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Ecohydrological Processes and Sustainable Floodplain Management

Towards a sustainable management concept for ecosystem services of the Pantanal wetland

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Abstract

Among globally important wetlands, the Pantanal stands out because of it's a history of harmonious coexistence of man and biodiversity. In the recent years, however, severe human impacts have emerged, which are capable of disintegrating Pantanal's natural characteristics. This paper contributes to the development of a sustainable management concept considering ecological and socioeconomical demands. Use of natural resources in the highly productive catchment of the tributaries have direct effects on the floodplains of the Pantanal. A careful planning of hydropower plants is needed to maintain (a) some of the tributaries remaining open for fish spawning migration, and (b) the natural flood pulse as the overriding ecological factor. The traditional human population of the Pantanal is threatened by the developments of global change. Their knowledge to use floodplain-specific species is very important for developing sustainable use strategies. Several positive initiatives are highlighted, including the development of a green seal for Pantanal beef and the re-establishment of gallery forests along tributaries. The sustainable use of the fish ressources requires a precise analyis of the stock dynamics. For the further development of the sustainable use, a classification system is needed, which specifies the use potential and conservation demands of the individual habitats.

Key words: Pantanal, floodpulse advantage, traditional knowledge, biodiversity, adaptive management, Brazil, South America.

1. Introduction

The Pantanal is a large seasonal transboundary wetland that belongs mostly to the Brazilian States of Mato Grosso and Mato Grosso do Sul, and smaller portions to Bolivia and Paraguay (Fig. 1). The key driver for its ecological processes and its patterns of biodiversity is the floodpulse, i.e. the annual changes between drought and flooding, caused by seasonal rainfall patterns in the catchment of the Upper Paraguay River (Junk, Wantzen 2004). The floodpulse is monomodal with a drought period peaking in July to September, and a flood averaging about 1m flood height with variable peaks from December to March (in the Northern section of the Pantanal) and March to May (in the Southern Section). The pulse shape varies between years, and multi-year phases of drier and wetter years exist (Hamilton 1999; Wantzen *et al.* 2005; Junk *et al.* 2006). The alternating dry and wet stages cause a quick turnover of organic carbon. Biota in the Pantanal have been selected for adaptations to survive these alternating and harsh conditions (including bushfires during drought), and to make use of the supply of food resources and nutrients during the shifting between aquatic and terrestrial phases (Heckman 1994; Junk *et al.* 2006). A combination of flood-patterns and ecological engineering by aquatic macrophytes, termites and other ecological engineers manipulates the topography of the physical habitats, and the survival conditions of a rich fauna and flora (Wantzen *et al.* 2005).

The ecological integrity of the Pantanal, however, is continuously degrading. A series of environmental impacts affects its biodiversity and ecosystem functions (Harris *et al.* 2005; Junk *et al.* 2006; Junk *et al.* in press). Current economic changes, the connection of the national economy to international markets and climate change create new endeavours to the society of the Pantanal.

Several parts of the Pantanal wetland are currently preserved possessing the status of National Park, private reserve (RPPN), or indigenous reserves (Harris *et al.* 2005). And yet, existing conservation efforts such as the Pantanal National Park and nearby RPPNs are not enough to maintain this unique wetland for future generations. Over the past decades it has become clear that the Pantanal, a wetland with a very rigid wet-and-dry regime and low nutrient supply, is not suited for "regular" agriculture or intensive pasture, albeit efforts to transform its landscape units into "usable land" have already modified a considerable of its area by inadequate dike construction and deforestation. For example, attempts to plant rice in the 1970s (Antunes 1986) failed. It is not realistic to protect the Pantanal entirely as a National park either, as there are native and traditional human communities living within it. Even within the

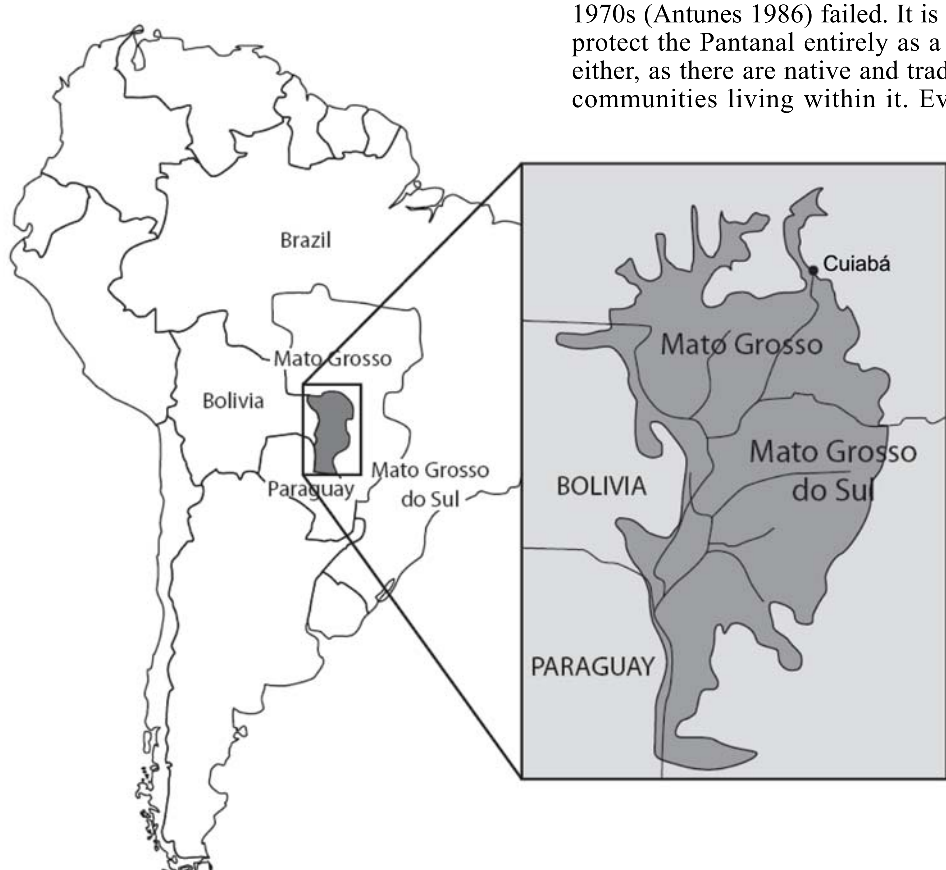

Fig. 1. Position of the Pantanal in the centre of South America.

existing reserves, it is very difficult to maintain the natural features due to a high pressure of users and an extremely low number of game wardens and material resources for protective measures.

Thus, a compromise between complete conservation and human use seems to be the most promising alternative for the future of the Pantanal. Notwithstanding, a considerable area needs full protection in order to protect those species that are sensitive even to minimal human impact. The word "sustainable use" has been raised as an "ideal" solution for landscape management concepts in the 1980's and especially during the first meeting of the Convention of Biodiversity (CBD) in Rio 1992. Meanwhile, the term "sustainable" has become one of the most abused and misinterpreted words in landscape management and recently, decision makers prefer to avoid this term. Efforts are needed to separate the euphemisms from feasible, real-world practices.

The purpose of this paper is directed towards subsidizing management programs and defing a new concept for the Pantanal, and, if already available, management solutions. The concept and management ideas gathered here are the result of a workshop on the elaboration of a sustainable management concept (SMC) for the Pantanal by practitioners from different fields, including scientists, NGO representatives, Federal and State institution responsible for conservation, and representatives of the ranchers of the Pantanal. It was held in Chapada dos Guiamarães on 26 and 27 July 2007 and addressed the following topics:

- Definition of "sustainability" in the Pantanal context
- Area to include for sustainable management of the Pantanal
- Ecosystem services offered by the Pantanal
- Classification of different landscape units as a baseline for a SMC
- Water-related issues
- Biogeochemistry
- Aquatic food webs and native fish production
- Terrestrial food webs and cattle production
- Traditional and alternative use of the natural resources
- Bioindicators for sustainable use
- Sustainable use and/or conservation

2. Elements of a Sustainable Management Concept (SMC) for the Pantanal

What does "sustainability" mean in the Pantanal context?

The "pantaneiros", i.e. the local population of the Pantanal originate from native tribes and Portuguese, Spanish and African settlers in the past 300 years (Costa 1999). They have empirically developed specific methods to use the different structures and ecosystem services of the Pantanal without destroying its ecological functions and values. Sustainability of traditional management was not a declared goal by the Pantaneiros as this term did not exist when their methods were developed, it was rather the adaptation of management practices to a harsh and seasonally changing environment. The sustainability of the traditional management system has not been assessed in scientific detail; however history proves that this kind of management has preserved the features of the Pantanal until today (Rosetto, Brasil Jr. 2003; Rosetto 2006; da Silva, Silva 1995, and see discussion on a "flood culture below").

For example, the migration of small floodplain fish species into the main water bodies during new moon nights in April each year ("lufada") was regularly used by collecting fish with baskets (Wantzen, Junk 2006). Due to the limited temporal and spatial extension of this sampling and the focus on small floodplain fish species that were not used otherwise, it did not influence the entire fish population. A series of highly specialized fishing gears was developed, which allowed the selective hunting (and population control) of individual fish species. For cattle production during the dry season, a cattle race (tucura) was used that was adapted to the climatical conditions and, having a small body size, had a lower trampling impact on the soil than races currently being used. Natural pastures were enlarged by deforestation however only in transitional areas. Man-made bushfires were a traditional landscape management practice by the native tribes during the dry season (Fleming 1999) that kept the amount of fuels low, so that fires did not severely damage the fire-adapted woody species however controlled fire-sensitive species such as *Vochysia divergens* (Nunes da Cunha, Junk 2004). Poaching losses of large carnivores such as jaguar and cougar, and the nearly extinct giant otter for fur trade occurring in the 1970's were mainly caused by groups coming from outside the Pantanal, whereas the *pantaneiros* used of beef rather than game as animal protein supply. Overall, the low human density warranted that human impacts were low.

Today, this situation has changed completely. The use of heavy machines allows fast deforestation during the dry season (Silva, Abdon 1997). Dikes inside the wetland and dams on the tributary rivers change the key ecosystem driver of the wetland, the floodpulse (Junk *et al.* 2006). According to both the Ecohydrology Concept (Zalewski *et al.* 1997; Zalewski 2002) and the Floodpulse Concept (Junk *et al.* 1989; Junk, Wantzen 2004; Wantzen *et al.* 2008), hydrological patterns are the overriding factor in structuring the organismic communities in floodplains, and - *vice versa* - floodplain plants may influence the flow patterns (Zalewski *et al.* 1997), e.g. main channel blockage by macrophyte mats changes the hierarchy of floodplain channels and triggers opening of new channels in the Paraguay River (Wantzen *et al.* 2005).

There is a large range of environmental impacts effecting both on the catchment of the tributaries and in the main wetland area. To name the most important ones, change of the flooding regime, the dwindling size of natural areas, massive sediment and pesticide inputs from the catchments, deforestation, overfishing of some important species, poaching, and regional overstocking with cattle have to be mentioned (see detailed analysis by Alho *et al.* 1988; Hamilton 1999; 2002; da Silva 2000; Seidl *et al.* 2001; da Silva *et al.* 2001; Laabs *et al.* 2002; Harris *et al.* 2005; Junk *et al.* 2006). The continuous degradation of the ecological integrity in the Pantanal coincides with the obvious but badly documented loss of its biodiversity.

The term "sustainable development" was first used by the Brundtland Commission (World Commission on Environment and Development 1987) as "economic development that satisfies the needs of the current generation without reducing the possibilities of future generations to satisfy their own needs". This statement recognizes the physical and biological limits of growth (Meadows *et al.* 1972). The Consultative Group on International Agricultural Research (CGIAR) corroborates this definition by defining sustainability as the "efficient management of the resources for agriculture to satisfy the variable needs of the humanity and at the same time to maintain or improving the environmental quality and to maintain the natural resources". Ecologists and economists often have different views on sustainability: While ecologists mainly think about the maintenance of biodiversity and natural resources, the economists generally consider the maintenance of an enterprise, which can switch from one (natural) resource to another when the first resource has been completely exploited (Malik 2007). This misunderstanding shows the multidimensionality of the problem. The needs of the different societal groups are variable and often contradictive. As indicated in both definitions of WCED and CGIAR, the satisfaction of the needs of the human population is an important element of sustainability (Clüsener-Godt, Sachs 1995).

For the definition of sustainability in the Pantanal, (at least) four aspects need to be added to these considerations: maintenance of (a) biodiversity, (b) natural dynamics, (c) cultural diversity, and (d) adaptability. The Pantanal is an intrinsically diverse system. The floodpulse with its annual and multiannual variations provokes the synchronous existence of different successional stages, thereby it creates a high diversity of habitats, in which the populations and biomass of which are submitted to permanent changes (Junk, Wantzen 2004; Junk *et al.* 2006). The prime characteristics of the biota of the Pantanal (including the local human population) is their adaptedness to multiple stressors such as drought, flood, fire, and scarcity of nutrients (Junk *et al.* 2006). Maintenance of stable conditions, especially in hydrological terms, withdraws the selective advantages of their species traits and opens the gates for the invasion of exotic species that can quickly outcompete these dynamic-requiring species. A vivid example is the invasion of the Camargo Correia farm and other areas near the Transpantaneira road by a low-diversity shrub community after changing the natural hydrological variation by dike construction (Junk, Nunes da Cunha 2005; Nunes da Cunha *et al.* 2006). The Pantanal is not only subject to annual water-level-fluctuations but also to multi-annual phases of generally wetter and dryer years (Hamilton 2002; Wantzen *et al.* 2005; Junk *et al.* 2006). Therefore, a sustainable management concept does not mean the strict maintenance of the current status quo forever but it includes the possibility that the natural biota adapts to overall changes, especially climate change, due to an adaptive management system fostering the natural resilience of the ecosystem. This also applies for the cultural dimension, which includes dynamic elements that are constantly restructured, by selecting and incorporating new values, habits, and techniques that become traded to the next generations (Rosetto 2006).

Unfortunately, many recent landscape management practices contradict the basic principles of the functioning of the Pantanal, e.g. the increasing number of impoundments of tributary rivers reduces the natural variability of the floodpulse, thus the dynamics of the system. This prevents the natural communities from being selected by the natural dynamics, and consequently weakens the adaptability of the entire system towards future changes.

Different approaches for the upper part of the catchment ("Planalto") and for the wetland ("Pantanal")?

The catchments of the tributary rivers to the Pantanal wetland drain one of the most intensively used agricultural areas, the so-called Planalto (high plain, Nepstad *et al.* 2002) in the upper catchment of the Paraguay River. Thus, most of the environmental problems of the Pantanal arise from the catchment areas (e.g. damming of tributaries, erosion and siltation, pesticide use, see Fig. 2). Natural processes in the Pantanal, such as colmation of the riverbeds, inundations, sedimentation and river braiding are sped up by the human impact in the Planalto.

There are two confronting concepts of the term Pantanal in the context of management and conservation. One includes only the wetland area (158 592 km^2), the second includes the entire catchment of the upper Paraguay River (624 320 km^2). From this bias, conflicting scenarios arise for the management of the Pantanal. While the wetland is still under relatively low use pressure, the highlands (465 728 km^2) are intensively used. Therefore, the 'floodplain-only scenario' allows more rigid recommendations for the conservation of nature; while the 'whole-catchment scenario' needs to consider the requirements of the farmers that produce the major part of the net income of the gross domestic product of the States of Mato Grosso and Mato Grosso do Sul. The harvest season 1998-1999 put the State of Mato Grosso on the first rank of soy bean and cotton producers, rank 2 of rice producers and rank 3 of grain, oil and fibre crops of Brazil. Soy production has flourished in the past years (Fig. 3.) and sustainable use and conservation concepts need to provide economic incentives for the farmers of the highly productive Planalto region that allow them to dedicate parts of their intensively used acres into vegetated buffer zones (Wantzen *et al.* 2006). In the case of the beef production, there is a linkage between the Pantanal and the *terra firme* area in the surroundings of the wetland, as during strong flood events, the cattle becomes transferred from the wetland to the *terra firme* pastures (causing enormous costs for the Pantanal ranchers). The farmers' and ranchers' federation of Mato Grosso (FAMATO 2008) recently reported trends that 1.9% of the cattle production of the state (half a million heads of cattle in 170 out of 110 000 ranches) employ techniques including the use of fodder that is produced by recycling side-products of the sugarcane, corn, and cotton production, in order to reduce the area needed to raise cattle. The same report claims the strengthening of the linkages between different areas of agricultural production, and an improvement of the logistic and transport conditions, which could be achieved by formation of new partnerships and strategic alliances, including commercial agreements between countries in order to adapt hygienic patterns and to facilitate exportation.

There is a considerable debate whether the same measures can be applied to both wetland and catchment, as suggested by several NGOs. During the workshop in Chapada dos Guimarães, unanimous consent could not even be established among the 25 participants! Rather, the discussion theme was complemented by the fact that whithin inside the wetland, the sensitivity to human impacts (including different use forms) largely differs among the variable habitat types. The result was that a decent characterization scheme of both areas would allow to define tolerable degrees of management impacts in different habitat types of the entire catchment, however most suggestions made here focus on the wetland area.

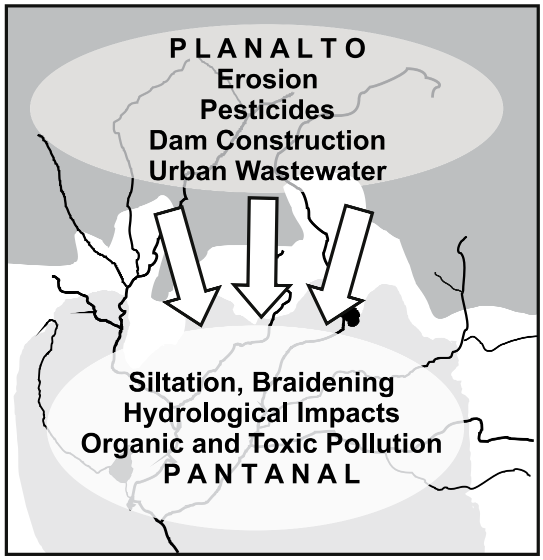

Fig. 2. Many environmental problems of the Pantanal derive from the Planalto high plains from which the tributaries to the Paraguay river originate. Modified from Wantzen (2003).

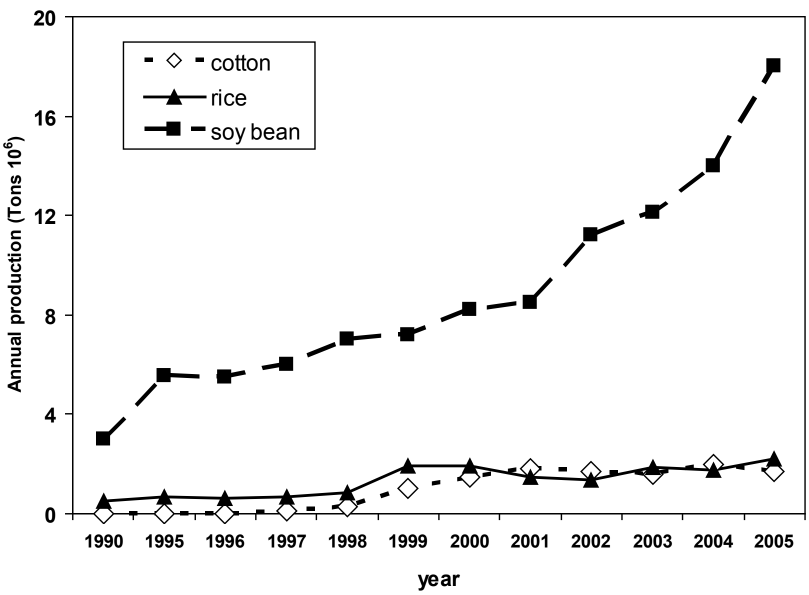

Fig. 3. Major crop yields in 1995-2005 in the State of Mato Grosso. Note the non-continuous scale on the time axis. Modified after Caovila (2007) based on data by Brazilian Institute for Geography and Statistics (IBGE).

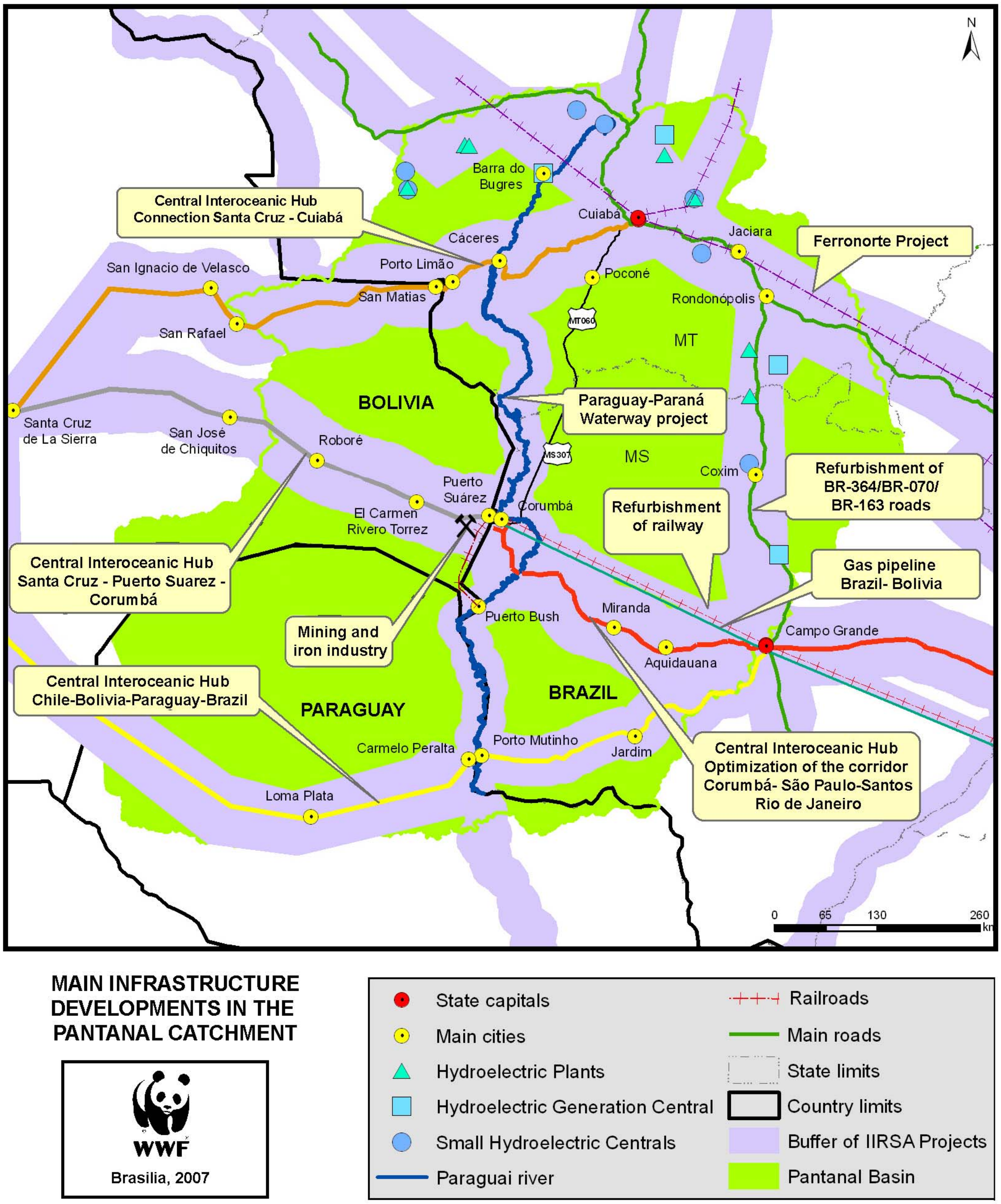

Fig. 4. The Pantanal at crossroads between several national and international transport projects. Data and graph provided by M. Becker, WWF-Brasil, based on Mendes and Johnston (2002)

An alarming fact is that the Pantanal lies on the crossroad of current developmental plans. It is the geodesic centre of South America, and several plans exist for waterways (see Lourival *et al.* 1999; Hamilton 1999; Gottgens *et al.* 2001), gas pipelines, highways railways, mining and iron complexes. Figure 4 illustrates the full complexity of the development options that are being planed for the region and its cumulative effect will shape the Pantanal catchment in medium and long terms.

Ecosystem services offered by the Pantanal

The Pantanal provides a range of ecosystem services that have supra-regional importance. The most prominent one is the buffering of hydrological changes (both annual floodpulse and multi-year cycles). The Pantanal is a vast plain that becomes flooded by rain and river water. During the flood, it stores large portions of the flood water, conveys another part to evapotranspiration and groundwater, thereby lowering the crest of the hydrograph of the Paraguay river and retarding it for about three months compared with the Paraná river. The Paraná receives rainwater approximately at the same period as the Paraguay river, however it lacks such an extensive floodplain (Drago 1990). All cities at the Paraná river below the confluence of both rivers at Corrientes profit by this buffering effect, as the two individual flood peaks can be handled much easier than if they were synchronized. It can be speculated that if the buffering effect of the Pantanal would not exist, the flood levels of these cities would be much higher. The Pantanal is "the largest evapotranspiration window in Central South America" (Por 1995) and neither this contribution to buffering the regional temperature regime nor the contribution of the Pantanal to the groundwater have been fathomed yet. By acting as a natural sink for sediments, the Pantanal reduces the sediment load of its tributaries. The importance of the Pantanal as an infiltration area for groundwater is still poorly understood however it can be surely assumed that it contributes substantially to refilling the regional aquifers.

Secondly, the Pantanal is a biogeochemical switchboard and a gigantic water purification plant. It is a huge area being shallowly flooded every year with water of very different provenience, including nutrient-poor to nutrient-loaded waters (Hamilton 2002). Dense aquatic macrophyte mats are covered by biofilms and act as huge bioreactors that are equipped with steep redox gradient to process all kinds of incoming dissolved organic and inorganic substances at high water temperatures. Biogeochemical turnover processes occur very fast in the Pantanal due to biogeochemical and biotic hot spots and hot moments (McClain *et al.* 2003; Wantzen, Junk 2006) - Fig. 5. In spite of the (yet) low clearing rate of organic waste water by the cities neighbouring the Pantanal, the organic pollution below the cities is still relatively low due to this autopurification capacity of the Pantanal rivers. However, the large amounts of coliforms below the cities clearly indicates that it is necessary to foster water purification in specific clearing plants (Figueiredo 1996; Zeilhofer *et al.* 2006).

Thirdly, the aquatic food webs in the Pantanal are highly productive in spite of nutrient poverty in large parts of the region. A major output of these food webs is a large production of fish that sustains the protein demand of the human population inside and in the vicinities of the Pantanal (Mateus *et al.* 2004; Wantzen *et al.* 2002). Moreover, fishing has shaped the social structure of the traditional communities and subsistence fisheries is an important gender issue. Fishing women and children substantially contribute to the daily protein uptake of families living in the Pantanal and the neighbouring towns (Calegari 1998). It is worrying that a large part of the fisheries tourism is performed near the reproductive and nursery areas of the economically most important species, i.e. near the Pantanal National Park. Another problem with recreational and professional fisheries in the Pantanal is that it is focused mostly on migrating top predator species, such as the dorado *(Salminus brasiliensis)* and catfish *(Pseudoplatystoma corruscans)*, or on the pacu *(Piaractus mesopotamicus),* which is suggested to be an important seed disperser (Galetti *et al.* 2008).

The productivity of the terrestrial food webs of the Pantanal is a forth type of ecosystem services. In floodplain food webs, the terrestrial organisms are specialized on rapidly using the resources released by the phase change from wet to dry. Terrestrial vegetation quickly uses the available nutrients from decomposition of aquatic organisms, and in turn this fresh vegetation yields the highest growth rate for herbivores including cattle. The human use of this ecosystem service is - so far - mostly focused on cattle production (Remppis 1995).

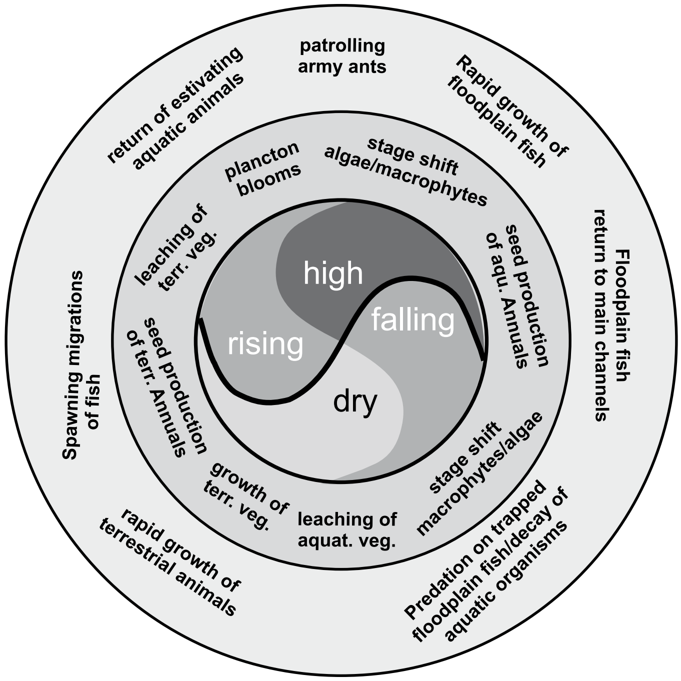

Fig. 5. The floodpulse-driven wet-and-dry cycle in the Pantanal provides a rather high productivity in spite of low nutrient levels, as its organisms are adapted to avoiding losses by drought or water stress and to efficiently profit by the floodpulse-derived resources. Modified from Wantzen and Junk (2006)

The fifth pillar of ecosystem services is its biodiversity. Even though the diversity of some taxa is relatively low in the Pantanal compared with more stable ecosystems, the overall numbers of species richness are impressive (Junk *et al.* 2006; Junk *et al.* in press). For some animal and plant groups it has become clear that the diversity has not been fathomed yet in due detail. The potential use of biodiversity is manifold. Good field conditions to observe large quantities of piscivorous bird and reptile species have opened the doors for an intensive eco-tourism, which is still in its infancy in the Northern section of the Pantanal. Whether this use is sustainable or not, needs to be examined case by case. The integrity of the ecosystems of the Pantanal and the large populations of rare species (jaguar, hyacinth macaw, marsh deer, giant otter etc.) make the wetland a "Noah's Ark" for the surrounding seasonal wetlands, i.e. the Pantanal can serve to recover extinct populations of these species in other areas of South America. Many species of the Pantanal certainly hold potential economical use for the future which has not been analyzed yet. Other ecosystem services provided by biodiversity (e.g. biodiversity effects on biodiversity; productivity; soil quality; water quality; genetic storage; climate; water cycle; nutrient cycle; human goods (medicines, food, recreation) have been analyzed in other ecosystems (e.g. Amazonia, Junk *et al.* 2000; Prance 2002), and can be assumed to be valid in the Pantanal, too.

Diversity also encompasses cultural diversity. The Pantanal unites a large array of cultural adaptations to the life in a wet-and-dry seasonal floodplain. From the early native tribes on, the human population has developed techniques to use floodborne resources and makes variable use of the natural resources, e.g. the use of the acuri-palm (*Scheelea phalarata*) by the Guató tribe (Schmidt 1912;1914).

Proposal: Classification of the different landscape units as a basis for sustainable management for the Pantanal

The scientific baseline for a sustainable management of the Pantanal requires a classification of its ecological complexity into a concise and transparent system that allows a quantitative and qualitative analysis of the human impacts on the different compartments of the ecological system. This baseline gives value to the empirical knowledge already used by the traditional human population of the Pantanal. The units created by this system form ecoregions that unite different proprieties or parts of them.

The classification is primarily based on hydrological patterns (flood-drought). In the second level, it is the chemistry of soil and water that defines the composition of the species and the productivity of the different units. In the third level, large plant communities are used for classification, as they lastly define the habitat types on the fourth level, which are the central target of the management measures. Some of these habitats occur in restricted areas with key functions that need to be fully protected, for example, *cordilheiras, capões* and all system units that store and distribute water (e.g. lakes, floodplain channels etc.). Others may be used in a selective way, e.g. for the extraction of wood and non-wood-products. The third group of habitats occurs in extensive areas and is subject to natural fluctuations in a larger scale. These habitats may be modified to certain degree without negative impact to the ecological integrity of the Pantanal, e.g. brushcutting of *campo sujo de cambara, campo sujo de canjiqueira* and different types of *espinhais* (for definition of these terms, see Nunes da Cunha *et al.* 2007). Adoption of the hierarchical habitat classification system will serve as an instrument to develop future ecological studies, subsidize the environmental legislation, analyse the impacts of management both in the Pantanal and the surrounding *terra firme* areas, and to recommend environmental measures for mean-term and long-term planning respecting the socio-economic wellbeing of the human population of the Pantanal. Positive examples for this habitat-classification-based management schemes already exist for the Northern Pantanal (Nunes da Cunha *et al.* 2006).

Water-related issues

The natural rhythm of the water level (natural floodpulse dynamics) is the key component for the ecological integrity of the Pantanal. Hydrological sustainability of the Pantanal (the water cycle) depends on the management of the entire catchment of the Upper Paraguay River and not only of the floodplain area. Therefore, the maintenance of these natural floodpulse dynamics needs to be included into laws and relevant standards. The natural hydrological variations, both in annual and multi-year scales, must be maintained to guarantee the coexistence of diverse species and ecological processes.

The dramatic recent increase of small and large hydroenergy power plants (Table I., Fig. 4.) causes concern because of the cumulative effects, including the weakening of the flood pulse, erosion of river channels below the dams and the interruption of longitudinal connectivity of the rivers that impede the natural spawning migrations of many fish species of the Pantanal (including most commercially important species). Untimely floods of the Cuiabá River caused by reservoir operation of the Manso dam above Cuiabá during the low water phase have killed large numbers of fledgelings of black skimmer

Table I. Status of existing and planned hydroelectric power plants in tributary rivers to the Pantanal in 2003 and 2007 (data by Brazilian Agency for Electrical Energy (www.aneel.gov.br), summarized by Girard (2005; in press).

Watershed	Dams in 2003			Dams in 2007		
	> 1 MW	> 100 MW	operating	> 1 MW	> 100 MW	operating
Correntes	3	1	0	3	1	2
Cuiabá	5	1	3	8	1	4
Itiquira	1	1	0	1	1	1
Jauru	6	1	1	6	1	5
Paraguay	11	0	4	10	0	4
São Lourenço	4	0	0	14	0	5
Taquari	1	0	1	1	0	1
Total	**31**	**4**	**9**	**42**	**4**	**22**

(Rynchops niger) when their nests on the sand banks became washed away.

Concerning the water balance, it is important to maintain the functions of the wetlands as a hydrological buffer both in the headwater region and in the Pantanal floodplain, including the important function of the floodplains for evapotranspiration and regulation of the regional climate. For the headwater regions, we suggest the use of the erosion combat and catchment management concept for Pantanal tributary rivers as given in Wantzen *et al.* (2006) including a rigid conservation of the marshy campo and *vereda* wetlands, replantation of cerrado vegetation in the transition zone between the acres and the veredas, and the employment of vegetated (grassy) buffer strips. Current activities of the state environmental protection agencies (e.g. SEMA in Mato Grosso and the Taquari recovery Project leaded by COINTA in Mato Grosso do Sul) for replantation need to be reinforced. Moreover, an initiative by the FAMATO called Instituto Ação Verde is currently performing replantation of gallery forests in the Rio Cuiabá catchment (www.acaoverde.org.br), which can be seen as a positive signal for future replantation activities.

Therefore we suggest to select river systems to be kept entirely open (i.e. without any dams) to water, sediments, and especially for migrating fish. Run-of-river hydroelectric power plants (*fio d'água* i.e. maintaining the water flow) should be preferred in all cases. The management of the reservoirs needs to follow the natural hydrograph (Bunn, Arthington 2002; Zalewski, 2002; Junk, Wantzen 2004; Collischonn *et al.* 2008). Girard (2002) has developed scenarios for the future development of the discharge of the tributaries to the Pantanal. In his "business as usual" scenario, the impact would be very high, and several large dams would be built that produce hydroenergy far beyond the regional demand. In an alternative "intelligent energy" scenario, these large dams would not be built, and most smaller hydropower plants would employ the *fio d'água* technique, thus reducing the average residual time of the water, the modifications of the minimum and maximum flows and the number of impassable dams for fish to nearly half of the values of the "business as usual" scenario (Girard 2002). Zeilhofer and Moura (2008) have provided an analysis of the hydrological impacts of the Manso dam, and given a scenario how to manage the dam in a more sustainable way. Collischonn *et al.* (2008) have discussed the environmental flows concept (Bunn, Arthington 2002) in the context of the Pantanal watersheds and have analyzed the conflicts to be solved (Table II.) and a six-step-procedure how to develop an adaptive management procedure for the water resources in the catchment of the Upper Paraguay. More recently, an expert group met during the INTECOL Wetland Symposium at Cuiabá, 2008, and developed a precise research task list for hydropower management in the catchments of the Pantanal tributaries (http://www.unemat.br/prppg/docs/publicacoes/recomendacoes_UHEs_pantanal5.pdf).

The Pantanal floodplain has a natural variation between flowing and stagnant water bodies. Due to the little declivity of the landscape, this pattern has a very high spatiotemporal dynamic, i.e. flow direction and flow/no-flow phases of floodplain habitats vary frequently during the flood cycle (Wantzen *et al.* 2005). Dike roads in the Pantanal impede these flow dynamics. The Transpantaneira Road that crosses 140 km of the northern section of the Pantanal initially had bridges only at river crossings. The more than 100 bridges existing today were build at flow concentration areas, however the blockage of the superficial discharge has completely changed its vegetation, with very negative consequences for biodiversity and sustainable cattle management (Nunes da Cunha *et al.* 2006). More recently, the "estrada parque" (i.e. a road that is declared a conservation unit at the same time) at Barão de Melgaço was also built without bridges. Therefore the SMC suggests to reduce or even remove dike roads if possible, to consider the superficial flow patterns of the Pantanal whenever roads are constructed (sufficient number of bridges), and to prefer roads (or road sections) that are built on stalks.

Table II. Conflicts arising from different requirements of human users and nature considering different natural and artificial hydrological situations (Collischonn et al. 2008)

Situation	Energy supplier/cities	Nature
Water withdrawal during low water period	power generation, irrigation	minimum discharge needed (environmental flows)
Large floods	stored in reservoirs to avoid inundations in cities	floodplain inundation and connectivity between lakes and rivers (fish productivity)
Small floods at the beginning of the rainy season	used to recover water storage in the reservoir	timely floods needed as triggers for fish spawning migrations
Frequent discharge peaks from the power plant (untimely floods)	management according to energy demand	should be avoided as they impair the use of floodborne resources and cause mortality
Permanent high discharge from reservoir during low water period	management according to demands of navigation	should be avoided as it impairs the use of resources in dry-fallen habitats
Increased discharge from reservoir at the end of low water period	necessity to create volume in reservoir for coming floods	would impair the use of resources in dry-fallen habitats

Another urgent issue is the treatment of waste water. In spite of a high autopurification capacity of the Pantanal rivers, which (still) reduces the impacts of the large inputs of untreated sewage, alarmingly high numbers of coliforms downstream the city of Cuiabá (especially during the low water period) indicate the urgent need to foster the installation of sewage treatment plants (Figueiredo 1996). Special care is needed to recover urban streams, which have been transformed into concrete channels with extremely bad water quality. River names like the *"Córrego do Barbado"* (named after the catfish species *Pinirampus pinirampu*) remind us that in earlier times fish were frequently seen in these channels. Elevated concentrations of phosphorous and chemical oxygen demand (COD) as indicators of organic pollution can be observed as far away as the Pantanal floodplain, about 120 km downstream from the urban agglomeration Cuiabá/Várzea Grande (Zeilhofer *et al.* 2006), in spite of the fact that there are significant current efforts to improve the coverage of wastewater treatment in the State of Mato Grosso (current average: ca. 15%). In the past 10 years, the coverage in the city of Cuiabá increased from 38% to a projection of 58% by the end of 2008 (Caovila 2007). Concluding from her thorough revision of the current situation of sanitation in the State of Mato Grosso, this author suggests a catalogue of measures including (a) a revision of the legal situation in order to have a better control on the efficiency of private sanitation enterprises, (b) to create a central register for the information about sanitation, (c) to foster municipal and basin commissions for the implementation or improvement of the sanitation infrastructure, (d) studies on the self-purification capacity and discharge of the catchments in order to assess the risk of groundwater contamination and to prioritize the most urgent constructions of wastewater treatment plants, (e) to foster low-cost solutions for water disinfection and sanitation in precarious urban and rural zones, (f) to improve environmental education programs to combat the loss of drinking water, including recycling and separate collection of waste products, to minimize the per capita production of waste, and (g) to continue studies and actions on surface and groundwater yields, and assessment of collected and treated waste water.

Biogeochemistry, soil diversity, and land use possibilities

The alternation between aquatic and terrestrial phases facilitates the mineralization of organic matter in the Pantanal, and the cyclic release of important nutrients (Nogueira *et al.* 2002a). Changes of the flood pulse would disturb the natural cycles of carbon and nutrients. Significant carbon storage occurs mostly in permanently flooded areas and forests. These areas are threatened by drainage (Hamilton 1999; 2002) and by inadequate use of fire. Current predictions on increased drought in the Central-Western region of Brazil (IPCC 2001) raise concern about the future of the important functions of the Pantanal as hydrological and biogeochemical buffer. In spite of an increasing body of recent studies, the current knowledge is still scarce; however it is sufficient to claim a better protection of the hydrological cycles from a biogeochemical perspective. Moreover, facing the climatical changes, we suggest analyzing the function of the Pantanal as a carbon stock in detail.

The soils of the Pantanal are defined by the type of source materials from the catchments of the tributaries and by the processes of sedimentation. Thus, several regions of the floodplain have received different types of sediments (regarding sand, clay, and mineral concentrations) resulting in different water and nutrient exchange in the soil profiles. The soils are, in the majority, influenced by the hydromorphism, favored by the flat relief and the seasonal flooding. Only where the forms of relief are slightly more elevated, represented by "cordilheiras", soil profiles are well developed. Morphological features of seasonally reduced soils include specific colour patterns, odours, colour changes that occur on exposure to air, or a specific kind of organic material.

High sodium contents are observed locally particularly in the Southern Pantanal. They occur when evapo-transpiration equals or exceeds effective rainfall. Under the influence of evaporation, the concentration of solutions and associated chemical precipitations are identified as the main factors responsible for the geochemical variability in this environment (Barbiero *et al.* 2002). Studies aiming at proposing a model to explain the high pH in sodic soils of the Pantanal showed that the concentration of the alkaline sodic salts strongly restricted the presence of bivalent cations in solution due to precipitation mainly of calcium carbonate (Guerrero-Alves *et al.* 2002). These soils, identified as solonetz, are susceptible to clay dispersion which leads to sealing, crusting, low permeability, high bulk density and low porosity (Rengasamy, Olsson 1991). Sodic soils also tend to have high soil erodibility. Hence, it is important that farmers have some familiarity with the properties, development constraints and management practices appropriate for these soils (Lobato 2000).

Apart from the changes in soil quality deriving from the impacts in the upper parts of the catchment (inadequate use of the soils, gold mining, deforestation, inadequate use of pesticides), there are severe and direct impacts affecting the soil in the Pantanal floodplain, such as increasing plantation of exotic grasses, deforestation of *terra firme* islands and levees, and especially the transformation of the *campos de murundus* into pastures (see Nunes da Cunha *et al.* (2006) for terminology of landscape units). The soils are the basis for the development of the vegetation and the habitat structure. Therefore, the inclusion of the soil types into the classification of the habitats in the Pantanal is essential for sustainable use.

Aquatic food webs and native fish production

The wet-and-dry cycle favours the reuse of organically bound nutrients in the Pantanal. When the water level rises, many fish species directly use terrestrial resources in the recently inundated floodplain, e.g. terrestrial insects (Wantzen *et al.* 2002) or fruits (Galetti *et al.* 2008). Moreover, the primary and secondary production of biofilms on the surfaces of aquatic macrophytes and of plankton are triggered by quickly released nutrients during the flooding (Heckman 1994; Nogueira *et al.* 2002b) and form the base for a species-rich food web including more than 260 fish species and numerous piscivore reptiles and birds (Britski *et al.* 1999; Junk *et al.* 2006). The use of the fish resources is one of the most traditional use forms in the Pantanal, however only from the 1960's on, with the installation of ice plants in the region, that fishing became commercially important (da Silva, Silva 1995). Nowadays, there are four kinds of fishing in the Brazilian Pantanal: subsistence, occasional, commercial, and recreational (Mateus, Penha in press). Depending on their necessity, the subsistence and occasional fishermen can contribute to the commercial fishery. Since there are no industrial fisheries in Brazilian Pantanal, all of the different fishermen groups are artisanal fishers.

Fishing in the region is of small-scale, scattered along the basin, and focuses on approximately 20 fish species (Petrere *et al.* 2002; Mateus *et al.* 2004). Although catches in the past were carried out by a wide variety of different strategies, legal restrictions currently restrict fishing basically to hook-and-line (Ferraz de Lima 1987; da Silva, Silva 1995). Fish are caught chiefly in the main channels of rivers, while the macrophyte belts of lakes are used for catching bait fish during floods. An unpublished economic analysis suggests that the commercial and recreational fishery in Mato Grosso and Mato Grosso do Sul yielded about US$ 230 000 000 per year by end of 1990s, with only US$ 6 900 000 (3%) deriving from commercial fishery and the largest part coming from the recreational one (Hasenclever *et al.* 2002). The same study revealed that the recent fish yields of the most important species, the Pacu *(Piaractus mesopotamicus)* shows a strong decrease (of approximately 12% per year) indicating that even using the most conservative scenario, with high discount rates and reproductive capacity for the species, resulted that 'business as usual' harvesting is anti-economical, leading to future losses larger than present gains. Other studies show that in spite of a limitation to fishing methods, the fish yields (data are only available from Mato Grosso do Sul, see Fig. 6.) continuously decline since 1999 (e.g. Campos *et al.* 2003 and literature therein). The Pantanal National Park, which is one of the most important reproduction and growth sites for the Pacu, lies at the border between the Brazilian abutter states of the Pantanal, and its surroundings are much sought after by large numbers of fishing tourists. Photographical records and memory protocols of old fishermen indicate that not only the catch size but also the average size of the large predatory fish species (especially pimelodid catfish species, and the dourado, *S. brasiliensis*) has dramatically declined in the past 40 years. The four largest catfish species *P. corruscans, P. fasciatum, Pinirampus pinirampu* and *Zungaro jahu* belong to the most sought-after fish in the region. Recruitment models for the Cuiabá River showed that *P. fasciatum* and *P. pinirampu* are in imminent threat of overfishing, while the other two species and the smaller pimelodid species *Hemisorubim platyrhynchos* and *Sorubim cf. lima*, are not (yet) overexploited (Mateus, Penha 2007a, b; Penha, Mateus 2007).

Solutions to this unsustainable use of the most important fish species are hampered by the lack of a joint management plan by the abutting owner states of the Pantanal (two Brazilian states, Bolivia, and Paraguay) that is legally binding. Precise information about the fish stocks (which migrate between these territories), and the carrying capacity of the system as a baseline for a science-based definition of Total Allowed Catches (TACs) are hardly available. Moreover, the economical return of recreational fisheries is much higher than the yield by the declining professional fishermen who have a long-term interest in maintaining the fish stocks. This leads to a decline of the traditional fisheries, and at the same time, much of the knowledge about behaviour, reproductive strategies and life cycle of fish is lost.

A solution to this multifaceted use conflict is urgently needed. Our suggestions to contribute to a sustainable management of the fish stocks in the Pantanal (including the maintenance of large reproductive stocks) include several aspects. On the way towards a joint legislation by the abutters and a TAC for the entire system, the individual territories should take care that the territorial borders are maintained. The natural interannual variation of the flooding regime also needs to be considered in these TAC, especially for the case that climatic events drastically reduce the fish stocks. If fishing yields are not adapted to these natural variations, stocks of important species can collapse (Smolders *et al.* 2000). Traditional knowledge by the fishermen should be acknowledged when management plans are developed, and a fair proportion between local/professional and recreational/tourism fisheries needs to be defined. The current law of the Brazilian states limits the catch by individual fishermen (both commercial and recreational), but it does not limit the number of the fishermen. The number of the licences need to be limited to enable a better control, and even reduce, fishing effort for those species of which the stocks are declining. Discussions about how to change the fisheries law in Mato Grosso (Lei de Pesca – # 7.881, of 30 December 2002) are currently ongoing.

On the other hand, there is a large number of fish species in the Pantanal that have not been used yet as they can not be caught with hooks, e.g. iliophagous or herbivorous species from the Prochilodontidae, Curimatidae and Anostomidae families. In the Paraná River system, these fish make up the largest part of the yields (Cordiviola de Yuan 1992) and it should be investigated if a similar use strategy could be adopted for the Pantanal. However, care must be taken when including fish species of lower position in the food web. These species are consumed by the top predator fish species, and exploring them we would compete with the carnivores. This process

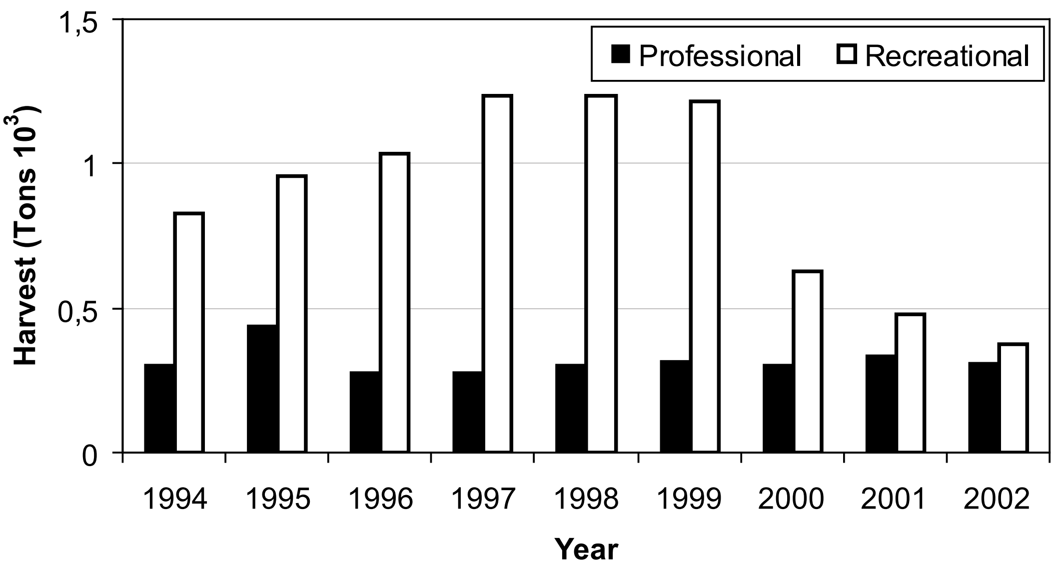

Fig. 6. Fish harvest at Brazilian south Pantanal, in Mato Grosso do Sul state based on data by Campos et al. (2003).

may initiate a cascading effect which could enhance the decline of the top predator fish species. A use strategy for iliophagous or herbivorous species for the Pantanal should therefore be developed on the basis of a detailed analysis of stocks and productivity data, and impacts on ecosystem and food web, potential problems controlling net fishing, and introduction of new products to the consumer market.

Terrestrial food webs and cattle production

In the largest part of its area, the Pantanal has a low potential of productivity due to a scarcity of nutrients in the soils and by the environmental extremes by which the wet-and-dry cycle limits the occurrence of many species. Immediately after dry-falling however, the wetland area is fertilized by decomposing aquatic biomass. Adequate moisture conditions and nutrients allow a fast development of natural pastures. Locally, these native pastures become complemented by introduced exotic grass species, and large forests and shrublands have been cleared to increase the pasture area.

Traditional ranching in the Pantanal has existed for more than 200 years. It is characterized by an orientation on natural pastures (*campo limpo, vazantes, bordas de corpos d'agua, campo cerrado*), limited brushcutting of transitional habitats, and maintenance of the natural levees *(cordilheiras)* and *terra firme* islands (*capões*, see Nunes da Cunha *et al.* (2006) for a description of the vegetation units). Input of treatments was low (e.g. vaccination and mineral supplementation), as was the productivity. Traditional farmers lived on low incomes and subsistence horticulture. With the development modern ranching techniques, including large scale clearing of forests, planting of exotic grass species, and supplementary fodder, these old-fashioned ranchers were brought near the limits of existence, and many of them sold their proprieties to great land owners from the large Brazilian cities (Remppis 1995; Santos *et al.* in press). In other cases, farms become abandoned, and the secondary vegetation *(campo sujo)* closes patches that were previously kept free of woody vegetation, thereby maintaining a higher beta-diversity of the region. With the decline of traditional farming, much of the regional knowledge is lost, which is urgently needed for the habitat classification and the participative management of the Pantanal.

Low productivity and the strong reduction of pasture areas during flood hamper the competition between cattle production in the Pantanal and the highlands in the upper parts of the catchment. Traditional ranches in the Pantanal suffer i.a. from subdivision of the terrains due to heritage, invasion and control of woody "weeds" (Nunes da Cunha, Junk 2004), low value of the products, strong competition with ranches in the uplands, and excessive pasture pressure. Moreover, multiannual cycles of wetter and drier years affect the potential pasture area (Hamilton *et al.* 1996). During the dry period from 1960 to 1974, a record of six millions heads was estimated. This number was reduced by half in moister phase around the mid 1980's (see Santos *et al.* in press for a thorough review of the existing literature on case studies).

Santos *et al.* (in press) quote learning how to produce beef cattle in a sustainable manner that will not cause environmental degradation or habitat alteration as one of the main challenges for the region today. Floodpulse-adapted cattle races such as the tucura or Pantaneiro cattle *(Bos taurus)* have been nearly completely replaced by more productive ones, especially the Nelore race *(Bos inidicus)*. Specific challenges are the establishment of good practices, the resilience of the ranching systems due to a diversification of the production, coexistence of cattle with other herbivores (including disease control), mapping of pasture types and analysis of feeding preferences of the cattle. Due to the complexity of the system it is necessary to develop tools to evaluate and monitor the different ecosystems of the Pantanal in a holistic manner. Another priority is to develop adequate livestock management practices associated with marketing strategies that provide and added value to products from Pantanal. It is important to define management practices that cause limited impact on the environment, such as natural pastures, adaptive management and feeding supplementation on pasture. To reach these targets, multidisciplinary studies and initiatives are being realized in the region. One of these initiatives includes the Livestock Network coordinated by EMBRAPA (Embrapa Brazilian Corporation for Agricultural Research) and CPP (Pantanal Research Center) on about 20 model farms.

Sustainable management of the cattle stocks of the Pantanal implies the long-term maintenance of environmental and social qualities. This does not necessarily mean a maximization of the beef production. In their recent review Santos *et al.* (in press) quoted as crucial elements for a sustainable use of cattle (a) an adaptation of the breeds and lineages to the environment (resistant cattle races), (b) habitat-specific cattle management, and (c) a specific recognition of the "environment-friendly" produced beef.

Best practices for organic beef production include the use of native grasslands, rotational grazing, increased distances between fence posts to reduce the wood demand, use of wildlife-friendly fences that allow free transit of wild animals, reduced use of chemical inputs, management techniques that improve animal welfare, reduced use of fire for weed control, and investments to improve working conditions and quality of life for local residents. We suggest strengthening existing initiatives to develop seals of environmental quality for natural products of the Pantanal (such as the organic certified beef production, Table III.). These best practices not only include environmental related standard, but also certified social criteria (Domingos 2005). It is important to stress that these kinds of activities only will be accepted by a larger constituency when economic sustainable has been proven. Therefore the recognized certification system and the access to exporting markets, which are willing to pay a premium value for the beef, are important premises. Studies revealed that the international market already shows a demand for organic products stimulated by questions over food safety, with willingness to pay up to 20% premium for organic meat (Conservation International do Brasil 2008). This added value can be considered one of the strongest economic arguments in favour of a sustainable management of the Pantanal. The use of fire for landscape management is ardently discussed for the Pantanal, as a strict exclusion from fire may cause an unwanted accumulation of natural fuels.

The human dimension: traditional and alternative use of the natural resources in the Pantanal

The traditional social groups of the Pantanal have developed a detailed knowledge of the environment and a special skills for the use the natural resources in the rhythm of the wet-and-dry cycle (da Silva, Silva 1995). For example only regional products are used, for the construction of typical houses, the basic construction with wood from the pindaíva tree *(Xylopia aromatica)*, the walls filled with clay from nearby lakes, mixed with carona grass pieces *(Elyonorus muticus)* and cattle dung, and the roofs covered with leaves of the acuri palm *(Scheelea phalerata)* (Rosetto, Brasil Jr. 2003). Each working step requires detailed knowledge about when and where to withdraw these substances. With ongoing globalization, this knowledge, which has been traded between generations, becomes lost. For example, traditional rocking chairs built in the Pantanal from 4 different wood species today are often infested with woodboring beetle larvae, as many people do not consider the ideal harvesting time any more (Fachim 1995).

There is a shift from traditional to modern activities (Table IV.). With the expansion of the activities related to fodder plants and the transformations in the ranching techniques, the number of jobs offered to land workers *(peões)* decreases continuously. Those who do not adopt the new system by learning new skills e.g., driving and repairing machines, often migrate into the peripheries of urban agglomerations seeking employments but often ending up in poverty.

These transformations in the cultural area, by losing and substituting the *"pantaneiro"* (i.e. traditional Pantanal) knowledge, coincide with increased impacts on the environment such as excessive wood extraction for fence construction etc. This phenomenon gives these cultural changes are an important role in the discussion about sustainability (Rossetto 2006). The current cultural crisis in the Pantanal may be overcome by acknowledging the cultural diversity and by transferring these activities into modern, economically sustainable practices without destroying them. The cultural elements *("pantaneiro way of life")* may receive the status of goods and could be commercialized to a group of consumers that seeks products and services associated with authenticity and tradition. In this context, rural incomes based on multiple sources would become possible (Kageyama 1998) that include new forms of organizing the production or that old working practices attain new importance as an alternative source of income, e.g., in the cultural tourism. For example, the recently declining festivals in the Pantanal honouring Christian saints could be saved with an appropriate cultural tourism. However, there are several problems in the context of ecotourism and cultural tourism. Small regional enterprises have little experience in how to meet the requirements of international tourists or to develop a decent marketing for the products they offer, e.g. in the English language. Again, large enterprises from outside the Pantanal have taken over the largest parts of ecotourism, at least in the Northern section of the wetland.

Changes in the Pantanal due to the decline of the traditional ranching have also brought upon a reorganization of the property structures. These

Table III. Number of already-certified farms for green seal production, and projections to the future based on unpublished data by IBD 2007 and WWF Brazil.

	Certified		**Under Conversion**		**Total IBD 2007**	**Target certifi-cations 2008**	**Total expected 2009**
	MS	MT	MS	MT			
Farms (projects)	2	15	10	1	28	12	40
area (1000 ha)	13	40	100	3	156	150	306
stock (no. cattle)	7 600	60 000	23 000	2 000	92 600	30 000	122 600

Table IV. CIdentities of Pantanal professions in the traditional and modern system (Rosetto 2006)

Profession	Traditional	Modern
Fazendeiros -landowners	extensive traditional ranching	mix of extensive and intensive ranching
Peões farm workers	highly qualified, well-known and respected for their extraordinary skills to work with animals	daily paid workers who accept all kinds of work. Some of them become tractor drivers or learn to apply other machines, others emigrate into the urban periphery
Sitiantes - smallholders	developed extensive small-scale ranching and farming for their subsistence	lost their small proprieties and now live as farm workers or emigrate

go along with results from the land reform. There is a progressive development of settlements in the municipalities of the Pantanal (Table V.). These settlers have claimed their land property rights from earlier generations and receive terrains distributed by the Brazilian institution of land reform (INCRA, www.incra.gov.br) who buys it from landowners throughout the country. The 'movement of the landless' initiative (www.mstbrazil.org/) supports the claimers in this process. The settlers often lack the knowledge about specific resource use in the Pantanal and its nearby environments, and severe social problems arise from settlements where the agricultural production does not prosper on the often equally low-productive soils. Recently settled people may abandon their lands or impoverish. Social problems do not only arise with the decline of traditional farming. In the recent past, the gold mining in the Poconé region has ended due to low economic productivity and increased reinforcement of legal restrictions. Hundreds of workers became unemployed. A study by Rosetto, Souza (2005) recently alerted that these poor people often are forced to use and commercialize protected natural resources, e.g. by cutting wood in preserved areas to produce stakes for fences or charcoal production. Others poach wildlife as a protein supply, cut trees for their wood demand for construction and firewood, and settle in habitats that are highly threatened. In 2001 a large bushfire that affected thousands of hectares in the Pantanal was caused by illegal hunters. All these people represent an imminent threat to the biodiversity. The environmental legislation needs to consider the specific characteristics of the Pantanal. Activities by the authorities to tackle these problems (especially deforestation) with law enforcements and environmental education are urgently needed. Current efforts to alleviate poverty in the Northern Pantanal region do not distinguish between traditional Pantanal people and settlers from other regions, and include both groups in the same poverty alleviation programs. This leads to a further decline of the traditional knowledge.

However, there are many traditional management techniques that could be employed for a "modern" sustainable management. It is important to state that the term "traditional" does not imply a "freezing" of the old situation but that it also includes forms of development. Possible solutions include (a) new forms how to organize the production, and (b) that traditional practices receive new importance as alternatives of income e.g. for tourism, artisan crafts, and added values to typical products of the Pantanal. Stimulation of the Pantanal culture and an increase of the economic return would help to reduce the environmental problems caused by the new settlers and help to stop the cultural losses. These economic alternatives have a large potential in the Pantanal, which has only been weakly explored in the past years. Recent studies have shown that there were many initiatives, however a large part of them had a low profitability in current markets in spite of high potentials. Problems to implement these alternative lines of production include legal and/or hygiene problems (e.g. the use of caimans, wild boar *(porco monteiro)*, or capibara for meat and skin production), or the cultural resistance against a change of production practices (e.g. green seal for beef, or ecotourism). Traditional farmers in the Pantanal often lack the entrepreneur's point of view towards their initia-

Table V. Settlements due to the Brazilian land reform in the Pantanal in 2004 (Rosetto 2007)

Municipality	area (ha)	no. of families	no. of settlements
Barão de Melgaço	2 123 00	144	1
Itiquira	5 694 00	80	1
Poconé	20 876 00	684	12
Santo Antônio do Leverger	25 838 00	828	11
Nossa Senhora Do Livramento	32 600 00	1 214	23
Cáceres	74 629 08	1 556	17

Table VI. A preliminary list of indicators for sustainable management of the Pantanal. Not all terms printed side by side correspond to each other.
A: ENVIRONMENTAL INDICATORS

Ecosystem level	Farm/habitat unit level
Biodiversity	
ß-diversity	alpha-diversity
Fire	
number of fire foci and burnt area	existence of a fire management strategy (frequency, sites, distribution, season)
frequency of fires per landscape unit (fires/past 5 years)	which habitats are affected by the fire?
number of given authorizations for fires (n/past 5 years)	which area (ha, %) of the farm is burnt?
Impacts on aquatic systems	
quality and quantity of sediment inputs, concentration (mg/l) and total amount (kg/day) (only rivers)	springs: how many? degree of protection? Legal protection zones (*reserva permanente*) maintained?
quality and quantity of chemical pollutant inputs (organic/inorganic), concentration (mg/l) and total amount (kg/day) (only rivers)	management of solid waste on the farm
quality and quantity of solid waste input, total amount (kg/day) (only rivers)	adoption of erosion control measures? (contour tillage, direct planting, adequate earth road construction)
number of authorizations given for water abstraction	existence of erosion gullies (how many, dimension?)
number of authorizations given for source pollution (type of substance and quantity)	degree of conservation, quality and productivity of natural pastures (indicators for each type of pasture)
demand levels of water abstractions by the different users (agriculture, aquaculture, drinking water, hydropower, number of extreme flood events	
Conservation Units (CUs)	
percentage of habitat change compared to original vegetation	existence of a legal reserves? area? georeferenced registration?
number and area of CUs	existence of a RPPN? Area? registration? Georeferenced?
percentaged contribution of preserved habitats relative to the natural distribution of habitats	degree of conservation of the habitat diversity
degree of implementation of UCs	fences: total length, use of local wood reserves
number and area of CUs having a management plan	
number and area of CUs open for tourism	
number and area of CUs open for scientific research	
number and area of CUs open for fishing	
Fisheries	
number, average size and mass of caught fish (by species/year)	CPUE (catch per unit effort)
ranking of the top 10 caught fish species	

tives. Often, they become excluded from the production chain at a very early stage and therefore badly paid. In the case of use of the caimans, most farms merely serve as deliverers of the caiman eggs, while the raising of the animals, slaughtering and merchandising of the products is in the hands of a firm outside of the Pantanal. The introduction of traditionally produced items of the Pantanal region to the markets is hampered by a lack of a calculation basis for them. Thus, the production chain becomes economically unsustainable, i.e. the price for vending the products is lower than the production costs. This impedes the producers to compete in convention-

Table VI. Continuation.
B: SOCIAL- ECONOMICAL INDICATORS

Ecosystem Level	**farm/habitat unit level**
Ranching	
livestock number/exotic pasture area ratio Livestock number/native pasture ratio Expansion/intensification of cultivated land Ratio natural/cutivated area	Discard rates Weaned beef calves number
number of days of closed airports due to smoke per year	levels of diversification of economic activities of the farm
ecosystem emergy evaluation	eco-efficiency indices and emergetic indicators (transformability, renewability, emergy yield ratio, emergy investment ratio and emergy exchange ratio (Ortega 2003)
number and types of products of the regional culture that are used for economical purposes	
number of curses for human capacity building in qualified handcrafts	
Tourism/Alternative Business	
contentedness of tourists	tendency of numbers of ranchers that maintain traditional ranching
contentedness of the local people considering tourism	level of diversification in the tourism branch
number of institutions (and amount of support given) to support these manufactures.	percentage of traditional ranching (number of cows)
indicators of poverty	volume of taxes deriving from economic activities (by branch)
degree of adoption of worker's rights in the relationship farmer - employed	number of locally producing manufactures/societies of producers
percentage of children attending school in rural areas	health of the farm workers (human epidemiological statistics)
degree of literacy	
quality of living and food of the employees of farms	
contribution of traditional ranching to the regional / state GDP	

al markets. For example, people that produce *rapadura* (dry sugar), sweets, canned fruits, or leather and artisan products of it do not know about their production costs, and calculate only the value they need to survive. Many ranchers do not calculate the costs of their equipment used during production etc., and they cannot assess if the margins of profit are sufficient for them. Instead, they work for a price determined by the market. In an analysis of the current situation of the cattle ranching in the State of Mato Grosso (FAMATO 2008) alerts that many ranchers do not apply a thorough economical analysis of the production chain, and thereby set their capacity to compete at risk. This impedes a comparison of the economic profitability between these products and those of other regions. Economic studies about cost and price development, marketing and trade pathways for traditional products are urgently needed. The current initiative to develop a ‘green seal’ for organic beef is one positive example acquiring additional value for beef by producing it in a sustainable way.

There is a large resistance to transfer results coming from the academia (universities and governmental research centers) to be accepted by regional decision takers (science/policy gap). We suggest that in the Pantanal region the researchers and the civil society collaborate more efficiently, especially concerning the speed of the data flow. A positive example for this is the Pantanal Research Center (Centro de Pesquisas do Pantanal, CPP), which serves a communication platform between the Pantanal communities and the academic world. The lines of research and “science-communication” deal with (a) fisheries management, (b) pasture and ranching techniques and (c) economic alternatives.

Indicators for sustainable management in the Pantanal

Definition of indicators for a sustainable management in the Pantanal needs to be quantifiable and use a terminology, which reflects the feed-back from the effects of the activity in the landscape to the active people (farmers, local politicians etc). The state of the system, in our the case the Pantanal drainage basin, varies according to the inflow and outflow of energy, material and information. We measure this change using indicators that transmit the perceived state of the system. The indicators can be considered our link to the world and summarize complex information of value to the observer (Bossel 1999). From the systemic point of view it is important to consider that these measurements are not truly objective, since they are reflections of the things we care about. Clearly some of these values are culture and place specific, others common to all humanity. But we do not only measure what we value, we also value what we measure (Meadows 1998). This becomes evident by the fact that we compare the measured figures with goals that should be reached. According to the discrepancy of both values, strategies are devised to change the system into the desirable state.

The indicators differ according to scale. We identified two scale units. On a smaller scale, the farms and/or habitat unit is the direct management unit. On a larger scale, there are ecosystems and landscape units that may cross several borders of proprieties, e.g. the rivers and forest corridors. The hierarchical habitat characterization approach suggested above includes these different scales. The current problem is to include existing knowledge into this approach, and to speed up the studies that deliver missing data for this approach. Another problem is to define manageable landscape units in the current legislation. For example, the state and federal laws consider stretches of 50 - 100m aside rivers and streams as permanently protected riparian zones (see Wantzen *et al.* 2006 for a review and discussions), however in the Pantanal, the 'riparian zone' (or aquatic-terrestrial transition zone) between permanently wet and permanently dry areas is very hard to define (Wantzen *et al.* 2005). The States of Mato Grosso and Mato Grosso do Sul have undertaken the initiative to deliver these definitions for the Pantanal (see below: conservation). During the workshop, a list of possible indicators was established (Table VI.) which needs to become refined and their parameters quantified.

Sustainable use and/or conservation?

When discussing the possibilities of sustainable use in the Pantanal it has to be stressed that a considerable area needs full protection, i.e. should not be used at all. These zones should be permanent reserves that act as genetic heritage for future generations. The planning of productive/used areas needs to be integrated with an ecoregion-based conservation plan (see below). This includes the identification of the most important areas for the maintenance of biodiversity and areas with important ecological functions (reproduction of key species, important feeding grounds, sites of increased carbon fixation etc.). Apart from National Parks and other types of State and Federal preserves, the legal structure of the Private Natural Heritage Reserve (RPPN) appears to be an ideal tool for conservation of large areas of the Pantanal, as it maintains the original ownership and thus responsibility of the proprietor of the land. However, the initiatives of both States that cover the Brazilian part of the Pantanal, Mato Grosso and Mato Grosso do Sul, need to be aligned among themselves and with the conservation plans of the other countries contributing to the Pantanal, Bolivia and Paraguay.

When the Pantanal was declared a proper biome, the legal conservation areas from the Cerrado such as the riparian zones of streams and rivers (*area de proteção permanente*) were not longer valid, and there is an urgent need to define permanent conservation areas. The Pantanal law # 8830 of the State of Mato Grosso (lei do Pantanal, of 21. January 2008) therefore added a special term (*area de conservação permanente*, in which the landscape should not be changed despite the direct use is allowed) to the define those areas, however there are still some problems to be overcome, e.g. the definition of the floodplain area (Chapter II, Section I, Article 7, § 1 and § 2), the suppression of invasive species (Chapter IV, Article 11), the introduction of neophytes (Section II, Article 8, § 2), and the socioeconomic zonation (Section V) are currently discussed between floodplain ecologists, ranchers and administrators.

A major aspect of conservation is the maintenance of the flood pulse as the key component for the abiotic and biotic structure of the Pantanal. This implies that the tributary rivers to the Pantanal must not be fully regulated but have to keep their natural hydrological regime (Zeilhofer *et al.* 2008). The water level fluctuations have also been proven to be an effective weapon against invasive species. For example, the golden mussel *(Limnoperna fortunei)* a strongly spreading exotic species was shown to be unsuccessful to colonize the uppermost sections of the Paraguay River which have a strong floodpulse, which causes an exposure of the recently settled and fixed mussels to prolongued drought (Marchese *et al.* 2005). Similar patterns appear to limit the expansion of the introduced basses (*Cichla* spp.) from Amazonia.

Another important point is that the conservation units in the Pantanal become enlarged or new units added in order to provide a portfolio of ecosystems that are representative for the existing diversity. One example is the Nhecolandia region where its unique landscape shelters alkaline ponds amidst fresh water ponds, both very important habitat for migratory birds and other wildlife. Both conservation and sustainable use of the Pantanal require identification, characterization and a typology of the different habitats of the wetland.

3. Conclusions

This paper should be regarded rather as a trial to gather the different perspectives on sustainability in the Pantanal than a precise action plan. One of the workshop findings, even with a small crowd of 25 persons, was that there is widely varying perceptions of the Pantanal, its conservation use and meaning of sustainability. What is true in this small group of academics is also true for the whole society. There is still minimal knowledge of how the various stakeholders perceive the Pantanal, its management conservation or sustainability (da Silva, Girard 2004). It seems essential to multiply and link forums and events where such issues are discussed. Few forums already exits, mainly driven by NGOs such as, for example, The Rio Vivo coalition or the Pantanal Research Centre (http://www.cppantanal.org.br/) which promoted various workshops on similar issues in the past four years. Another effort discussing these issues was the INREP project to identify further research needs and to make efforts towards river basin authorities in the Upper Paraguay basin (INREP 2007). The critical density of permanent/non-permanent forums is still too low to produce a common sense or perception about the Pantanal sustainability and thus real political alliances for its wise use. However, in spite of these uncertainties, it is necessary to formulate some overall principles that can be extracted from these discussion groups and that should be developed further and/or implemented in current and future actions.

The Pantanal is an intrinsically diverse and dynamic system that provides important ecosystem services to all abutting states and beyond. Any sustainable management strategy and legislation of the Pantanal should to take into consideration at least three aspects: (a) maintenance of biological and cultural diversity, (b) maintenance of natural dynamics and (c) adaptability to future changes.

The natural floodpulse (annual and multiannual wet-and-dry cycles) provides the fundation for the biodiversity and biological productivity of the Pantanal system. The floodpulse depends on the seasonal climate, on the natural flow regime of the tributary rivers and on the undisturbed water flow within the wetland. Thus the maintenance of the natural hydrological dynamics has to be regarded as the prime issue for all management plans.

The low-productive Pantanal is linked to the high-productive catchment areas in the Planalto and to the urban agglomerations in the transition zone. Plans concerning the use of water (including hydroenergy), and release of any pollutant (organic, toxic, or physical) into the rivers, need to consider this connectivity, and should aim at reducing any kind of impact into the wetland. Hydropower plants should employ the run-of river *(fio d'agua)* technique whenever possible.

There is an urgent need to define tributary rivers to the Pantanal that should not be dammed at all and their riparian systems fully maintained in order to guarantee sufficiently large spawning areas for migratory fish, migration corridors for the genetic exchange between Pantanal and Planalto and sufficient discharge for the maintenance of the floodpulse.

The basis for a sustainable management is a characterization of the habitats in the Pantanal and in the catchments of the tributary rivers, based on hydrological, edaphological and floristic characteristics. Based on this characterization, individual management plans, including participatory management and sustainable use of the natural resources can be given. Large datasets already exist but need to be converged.

Traditional human communities have adapted their culture and use strategies according to the natural system dynamics over centuries. The current decline of this knowledge due to impoverishment of these communities needs to be stopped by transferring their knowledge into ecologically sustainable, socially acceptable and economically feasible management strategies.

The economic value of the production chain of products deriving from sustainable management needs to be precisely assessed, hindrances in their commercialisation (e.g. incompatibility with market standards) need to be removed, and all possibilities for the use of added values by accreditation of green seals etc. need to be employed.

The wet-and-dry cycle enhances the productivity of the aquatic and terrestrial food webs. However, the harvest of the few economically most important fish species has already reached the maximum yield and needs to be reduced, while other fish species should be carefully tested as to their carrying capacity and their interrelationships with other species and ecosystem functions. For the ranching, appropriate cattle races, managing strategies, and a sustainable fodder strategy are being developed.

Even if thorough principles of sustainability are employed on the used areas, some of the area of the Pantanal requires full protection in private, State or Federal Reserves, which need to be enlarged.

The establishment of a new environmental legislation specifically for the Pantanal and Paraguay River basin should be addressed, as the current Brazilian "Codigo Florestal" (Forest Code) is hardly applicable in such a complex landscape and ever-changing environmental conditions. This is due to difficulties in applying the metrics to define permanent protection areas, which is key to preserve biodiversity and water courses.

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