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Review Article

Exposure of Fishery Resources to Environmental and Socioeconomic Threats within the Pantanal Wetland of South America

Abstract

The huge Pantanal wetland, located in the central region of South America, mainly in Brazil, formed by the Upper Paraguay River Basin, comprising 150,355 km^2 (approximately 140,000 km^2 in Brazil), is facing environmental and socioeconomic threats that are affecting fish populations and fishery resources. The Paraguay River and its tributaries feed the Pantanal wetland, forming a complex aquatic ecosystem, harboring more than 260 fish species, some of them with great subsistence and commercial values to regional human communities. Sport fishing is also preeminent in the region. The natural ecosystems and the increasing human population that depend on them are at risk from a number of identified threats, including natural habitat disruptions and overfishing. Fishing catches have been decreasing, as has the size of captured fish. Riverine vegetation, which is periodically flooded during the high-water season, forming feeding and reproductive grounds for some fish species, has been affected by deforestation and other impacts. Conversion of natural vegetation for human use and wild fires are severe and have become part of the annual cycle of ranch owners. Flooding dynamics have been threatened by infrastructure, including small hydroelectric plants on the riverheads.

Introduction

The scientific literature has pointed out the importance of freshwater ecosystems and their associated biodiversity, including fishery resources, due to the increasing human land uses that have affected those ecosystems along all large river systems on the planet, including the Pantanal region [1-3]. Freshwater is emphasized in several worldwide studies as one of the most important resources of this century, and the following publications have highlighted the increasing problems that global fisheries face. Evidence of this overall concern was expressed at the Symposium on the Management of Large Rivers for Fisheries, held in Phnom Penh, Cambodia, in 2003, pointing out fishery decline in many large rivers [1]. Freshwater conservation was also a subject raised by the United Nations General Assembly, which proclaimed the period from 2005 to 2015 as the International Decade for Action—"Water for Life." In addition, the document Millennium Ecosystem Assessment [4], emphasized the role of biodiversity, such as fishery resources, contributing to safeguarding subsistence use for human communities. Also, the Intergovernmental Panel on Climate Change (IPCC) held in Yokohama, Japan [5], stated that climate change interacts with other stressors, such as habitat alteration, overexploitation of live resources, pollution and invasive species [5]. In addition, the IPCC held in Bangkok, Thailand, [6], presented guidelines to update the role of gas emissions (CO^2 and CH^4) from wetlands [6]. Also, a comprehensive document produced by WWF-International, the Zoological Society of London, Stockholm Resilience Centre, Global Footprint Network, Stockholm Environment Institute, and Metabolic [7], Indicated that species are increasingly affected by pressures from unsustainable agriculture, fisheries, mining and other human activities that contribute to habitat loss and degradation, overexploitation, climate change, and pollution. Wild species are affected and, in consequence, people too are victims of the deteriorating freshwater and fishery resources.

The Pantanal was declared a National Heritage Site by the Brazilian Constitution and a Biosphere Reserve by UNESCO in 2000. It is a large tropical wetland of 150,355 km^2 with more than 90% of its area in Brazil (nearly 140,000 km^2), touching Paraguay and Bolivia, forming a lowland as part of the Upper Paraguay River Basin (Figure 1). The size of the Brazilian Pantanal was delimited at 138,183 km^2, comprising various physiomorphological and ecological aspects related to surface

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Figure 1: The Pantanal is a large wetland in the central region of South America (between parallels 15°30' and 22°30' S and meridians 55º00' and 57°00' W), mostly in Brazil, touching Paraguay and Bolivia, mainly formed by the Paraguay River and by its tributaries, on the left bank, where fishing is of essential socioeconomic importance (image based on ANA – Brazilian Water Agency).

relief features, flooding and drainage, soils and vegetation, resulting in 11 distinct sub regions [8].

The major rivers feeding the Pantanal are tributaries on the left bank of the Paraguay River (from north to south): Bento Gomes, Cuiabá, São Lourenço-Itiquira, Taquari, Negro, Aquidauana-Miranda, Nabileque, and Apa. The land ranging 200–900 meters above sea level is known as highland or plateau and the lowland between 80 and 150 meters is the floodplain wetland. This enormous wetland is formed by a complex mosaic of terrestrial and freshwater habitats, including the large rivers, and the reduced runoff on the plains results in flooding of the wetland [2,9]. Depressions retain water volume, forming small temporary lakes, locally known as "baías" or flooding permanent ones, which are important grounds for fish. The rivers which have their headwaters on the plateaus are slow-moving when they meet the lowland of the Pantanal and periodically (October-March) overflow their banks, inundating up to 80% of the biome. During the dry season (April-September) most of the flooded areas remain dry. Annual rainfall in the highlands generally exceeds 1,200 mm, which produces a rapid response in the drainage basin [10].

The heterogeneous complex of freshwater habitats within the Pantanal wetland supports a diverse fish assemblage with 269 described species [11]. Among commercial and sport species with high socioeconomic value are the "Cachara" *Pseudoplatystoma reticulatum* (Eigenmann & Eigenmann, 1889),"Pintado" *Pseudoplatystom acorruscans* (Agassiz, 1829), "Pacu" *Piaractus mesopotamicus* (Holmberg, 1887), "Dourado" *Salminus brasiliensis* (Cuvier, 1816), "Piavuçu" *Megaleporinus macrocephalus* (Garavelo & Britski, 1988),"Jurupoca" *Hemisorubim platyrhynchos* (Valenciennes, 1840), "Barbado" *Pinirampus pirinampu* (Spix, 1829), "Curimbatá" *Prochilodus lineatus* (Valenciennes, 1847), "Jaú" *Zungaro jahu* (Ihering, 1898), among others.

An ichthyological survey carried out in the Pantanal National Park (1,360 km²) located in southern Pantanal, Mato Grosso do Sulk state, captured 182 species or approximately 70% of the total species known to inhabit the Pantanal [12].

Fish community assemblages vary according to different selected kinds of habitats. Commercially important, large species in general occur in the large rivers, while smaller species usually inhabit smaller rivers and streams. On the other hand, fishes of the floodplain, generally small in size, survive in shallow water and some may survive in the dried sediment during the dry season; they migrate throughout the shallow waters of the wetland while they are flooded [13].

Another study aiming to characterize the structure of the fish assemblages in the Pantanal National Park, during the dry season in late October and early November, employing the Index of Biotic Integrity, identified 154 species of fish, totaling 19,839 individuals from which 146 species (18,954 individuals) were considered for the index [14]. The results showed no association between the structure of the fish assemblage and the different habitats surveyed, indicating the homogeneity of environment at that protected area, considering fish assemblages. However, the rates of fish diversity differed significantly among the surveyed habitats, according to Shannon Diversity Index (H') and the Evenness (J), employed between the strata. The fish assemblage homogeneity in different habitats, in the study area, could be explained by the high flooding level of the habitats, which can last up to eight months in a single annual hydrological cycle. Therefore, the few dry months surveyed were not sufficient to show any detectable variability. The Pantanal National Park accounts for well-preserved habitats, since most metrics were framed in the "excellent" class, some in "regular" and none in "poor". The most surveyed species in the National Park [14], were small fish species with no relevance to fishery.

Fish abundance is related to the seasonal volume of the rivers and consequent flooding seasonality. In general, flood seasons show greater similarity of species, since there are fewer physical barriers for fish dispersion [15]. This study conducted in the Bento Gomes River observed that the variation in abundance may be related to seasonality, as the flood season provided a greater similarity of species among the studied points. This was also associated with a decrease in physical and ecological barriers. The variations found during the study confirm the influence of hydrological dynamics over fish species which occur in the Bento Gomes River.

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The aim of this study is to review the status of the fish biology within the Pantanal wetland and to discuss the identified environmental and socioeconomic threats to the integrity of the freshwater ecosystems and, in consequence, to fishery resources, as elements attain conservation and sustainable use. It discusses the need for a management plan under a suggested framework.

Methods

A revision of the relevant published literature in addition to the collection of recent data on human occupation and land use were performed. Field work has been conducted in different sites of the Pantanal wetland during the past 30 years, providing a large array of information on fishery, fishes, land use, and human activities. Occasional and informal interviews were performed to survey the perception of local people on fishery, diversity and size of fish caught, and other related questions.

Results and Discussion

Previous publications have pointed out the loss and degradation of natural habitats due to deforestation and other effects of human land use, particularly agriculture, contamination of water due to pollutants and erosion, occasional fish mortality, and many other factors [16, 2]. Some published works argue for the pristine role of the Pantanal ecosystem claiming that the wetland faces environmental threats that need to be taken into account for conservation measures [17,18].

A global review found that more than 80% of world wetland areas may have been lost over the past 300 years [19]. Around the world, the main cause for species loss, including fish, is the degradation of freshwater systems [20]. In addition, the interaction between habitat destruction and overexploitation endangers natural resources [21]. In general, for freshwater fish populations, habitat loss is the most important threat. Its causes are mainly agricultural and livestock activities, urban expansion, energy production, and pollution, followed by overexploitation [22].

The alteration and loss of permanent and seasonal freshwater natural habitats have been drastic in the Pantanal wetland during the last decades, as was the case of the Taquari River, negatively impacting on biodiversity [23,24]. The wetland is a flat region flooding seasonally with a shallow level of water near the surface of the substrate, due to the low drainage capacity of its river system. The seasonal flooding dynamic alternates annual and multiannual cycles of droughts and floods, which are determinant to fish biology and productivity [10].

Fishery resources are an important socioeconomic element of the Pantanal, together with cattle ranching and tourism. Fishing is a traditional activity from the point of view of commerce and subsistence, as well as sport fishing, generating direct and indirect economic benefits to local people. Most wetland functions increase with the size of the area, as is the case of fish production. The Pantanal is a large wetland, and its ecological complexity favors the productivity of the ecosystem [2, 25].

In spite of that, however, fishery resources have been in decline over the last two decades. The Brazilian states that share the Pantanal (Mato Grosso and Mato Grosso do Sul) have agencies to regulate and control fishery in the region:

1) Fisheries Control System of Mato Grosso do Sul State - SCPESCA/MS (http://www.cpap.embrapa.br/publicacoes/ficha.php?topicobusca=BP&titulo=BP-Boletim+de+Pesquisa+%26+Desenvolvimento).

2) The control of Mato Grosso state SISCOMP/MT (http: //www.cpap.embrapa.br/publicacoes/online/FOL117. pdf). The official fish production of the Pantanal during the years 1980-1983 was 2,539 tons and 1,542 tons for the years 1984-1989 [26].

Commercial fishery decreased more than 20% in annual capture from 1983 to 1999. Another piece of evidence for the decreasing fishery is the total fish catch registered in the south portion of the Pantanal (Mato Grosso do Sul), which was 645 tons in 2003, while 363 tons were recorded for 2015. In that region the total catch for the period 1997-1999 reached 1,200 tons – or 400 tons a year –which fell to 125 tons in 2006. On the other hand, sport fishing increased in the same period, suggesting a shift in the economic activities in the region.

Fishery and human population threats

In addition to the decline in fishery resources there has been a reduction in the size of fish being caught, as a result of overfishing. The increased demand for fish and the conflicts between commercial, subsistence, and sport fisheries are clearly identified. In fact, the total human population estimated living in the Pantanal wetland is greater than one million people [27].

The largest city in the region is Cuiabá, which has a population of nearly 590,000 people. The Cuiabá River, an important tributary of the Paraguay River feeding the Pantanal wetland, runs through the city. Corumbá, located on the banks of the Paraguay River itself, in the south of the Pantanal, has nearly 110,000 inhabitants, and Cáceres, also on the Paraguay River, in the north of the wetland, has more than 90,000 people. All these large cities plus medium-sized and small ones like Aquidauana (more than 47,000 people), Coxim (more than 32,000), Poconé (more than 32,000), Miranda (more than 27,000), and many others represent environmental and socioeconomic pressures on fishery. Environmental and socioeconomic threats are generally associated with human land use, and the demographic growth reported for the Pantanal wetland is evidence of that stressor.

In the region most cities, villages, and touristic resorts do not have sewage treatment plants, and most of the sewage is drained directly into rivers, polluting the water [27]. For example, in the Cuiabá and São Lourenço rivers there is greater deterioration of water quality from the discharge of domestic and industrial effluents [28].

Large cattle ranches, some with 30,000 hectares of area, with low cattle density relying mostly on natural pastures,

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were predominant within the Pantanal some decades ago [16]. However, this traditional practice could not compete financially with modern cattle ranching on the nearby plateaus, which receives inputs of genetically selected cattle breeds and more nutritious pasture. Consequently, cattle ranchers in the wetland also developed exotic pastures with African species *Urochloa decumbens* (former *Brachiaria decumbens*) and *Urochloa humidicola* (former *Brachiaria humidicola*). Nowadays these two exotic grass species aggressively cover areas where natural vegetation was predominant. The conversion of natural vegetation into homogeneous pastures also contributes to damaging nearby flooding ecosystems. Additionally, documented pollution with pesticides and toxic agricultural chemicals has caused the progressive deterioration of the natural environment of the Pantanal, including increased fish mortality [16].

Human occupation and land use within the floodplain of the Pantanal have facilitated the introduction of invasive species which alter ecological communities. This is the case of “Tucunaré” (*Cichla* spp), originally from the Amazon region, a voracious predator, feeding on native species [29]. Another exotic fish species registered in the Pantanal is the Amazonian “Tambaqui” (*Colossoma macropomum* Cuvier, 1916), and also the aquatic bivalve mollusc “Mexilhão Dourado” *Limnoperna fortunei* (Dunker, 1857), which was introduced into the Paraná-Paraguay rivers and has reached the Pantanal.

Environmental contamination with heavy metal, especially mercury used in gold mining, was detected in fish in the Pantanal [30], when gold mining was common in the northern floodplain. Along the Cuiabá River there were 700 functional gold-mining dredges. In the town of Poconé, unregulated gold mines have also contaminated the freshwater habitats with mercury. Approximately 50% of the fishes from the Cuiabá River and 35% from the Bento Gomes River were found to have mercury levels higher than 0.5 µg/g, which is beyond the international standard for contamination. Levels below 0.5 µg/g were found in fishes from the Paraguay River. Birds that feed on fish were also found to be contaminated [30]. Another study was made on mercury in the most consumed piscivorous fish species of the Pantanal and also confirmed fish contaminations [31].

Another important threat to the natural populations of fish in the Pantanal is the presence of artificial hybrids that are produced in pisciculture plants and then accidentally released into natural waterways. The two most conspicuous examples involve four very important species, including an alloctone one. The “Cachara” *Pseudoplatystoma reticulatum* and the “Pintado” *P. corruscans* form a hybrid usually called “ponto-e-vírgula” (semi-colon), because of the dot and slash mark they develop on the their flanks. The second example is a cross between the “Pacu” *Piaractus mesopotamicus* and the “Tambaqui” *Colossoma macropomum*, introduced from the Amazon basin, which were hybridized to form the “Tambacu”. Both hybrid forms are currently present in natural environments in the Pantanal, and even worse, interbreeding with the natural populations of the parental species. These hybrids represent a further threat to three very important native species, both ecologically and economically.

In general, however, the complex array of environmental and socioeconomic stressors threatening South American fishes and habitats, is still at a less desperate stage than in other large freshwater basins of the world [32]. Thus, this is the time to implement a conservation and management plan in the upper Paraguay River basin, rather than to search for a possible excuse to neglect it.

Fish migration versus agriculture and infrastructure

Reproductive strategies of Pantanal fishes can be categorized into four types. The first corresponds to the long-distance migratory species (“Piracema”) which annually migrate to the headwaters to spawn. Eggs and larvae are carried down by the water current and juveniles will grow in the highly productive lowlands. Examples of Piracema fishes are the “Cachara” *Pseudoplatystoma reticulatum*, “Pintado” *Pseudoplatystoma corruscans*, “Dourado” *Salminus brasiliensis*, “Piraputanga” *Brycon hillari*, “Piavuçu” *Megaleporinus macrocephalus*, and “Curimbatá” *Prochilodus lineatus*. The second strategy corresponds to fishes that perform small migratory movements between the flooded flatlands and the river channel to spawn during the flood season. Examples are the “Pacu-peva” *Mylossoma duriventre* and the “Tuviras” *Gymnotus* spp. The third strategy is to spawn in the flooded flats, during the flooding season, as occurs with the “Piranhas” of the genera *Serrasalmus* and *Pygocentrus* and the “Traíra” *Hoplias malabaricus*. Finally, some species of “Carás” of the family Cichlidae spawn in remaining grounds on the inundation flats during the dry period [33].

Upland habitat loss, where the headwater of rivers are located, has been drastic, since over 60% of its savanna (Cerrado) vegetation has been converted into pasture and croplands [34]. The native vegetation deficit was found to be severe and widely distributed across the plateau [35]. The deforestation on the plateaus impacts the Pantanal wetlands through hydrodynamic processes, for example, by the phenomenon of river avulsion. It causes the diversion of flow from an aquatic channel onto the floodplain, eventually resulting in new channel belts, creating alluvial megafan systems, as was the case of the Taquari River.

The fishes that are most affected by the construction of infrastructure, especially hydroelectric dams, are the long-distance migratory species. At the beginning of the wet season, a period of continuous rain occurring from October to April, fish schools of migratory species move upstream to spawn. These fishes are dependent on the quality of the water and they must find no obstacles to interrupt their migration upstream. In addition, water quality is fundamental, since the early stages (eggs and larvae) are highly dependent on water rich in oxygen, present in the nursery habitats. Many crop farms, mainly soybean, are established on the plateaus surrounding the Pantanal, where the headwaters are located. Herbicides and pesticides are applied to crop fields that reach the headwaters of the rivers which feed the Pantanal floodplain. There are documented publications on this effect on fishery resources [2,16].

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On the other hand, more than 100 SHiPs (Small Hydroelectric Plants) are planned for the rivers that have their headwaters on the surrounding. Most of this infrastructure is planned for the northern portion of the plateau [36], on rivers that are directly responsible for the annual floods of the Pantanal. The dams will interrupt the transport of sediments and nutrients downstream as well as the upstream movement of migratory fishes. The interruption in upstream fish migration will damage fisheries of important commercial fish, with high socioeconomic value, such as "Cachara" *Pseudoplatystoma reticulatum* and "Pintado" *Pseudoplatystoma corruscans*, among others. Migratory fish can cross the barrier created by the dam if a fish passage is included. However, even when a fish passage is in place, the number of eggs and larvae that cross the dam downstream, back towards the flooded areas, is very small [32,37]. The Manso River, linking the upland of Chapada dos Guimarães to the floodplain, an important tributary of the Cuiabá River, both draining to the Paraguay River into the Pantanal, has been dammed with a large hydroelectric dam and reservoir [38]. The reservoir and the river sector downstream from the dam show disturbance in fish ecological community structure as well as disturbances in the fish annual feeding and reproductive cycles caused by the regulatory role that dam operation imposes on the hydrological regime. The reservoir formed in a previously dry area now has an influence on the phenological rhythms of the surrounding vegetation, and it also alters the water quality and the seasonal phases of the hydrological cycle. The consequences of building such a large number of SHiPs will be catastrophic for the entire ecosystem, in regulating the annual pulse of floods of the Pantanal, in increasing the siltation already occurring in rivers like the Taquari [14], and imposing a heavy threat on all migratory fish species.

Fish migration versus deforestation of riparian vegetation

During the flooding season some species of fish leave the river bed and move into the flooded area to feed, because of the synchrony between fruit production and the flooding season.This is the case of the fruit-eating "Pacu" *Piaractus mesopotamicus*, one of the most important Pantanal fishes from the socioeconomic viewpoint, which forages on riparian vegetation during high-water periods. The main food item of the "Pacu" is the fruit of the palm tree *Bactris glaucescens* present in the riparian forest [39]. The small fish "Ximburé", an important prey of large carnivore fish, also feeds upon this fruit. Deforestation affects these species as they depend on the flooded riparian forest to feed upon fruits and seeds.

The productivity of the aquatic ecosystem in the wetland depends on two factors: (1) the amount of nutrients washed down by rivers from the headwaters on the surrounding plateaus, and (2) the extent of the Pantanal floodplain (lowland and its natural vegetation cover). Important fishes in the seasonally flooded aquatic ecosystems are detritivorous species that feed on decaying plant debris, followed by species of herbivores, and frugivores. In some surveyed areas, such as the Pantanal National Park, insectivorous fish accounted for 31%, omnivorous 28%, detritivorous 16%, carnivorous15% and herbivorous 8% [14]. Seasonal flooding is important to control productivity and food webs. The seasonally flooded areas favor fish habitats and the movements of water carry nutrients that supply feeding and reproductive niches for several species. During the movement of fish from the riverbed to flooded areas many fish shift feeding strategy. Thus, the feeding and reproductive niches change as a function of seasonal flooding. The negative impacts on the biogeochemical cycle, as consequences of clearing and burning of the vegetation cover, affect the ecology and the structure and function of fish assemblages.

The environmental disturbances that take place in highlands surrounding the Pantanal and their effects on the wetland are documented in other publications. These disturbances promote significant alterations in flood dynamics, ecosystem functioning, and ecosystem services [40].

Further evidence of the negative environmental impacts on fisheries is seen in the case of the Taquari River, an important tributary of the Paraguay River, which runs mostly in the wetland. In the period 1980-1984, the Taquari River supplied 16% to 32% of all fish catches in the Southern portion of the Pantanal (state of Mato Grosso do Sul). Later on, during 1994-1995, this river supplied only 6% of the total catches for that region (ANA - Brazilian National Water Agency, 2005). During that period of about 15 years there was a decline in catches in the order of 20%, mainly due to deforestation of the riparian forest and consequent erosion and siltation of the river. In 1982 the river's production was 2,300 tons, which decreased to 1,900 tons in 1984, decreasing again to 1,400 tons by1995. The large migratory catfish such as "Pintado" *Pseudoplatystoma corruscans* and "Cachara" *P. fasciatum* were mostly caught. Due to environmental degradation, the fish composition changed, with greater abundance of "Pacu" *Piaractus mesopotamicus* and "Curimbatá" *Prochilodus lineatus*.

Considering the historic trends inland conversion observed in the upper Paraguay River basin, based on data collected between 1976 and 2008, and if this trend continues, in combination with weak control, a complete loss of native vegetation can be expected by 2029 on the plateau and by 2045 on the floodplain [41].

Fishery decline and deficient implementation of fishing regulation

Fishing regulation enforcement is deficient due to the lack of a proper organizational structure by which to put the regulation and legislation into practice. Government officials, in charge of improving regulations, can rarely cover the entire wetland area, even throughout the year or especially during the period of the closed fishing season. When the first regulation on fishing gear (fishing accessories and equipment) was announced, in 1983, fishermen ignored it, arguing that it brought financial damages.

The main commercial fish species landed in 2000 and 200 and reaching the market of Cuiabá city, caught mainly in the basin of the upper Paraguay River, with the largest number

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from the Cuiabá River basin, were: "Pintado" *Pseudoplatystoma corruscans*, "Jaú" *Paulicea luetkeni*, "Cachara" *Pseudoplatystoma fasciatum*, "Pacu" *Piaractus mesopotamicus*, "Piraputanga" *Brycon microlepis*, "Barbado" *Pinirampus pirinampu*, "Dourado" *Salminus brasiliensis*, "Piavuçu" *Macroleporinus macrocephalus*, "Jurupensém" *Sorubim cf. lima*, "Jurupoca" *Hemisorubim platyrhynchos*, and "Curimbatá" *Prochilodus lineatus* [42]. That study also indicated a decrease in fish production in the years 2000-2001 in comparison to the high catch of the 1980's.

Fishery decline and overfishing

Fishing for "Pacu" *Piractus mesopotamicus* has been in decline due to overfishing since 1994 [43, 44]. Moreover, both commercial and sport fishermen claim that the size of captured fish has declined since a couple of decades ago, and the abundance of fish has decreased. A study analyzing data on the total length of the "Pacu", to assess the exploitation level for this species, confirmed that this fish is overexploited, so that restrictive measures are needed to manage fisheries. The overexploitation affects the potential catches, but also the population size reaching reproductive capacity [45].

In an attempt to control overfishing, the state of Mato Grosso do Sul passed laws forbidding the use of gill-nets in the period of 1983-1994. In the Northern Pantanal, the state of Mato Grosso also banned gill-nets in 1987. However, there is a study showing a conflict between fisheries in the Pantanal and policy-maker fishing controls to contest overfishing, claiming that controls are responsible for fishery decline, especially the reduction in tourist numbers for recreational fishing in the wetland [46].

Fishery and climate change

Wetlands perform many essential ecosystem services such as carbon storage, flood control, biodiversity maintenance, fish production, and aquifer recharge [47, 48]. Wetlands can be carbon sinks, with important implications for global climate change. The recent international conferences on climate change sponsored by the Intergovernmental Panel on Climate Change [6] indicate that it appears highly possible that the predicted climate change over the next decades may well cause additional damage to the Pantanal's aquatic ecosystems. In addition, recent studies emphasize the role of La Niña and El Niño Southern Oscillation on the climate of this wetland, with hydrometereological conditions exhibiting large internal variability in floods and droughts [49].

Conclusion

The environmental and socioeconomic threats identified here damage the Pantanal environment, favoring the decline of fishery resources, with consequent depletion of fish stocks. It is necessary to create a number of innovative solutions to elaborate a fair management plan to reach sustainable fisheries in the region. In the Pantanal, fisheries provide food for local people and income for commercial fishermen, as well as recreation for sport fishing. Unsustainable fisheries put those benefits at risk.

Regarding poor institutional governance, the present lack of trustworthy data on fish stock assessment control in the Pantanal is a gap to be filled, in order to develop an effective management plan. Overcapacity threatens the sustainability of fish stocks if fishing effort is not effectively controlled.

Outside the scientific forum based on published scientific information, around the Pantanal region, there are extreme positions on the concern over fisheries. On one extreme side, some people say that everything is fine, even arguing that the occasional scarcity of fish is due to the great number of caimans preying on fish; on the other hand, some call for a complete prohibition of fishery for a couple of years, a moratorium period.

The threats to biodiversity, including fish, are real and severe, and the Brazilian Ministry of Environment published an updated list of threatened species (PORTARIA 445 of the Brazilian Ministry of Environment of December 2014). However, instead of relying only upon list of threatened species, some Brazilian ichthyologists argue that it is essential that fishery stakeholders work to implement management strategies, which have been historically lacking in the country [50].

An innovative process in management rather than single solutions is recommended. Such multi-stakeholder dialogue is needed to reach an agreement that contributes to environmental sustainability. Fishery is a renewable natural resource, and if it is exploited under an efficient management scheme, it can generate a sustainable flow of socioeconomic benefits for local people. It also has to be recognized that, to enhance and enforce a management plan, with a collaborative approach, is not an easy task, with conflict and confrontation being part of the process. The innovative process has to consider the collaboration and inclusiveness in policy making to reach governance. The plan has to respect the scientific knowledge, perspectives and positions of different stakeholders, and many other actors and processes to develop the potential roles in contributing to sustainability.

The management plan has to consider the overall conservation requirements for the entire wetland, based on the scientific knowledge in the well documented recent publications. This includes a variety of methods of production and extraction, based on the biological characteristics of a given focal fish species. It must also emphasize ecological aspects such as seasonality, protection of reproductive and feeding habitats, and consider population parameters such as abundance.

When capacity to fish exceeds the available fish resources, under an inefficient fishing control, fishery declines and overfishing potentially occurs. Overcapacity threatens the sustainability of fish stocks if fishing effort is not effectively restricted. Fishery overcapacity is an impediment to the biological reproductive effort to restore the fish stock, therefore dissipating socioeconomic and ecological benefits. The prohibition of specific fishing gear alone is not enough to control overfishing and the decline in fishery resources. Gear modifications and other isolated measures are effective

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and successful if they work to the mutual advantage of fishers and the environment. This is a complex enterprise and this complexity can be only solved with the commitment of all actors. Top-down fishing restrictions focusing on a few fish species, through the limitation of use of fishing gear, are not enough to protect fishery resources.

The environmental and socioeconomic threats identified in this study have strong links with fish ecology, negatively impacting their biological cycles. The production of a management plan has to consider the scientific information available, necessary to understand how the Pantanal fisheries operate as an ecological system, and how the biological resources are regulated.

Important steps such as planning, consultation, and decision-making, distribution of tasks and resources, and formulation and implementation of rules for managing all fishing activities are relevant. The management scheme has to achieve environmental sustainability, the continued productivity of fishery resources, and the socioeconomic compatibility of the actors involved. A conservation plan is essential to deal with the stressors or threats identified here.

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