeus, 1766)

#### **Pristigasteridae**

*Pellona castelnaeana* (Valenciennes, 1847)  
*Pellona flavipinnis* (Valenciennes, 1836)  
*Pellona* sp.

#### **CYPRINODONTIFORMES: Anablepidae**

*Anableps microlepis* Muller and Troschel, 1844

#### **Poeciliidae**

*Pamphorichthys* sp.  
*Poecilia* sp.1  
*Poecilia* sp.2  
*Poecilia* sp.3  
*Poecilia* sp.4  
*Poecilia* sp.5

#### **Rivulidae**

*Rivulus* sp.

#### **GYMNOTIFORMES: Apterodontidae**

*Adontosternarchus* sp.  
*Apterodontus albifrons* (Linnaeus, 1766)  
*Apterodontus* sp.  
*Sternarchella* cf. *terminalis* (Eigenmann and Allen, 1942)  
*Sternarchella* sp.  
*Sternarchogiton nattereri* (Steindachner, 1868)  
*Sternarchogiton porcinum* Eigenmann and Allen, 1942  
*Sternarchogiton* sp.  
*Sternarchorhamphus muelleri* (Steindachner, 1881)  
*Sternarchorhamphus* sp.

#### **Gymnotidae**

*Electrophorus electricus* (Linnaeus, 1766)  
*Gymnotus carapo* Linnaeus, 1758  
*Gymnotus* sp.



**Hypopomidae**

*Brachyhypopomus brevirostris* (Steindachner, 1868)  
*Brachyhypopomus pinnicaudatus* (Hopkins, 1991)  
*Brachyhypopomus* sp.  
*Hypopomus* sp.  
*Hypopygus lepturus* Hoedeman, 1962  
*Hypopygus* sp.  
*Microsternarchus bilineatus* Fernández-Yépez, 1968  
*Steatogenys elegans* (Steindachner, 1880)  
*Steatogenys* sp.

**Rhamphichthyidae**

*Rhamphichthys marmoratus* Castelnau, 1855  
*Rhamphichthys rostratus* (Linnaeus, 1766)  
*Rhamphichthys* sp.

**Sternopygidae**

*Distocyclus conirostris* (Eigenmann and Allen)  
*Eigenmannia humboldtii* (Steindachner, 1878)  
*Eigenmannia* sp.1  
*Eigenmannia* sp.2  
*Rhabdolichops* sp.  
*Rhabdolichops troscheli* (Kaup, 1856)  
*Sternopygus macrurus* (Bloch and Schneider, 1801)  
*Sternopygus* sp.

**LEPIDOSIRENIFORMES: Lepidosirenidae**

*Lepidosiren paradoxa* Fitzinger, 1837

**OSTEOGLOSSIFORMES: Arapaimidae**

*Arapaima gigas* (Schinz, 1822)

**Osteoglossidae**

*Osteoglossum bicirrhosum* (Cuvier, 1829)

**PERCIFORMES: Centropomidae**

*Centropomus* sp.

**Cichlidae**

*Acaronia nassa* (Heckel, 1840)  
*Aequidens pallidus* (Heckel, 1840)  
*Aequidens* sp.  
*Apistogramma luelingi* Kullander, 1976  
*Apistogramma* sp.  
*Astronotus ocellatus* (Agassiz, 1831)  
*Chaetobranchopsis orbicularis* (Steindachner, 1875)  
*Chaetobranchopsis* sp.  
*Chaetobranchus* sp.  
*Cichla melaniae* Kullander and Ferreira, 2006  
*Cichla monoculus* Spix and Agassiz, 1831  
*Cichla nigromaculata* Jardine, 1843  
*Cichla ocellaris* Bloch and Schneider, 1801  
*Cichla* sp.1  
*Cichla* sp.2

*Cichla temensis* Humboldt, 1821  
*Cichlasoma* sp.  
*Crenicichla cincta* Regan, 1905  
*Crenicichla macrophthalmus* Heckel, 1840  
*Crenicichla notophthalmus* Regan, 1913  
*Crenicichla regani* Ploeg, 1991  
*Crenicichla reticulata* Heckel, 1840  
*Crenicichla* sp.1  
*Crenicichla* sp.2  
*Crenicichla* sp.3  
*Crenicichla strigata* Günther, 1862  
*Geophagus camopiensis* Pellegrin, 1903  
*Geophagus* sp.  
*Geophagus surinamensis* (Bloch, 1791)  
*Satanoperca jurupari* (Heckel, 1840)

#### **Gobiidae**

*Awaous flavus* (Valenciennes, 1837)  
*Bathygobius* sp.  
*Eleotris* sp.  
*Evorthodus* sp.  
*Gobioides* sp.  
*Gobionellus* sp.

#### **Mugilidae**

*Mugil curema* Valenciennes, 1836

#### **Polycentridae**

*Monocirrhus polyacanthus* Heckel, 1840  
*Polycentrus schomburgkii* Müller and Troschel, 1848

#### **Sciaenidae**

*Cynoscion microlepidotus* (Cuvier, 1830)  
*Cynoscion* sp.  
*Macrodon ancylodon* (Bloch and Schneider, 1801)  
*Pachypops fourcroy* (Lacepède, 1802)  
*Pachypops* sp.  
*Pachypops trifilis* (Müller and Troschel, 1849)  
*Plagioscion auratus* (Castelnau, 1855)  
*Plagioscion* sp.  
*Plagioscion squamosissimus* (Heckel, 1840)  
*Plagioscion surinamensis* (Bleeker, 1973)

#### **PLEURONECTIFORMES: Achiridae**

*Achirus achirus* (Linnaeus, 1758)  
*Achirus* sp.

#### **Paralichthyidae**

*Paralichthys brasiliensis* (Ranzani, 1842)  
*Paralichthys* sp.

#### **RAJIFORMES: Potamotrygonidae**

*Potamotrygon motoro* (Müller and Henle, 1841)  
*Potamotrygon orbignyi* (Castelnau, 1855)

*Potamotrygon scobina* Garman, 1913

*Potamotrygon* sp.

**SILURIFORMES: Aspredinidae**

*Aspredinichthys filamentosus* (Valenciennes, 1840)

*Aspredo aspredo* (Linnaeus, 1758)

*Bunocephalus aleuropsis* Cope, 1870

**Auchenipteridae**

*Ageneiosus inermis* (Linnaeus, 1766)

*Ageneiosus* sp.1

*Ageneiosus* sp.2

*Ageneiosus ucayalensis* Castelnau, 1855

*Asterophysus* sp.

*Auchenipterichthys longimanus* (Günther, 1864)

*Auchenipterus nuchalis* (Spix and Agassiz, 1829)

*Centromochlus heckelii* (De Filippi, 1853)

*Pseudauchenipterus nodosus* (Bloch, 1794)

*Tatia intermedia* (Steindachner, 1877)

*Trachelyopterus galeatus* (Linnaeus, 1766)

*Trachelyopterus* sp.

**Callichthyidae**

*Callichthys callichthys* (Linnaeus, 1758)

*Hoplosternum littorale* (Hancock, 1828)

*Megalechis personata* (Ranzini, 1841)

*Megalechis thoracata* (Valenciennes, 1840)

**Cetopsidae**

*Cetopsis* sp.

*Hemicetopsis* sp.

**Doradidae**

*Acanthodoras* sp.

*Anadoras* sp.

*Doras eigenmanni* (Boulenger, 1895)

*Doras* sp.

*Hassar* sp.

*Lithodoras dorsalis* (Valenciennes, 1840)

**Heptapteridae**

*Gladioglanis machadoi* Ferraris and Mago-Leccia, 1989

*Pimelodella altipinnis* (Steindachner, 1864)

*Pimelodella cristata* (Müller and Troschel, 1848)

*Pimelodella gracilis* (Valenciennes, 1835)

*Pimelodella* sp.

*Rhamdia quelen* (Quoy and Gaimard, 1824)

*Rhamdia* sp.

**Insertae sedis**

*Phreatobius cisternarum* Goeldi, 1905

**Loricariidae**

*Ancistrus* sp.1

*Ancistrus* sp.2



*Chaetostoma* sp.  
*Farlowella* aff. *knerii* (Steindachner, 1882)  
*Farlowella amazona* (Gunther, 1864)  
*Farlowella* sp.  
*Hemiancistrus* sp.  
*Hemiodontichthys acipenserinus* (Kner, 1853)  
*Hemiodontichthys* sp.  
*Hypoptopoma* sp.  
*Hypostomus* sp.  
*Lasiancistrus* sp.  
*Limatulichthys* sp.  
*Liposarcus pardalis* (Castelnau, 1855)  
*Loricaria catphracta* Linnaeus, 1758  
*Panaque* sp.  
*Pseudoloricaria* sp.  
*Pterygoplichthys* sp.  
*Reganella* sp.

#### **Pimelodidae**

*Brachyplatystoma vaillantii* (Valenciennes, 1840)  
*Hypophthalmus marginatus* Valenciennes, 1840  
*Pimelodus blochii* Valenciennes, 1840  
*Pimelodus ornatus* Kner, 1858  
*Pimelodus* sp.1  
*Pimelodus* sp.2  
*Pinirampus pirinampu* (Spix and Agassiz, 1829)  
*Zungaro zungaro* (Humboldt, 1821)

#### **Pseudopimelodidae**

*Batrochoglanis raninus* (Valenciennes, 1840)

#### **Trichomycteridae**

*Henonemus taxistigmus* (Fowler, 1814)

#### **SYNBRANCHIFORMES: Synbranchidae**

*Synbranchus lampreia* Favorito, Zanata and Assumpção, 2005  
*Synbranchus marmoratus* Bloch, 1795  
*Synbranchus* sp.

#### **TETRAODONTIFORMES: Tetraodontidae**

*Colomesus asellus* (Müller and Troschel, 1849)  
*Colomesus psittacus* (Bloch and Schneider, 1801)

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## **Research in Biodiversity - Models and Applications**

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The book covers several topics of biodiversity researches and uses, containing 17 chapters grouped into 5 sections. It begins with an interesting chapter considering the ways in which the very biodiversity could be thought about. Noteworthy is the chapter expounding pretty original "creativity theory of ecosystem". There are several chapters concerning models describing relation between ecological niches and diversity maintenance, the factors underlying avian species imperilment, and diversity turnover rate of a local beetle group. Of special importance is the chapter outlining a theoretical model for morphological disparity in its most widened treatment. Several chapters consider regional aspects of biodiversity in Europe, Asia, Central and South America, among them an approach for monitoring conservation of the regional tropical phytodiversity in India is of special importance. Of interest is also a chapter considering the history of the very idea of biodiversity emergence in ecological researches.

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