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Pantanal: a large South American wetland at a crossroads

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Abstract

The Pantanal, a large and still rather pristine wetland in the center of the South American continent, is becoming increasingly threatened by large development programs. Agroindustries and reservoirs for hydroelectric power generation in the catchment area modify discharge pattern and sediment load of the tributaries, plans for canalization of the Paraguay River (hidrovia) are putting in risk the natural flood regime of large areas inside the Pantanal, and attract industries with high potential for environmental pollution, economic pressure on the traditional cattle ranchers accelerates the transformation of natural vegetation into pasture, etc. These activities negatively affect habitat and species diversity and scenic beauty but also the hydrological buffer capacity of the Pantanal. The article summarizes the ecological conditions of the Pantanal, discusses commercial and non-commercial values of the area, describes constraints for the development of intensive agriculture and cattle ranching, and discusses development alternatives. Considering the low density of human population inside the Pantanal, it can be concluded that development pressure on the Pantanal arises mostly from pressure groups outside the area that will also mostly benefit from the economic return of the development projects. Low density of human population would still allow the application of economically viable and environmentally friendly development alternatives that maintain and sustainably manage one of the largest wetlands in the world.

Keywords: Pantanal; Floodplain; Sustainable management

1. Introduction

The Pantanal is a large wetland of about 160,000 km^2 in the center of the South American continent. Its isolation from major consumption centers and the difficult access to the ranches inside the vast floodplain hindered economic development since colonization by Europeans at the beginning of the 18th century. The low human population density and the extensive cattle ranching had little impact on the environment. Therefore, the Pantanal today is still in a rather pristine condition.

During the last decades, changing economic and political requirements increased the pressure on the Pantanal and its catchment area. In recent years, the governments of Brazil, Bolivia, and Paraguay, in which the Pantanal lies, have made major efforts to involve

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the Pantanal in national economic development. This is particularly evident for Brazil, which holds approximately 85% of the area (Alho et al., 1988). Developmental projects profess to improve living conditions and stimulate economic growth, with far-reaching ecological and socio-economic consequences; however, their consequences have not been analyzed in detail.

On the other hand, the local population, scientists, governmental and non-governmental agencies, and politicians are increasingly trying to find ways to protect the Pantanal and to maintain its unique natural resources. The Pantanal is considered "globally outstanding" (rank 1 of 4) in terms of biological distinctiveness and "vulnerable" (rank 3 of 5) in terms of conservation, and has "highest priority" (rank 1 of 4) in regional priorities for conservation action according to a conservation assessment of the WWF and the Biodiversity Support Program (Olson et al., 1998).

Discussions on the future of the Pantanal already started some years ago, but such discussions are hindered by insufficient databases on economic, socio-economic, hydrological, and ecological factors, as illustrated by the discussion of the *hidrovia* (Huszar et al., 1999; Gottgens et al., 2001). Increasing economic and political pressure requires fundamental decisions to be made in the near future, and the Pantanal, indeed, is now at a crossroads.

The aim of this article is to summarize the knowledge on major structures and functions of the Pantanal, to describe the role of the flood pulse for the ecosystem, and to delineate some important ecosystem functions for the well being of the human population. The major human impacts on the ecosystem will also be described and various developmental schemes will be discussed.

1.1. Ecological outlines

The Pantanal is situated in the Alto Paraguay Depression, which extends between the young uplifting Andes in the west and the old crystalline Central Brazilian Shield in the east (Fig. 1). The main phase of the subsidence that resulted in the wetland depression very likely occurred during the upper Pliocene to lower Pleistocene Epochs about 2.5 million years ago (Adámoli, 1981; Barros, 1982; Del'Arco et al., 1982; Alvarenga et al., 1984; Godoi Filho, 1986). Positioned 15–20° south of the Equator, the area is situated in a circumglobal belt of climate instability and was subject to severe climatic changes during the Quaternary Period. Alternating dry and wet periods led to different patterns of discharge and sediment load of the Paraguay River and its tributaries, which resulted in a mosaic of different geomorphologic formations that are covered today by various types of vegetation (Short and Blair, 1986; Jimenez-Rueda et al., 1998). During the late Pleistocene and Holocene, the Pantanal passed through several changes between wet and dry episodes as follows: 40,000–8000 BP cold and dry, 8000–3500 BP warm and wet, 3500–1500 warm and dry and 1500-Present warm and wet (Ab'Saber, 1988; Iriondo and Garcia, 1993; Stevaux, 2000).

During paleo-climatic dry periods, extinction rates of wetland organisms were high. Re-immigration from the lower Paraguay River, the surrounding Cerrado, the Amazon basin, and the Chaco occurred (Fig. 1). Mobile species, such as aquatic birds and insects, were favored. The time span since the last dry period was obviously not long enough for the development of endemic species. Furthermore, flood pulse induced migration, and passive transport of organisms hindered speciation by spatial segregation of populations.

Today, the Pantanal is a wetland subject to a predictable monomodal flood pulse (Fig. 2). This pulse is the driving force in the Pantanal landscape (Junk and Da Silva, 1999; Junk, 2000). The considerable annual and multi-annual variability affects the biota with different intensities and on different time scales (Fig. 3, Nunes da Cunha and Junk, 2004). The vast plain stores water during the rainy season and delivers it slowly to the lower sections of the Paraguay River, thereby buffering its flood amplitude. During the passage through the Pantanal, about 90% of the water returns to the atmosphere, contributing considerably to the regional water and heat balance (Ponce, 1995). Any long-term change of the pulse will result in fundamental ecological changes in the affected areas and also influence the living conditions of the local human population. Wildfires and human-induced fires represent important additional stresses to the Pantanal that also affect fauna and flora with different intensities and on different time scales. The long-term impact of fire on the distribution and abundance of the various organisms is not yet fully understood.

A large diversity of habitats leads to a broad species diversity. The Pantanal harbors only very few endemic species, but large populations of charismatic South

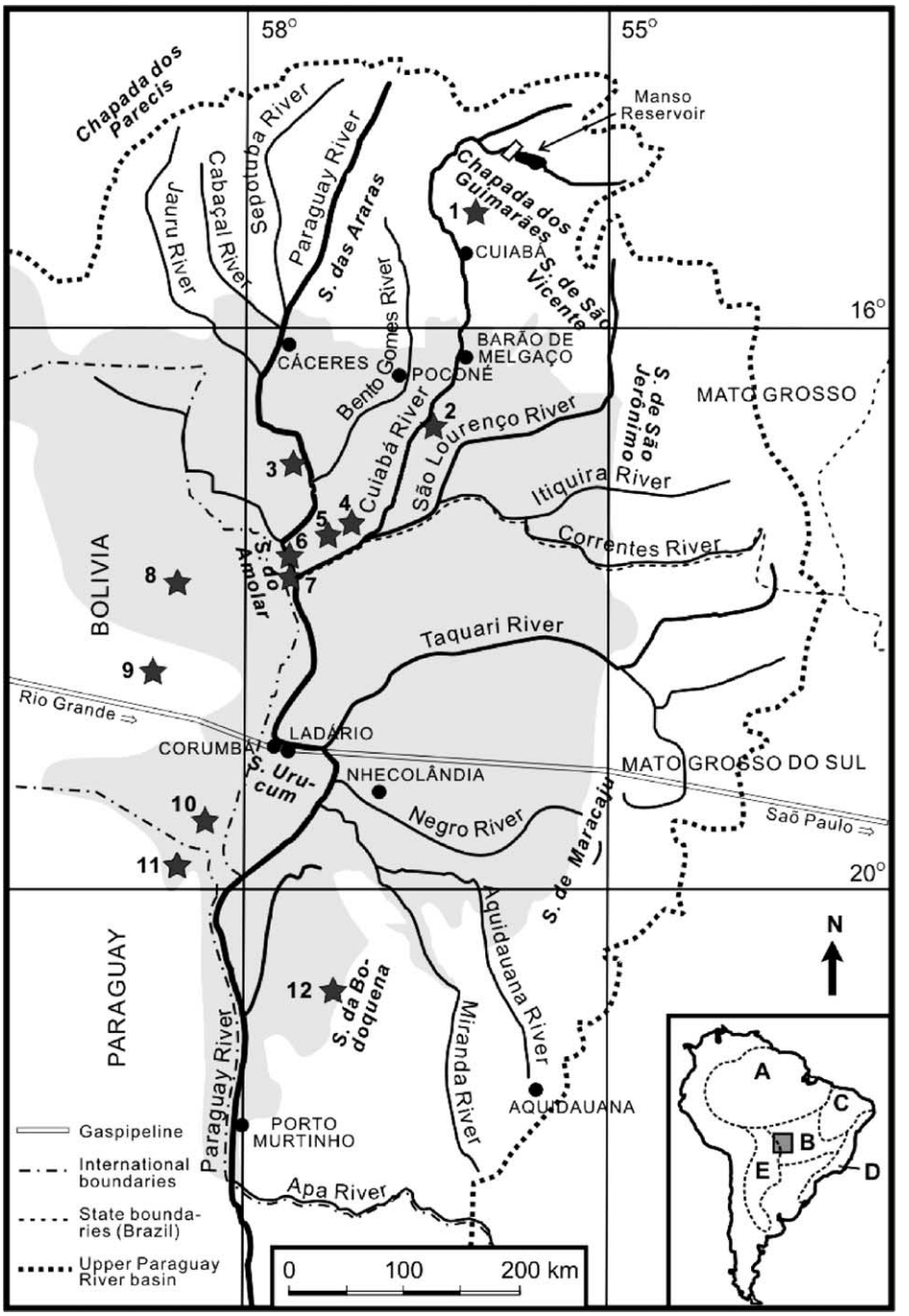

Fig. 1. Map of the Pantanal and its catchment area and position of protected areas. 1 = PN Chapada dos Guimarães, 2 = RPPN-SESC Pantanal, 3 = EE Taiamã, 4 = RPPN Dorochê, 5 = PN do Pantanal, 6 = RPPN Acurizal, 7 = RPPN Penha, 8 = ANMI San Matias, 9 = Reserva Municipal del Valle de Tucavaca, 10 = PN-ANMI Otuquis, 11 = PN Rio Negro, 12 = PN Serra da Bodoquena. The small map indicates the position of the Pantanal in South America and the surrounding biomes. A = Amazon forest, B = Cerrado, C = Caatinga, D = Atlantic forest, E = Chaco. Further explications in text.

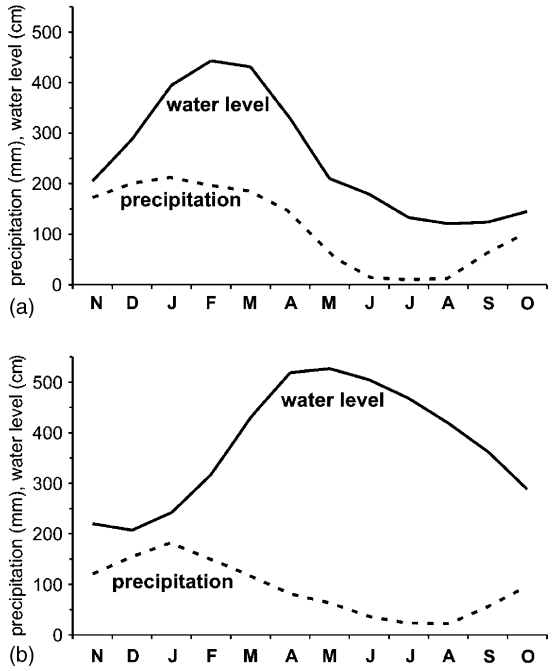

Fig. 2. (a) Mean monthly precipitation near Cuiabá (1933–1993) and mean water level of the Cuiabá River at Cuiabá (1971–1988), northern Pantanal (according to Zeilhofer, 1996); and (b) mean monthly precipitation near Corumbá (1912–1971) and mean water level of the Paraguay River at Ladário (1979–1987), southern Pantanal (according to Hamilton et al., 1999).

American species that are threatened outside the Pantanal by extinction are found there (Da Silva, 2000; Junk et al., 2005a). Diversity of landscape units gives the Pantanal a high aesthetic value, i.e., as parkland

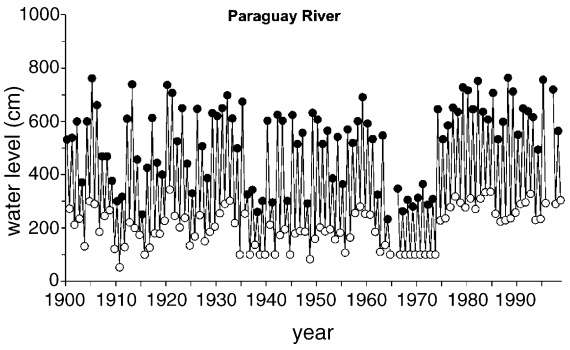

Fig. 3. Annual water level fluctuations of the Paraguay River at Ladário from 1900 to 2000 (data according to DNAEE): (●) maxima; (◯) minima.

landscape. The human population density in the Pantanal is low and concentrated in small urban areas at the non-flooded borders of the Pantanal, along the major rivers, and in the ranches scattered over the floodplain. Most soils of the Pantanal are acidic and of low fertility (Amaral Filho, 1986). Their agricultural potential is low. Furthermore, the correlation of rainfall with flooding hinders the planting of dry-land crops.

2. Economic and social development

The occupation of the Pantanal by humans dates back to about 5000 years BP, when the climate became moister and groups of Tupi-Guarani Indians began to colonize the Pantanal (Peixoto et al., 1999). When the Europeans arrived, the Pantanal was occupied by various indigenous nations. Wars, slave rides and diseases introduced by the Europeans quickly reduced the number of the native population. Today, only about 50 persons belonging to the Guató Nation and 270 persons belonging to the Bororo Nation live inside the Brazilian part of the Pantanal (Da Silva and Silva, 1995).

Cattle ranching started in the mid-18th century. During the Paraguay War (1865–1870), the ranches were devastated and abandoned. After the war, cattle ranching was stimulated by the export of salted and dried meat and meat extracts to national and international markets. This activity declined after World War II, when refrigeration techniques decreased the demand of meat preserves (Mazza et al., 1994; Pasca, 1994; Remppis, 1995). Environmental impacts of cattle ranching were relatively low.

In the mid-1970s, the Brazilian government started several large development programs that affected the Pantanal, such as the Intermunicipal Consortium for the Development of the Pantanal (CIDEPAN), the Program for the Development of the Pantanal (PRODEPAN), the Program for the Development of the Cerrados (POLOCENTRO), the National Alcohol Program (PROÁLCOOL), the Development Program of the Grande Dourados (PRODEGRAN), the Study of the Integrated Development of the Upper Paraguay Basin (EDIBAP), the Integrated Program of the Development of the North-East of Brazil (POLONOROESTE), the Program of the Agro-Environmental Development of the State of Mato Grosso (PRODEAGRO),

and the National Environmental Program (PNMA), with its sub-program Conservation Plan of the Upper Paraguay Basin (PCBAP) (Alho et al., 1988; Junk et al., 2005b).

The aims of the programs were to intensify the utilization of the natural resources of the Pantanal and its catchment area and to integrate the region into the national development scheme, for instance, by the construction of roads and lines for electric energy transmission. Indeed, they stimulated the agroindustrial development of the region, but also brought about serious negative ecological side effects for the savanna vegetation in the catchment area (Cerrado) and the Pantanal. Competition with cattle ranching on artificial pastures in the Cerrado place economic pressure on traditional ranches to increase beef production that affects the ecosystem, for instance, by overgrazing, deforestation for the increase of pasture areas, and plantation of artificial pastures. The sediment load of the tributaries, such as the Taquarí River, is rising because of increased erosion caused by large agroindustrial projects in the surrounding upland (*chapadas*). Since the 1980s, gold mining in the lowlands near the city of Poconé releases mercury in the environment, but superficial gold deposits are now exhausted and mining activities have sharply declined during the last years.

Actually there are nine hydroelectric power plants with a total capacity of 323 MW operating in the Pantanal catchment area but only the one on the Manso River, tributary to the Cuiabá River, is of large size (area 387 km^2, capacity 220 MW) (Fig. 1). Changes in hydrology caused by the large Manso River reservoir, begin to affect flora, fauna and also fishermen and cattle ranchers along the Cuiabá River inside the Pantanal. Reservoir number may rise in future to 31 with a total capacity of 1064 MW, three of them of large size at Rio Correntes (176 MW), Rio Itiquira (156 MW) and Rio Jauru (110 MW). An environmental impact analysis about the cumulative effect of the projected reservoirs on the Pantanal shows that the construction of large reservoirs should be avoided, because they strongly modify the hydrological regime of the affected rivers (Girard, 2002).

The projected Bolivia–Brazil gas pipeline from Rio Grande in Bolivia to Sao Paolo, Rio, de Janeiro, Campos, Belo Horizonte, Curitiba, Florianopolis and Porto Alegre will pass the Pantanal from Corumbá to Campo Grande (Fig. 1). The gas will be used for the generation of thermoelectric energy and there are plans for a large gas-chemical complex in Corumbá.

A major threat is the economic pressure, placed by agro-businesses and mining industry outside the Pantanal, to canalize the Paraguay River for inexpensive commercial navigation of soybeans and minerals to the Atlantic Ocean (*hidrovia*); this would lead to large-scale, irreversible wetland degradation and seriously affect the living conditions of the local human population (Ponce, 1995; Hamilton, 1999). The multiple interactions between man and environment in the Pantanal are shown in Fig. 4.

In Brazil, increasing concern about the future of the Pantanal has led to a variety of activities of the Federal Universities of Mato Grosso (UFMT) and Mato Grosso do Sul (UFMS), the State Universities of Mato Grosso (UNEMAT) and Mato Grosso do Sul (UEMS), Brazilian Ministry for the Environment (IBAMA), State Agency for the Environment (SEMA), Agricultural Research Unit in Corumbá (UEPAE) under the leadership of Brazilian Agricultural Research Agency (EMBRAPA), Institute of the Defense of Agriculture and Animal Ranching (INDEA), States Secretariat of the Environment and Sustainable Development of Mato Grosso do Sul (SEMADES) and others. Furthermore, several national and international non-governmental agencies are working in the area. In 1988, the Pantanal was declared by the Brazilian constitution as a National Heritage. In 1993, UNESCO declared it as a Ramsar Site, and in 2000 as a World Biosphere Reserve and granted it the World Heritage Certificate. In 2002, the Pantanal Regional Environmental Program, part of the United Nations University (UNU/PREP), was founded at the Federal University of Mato Grosso. UNU/PREP leads a consortium of local universities and professes to establish a network of national and foreign institutions interested in the sustainable management and protection of the Pantanal.

There are two National Parks and one Ecological Station under governmental administration and several private protected sites inside the Brazilian part of the Pantanal. Two major private protected sites are administrated by the NGO ECOTROPICA and the Social Service of Commerce (SESC). The total protected area inside the Pantanal consists of 360,000 ha, corresponding to about 2.6% of the Brazilian part of the Pantanal (http://www.ibama.gov.br/). The National Park Rio Negro in Paraguay covers 123,786 ha. In the Bo-

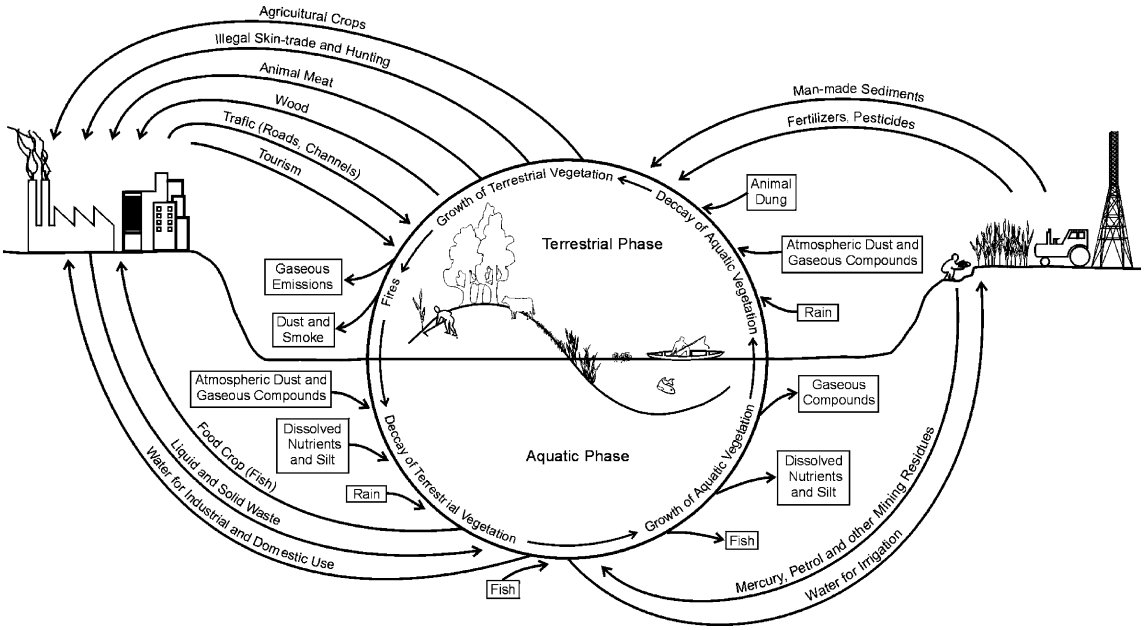

Fig. 4. Nutrient cycles and major human impacts on the Pantanal (according to Junk, 2002).

livian Pantanal, there are three protected areas: the Natural Area of Integrated Management San Matías (ANMI San Matías, 2,918,500 ha), the National Park and Area of Integrated Management Otuquis (PN-ANMI Otuquis, 1,005,950 ha), and the Municipality Reserve of Tucavaca (262,305 ha). These areas include wetlands but also uplands in different proportions (http://www.fobomade.org.bo/pantanal_bolivia/conociendo.php) (Fig. 1).

A research unit (Unidade de Execução de Pesquisa de Âmbito Estadual de Corumbá, UEPAE) under the leadership of the Brazilian Agricultural Research Agency (EMBRAPA) at Corumbá provides technical assistance for agriculture and cattle ranching inside the Pantanal. Researchers of the UFMT have been studying the Pantanal since the 1970s and have cooperated with the Max-Planck-Institute for Limnology in Plön, Germany, since 1991 on ecological research of the Pantanal, capacity building, and development of concepts for sustainable development. In 2002, the Pantanal Ecology Research Group (NEPA) was founded at the UFMT, and the Ecological Research Program of Long Duration (PELD) was established at the SESC Reserve.

3. Globalization and development alternatives

Today, many countries of the tropical and subtropical belt face similar problems to those occurring in the Pantanal and try to combine environmental protection with economic needs, social justice, and regional development requirements in wetland management. The complexity of the problem is illustrated by the rather small number of success stories and the large number of projects with heavy negative ecological, economic, and social side effects (Junk, 2002). In most African and Asian countries, the problem is aggravated by high population growth rates in and around the wetlands, the increased water requirement of urban and industrial centers, unsuitable agricultural practices, and inefficient energy use.

Countries bordering the Pantanal have the privilege of determining the future of one of the most famous wetlands under a low political pressure level: (1) the ecosystem is still in good health, (2) the population density in and around the Pantanal is very low, (3) in contrast to most African and some Asian countries that suffer from dictatorship, the democratic governments of the countries lying partly in the Pantanal can rely on

a well-developed network of governmental and non-governmental organizations that allow an efficient exchange of information between politicians, planners, scientists, the local population, and other stakeholders. This should give planners and decision makers the freedom to collect as much information as necessary, to analyze carefully the pros and cons of the various developmental alternatives, and to establish a long-term developmental policy for the sustainable use of the Pantanal and its natural resources by including the local population in the decision-making process.

There is no doubt that a sustainable development of the Pantanal should be achieved. But what is sustainable development? The term "sustainable" was defined by the Consultative Group on International Agricultural Research (CGIAR) as the "successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources" (Food and Agriculture Organization (FAO), 1989). This definition can be also used for wetlands, but without restriction to agriculture because wetlands can be managed for multiple purposes according to regional needs. The requirement that "sustainable development should be ecologically sound, economically viable, socially just, culturally appropriate and based on a holistic scientific approach" reflects the concern of many environmentalists, development agencies, and politicians not to separate society and environment, and economy and ethics (Becker, 1997). However, these definitions are too vague to be put into practice.

The real-world situation of the Pantanal and the necessity to develop feasible and viable activities for a "sustainable" development of the Pantanal require a detailed analysis of the "natural capital" represented by the natural resources of the Pantanal, an estimate of their development potential, a socio-economic impact study, and an ecological risk assessment for these activities. The "natural capital" considered in this analysis should not be based only on the economic value of single resources, as for instance, fish, wood, and beef production, but also on the value of ecological services, such as water and sediment retention, water purification, stabilization of regional climate, maintenance of biodiversity, and quality of life for the local population (Daily and Ehrlich, 1996; Daly, 1991; Goodland, 1991). The value of these services is often seriously underestimated because they do not provide an immediate cash return and therefore suffer the "tragedy of the commons" (Hardin, 1968): everyone wants to have clean air, clear water, beautiful landscape, and wildlife, but no one wants to pay for and take care of them because they are considered common goods.

The importance of wetlands is underlined by the following average values for ecosystem goods, services, biodiversity, and cultural considerations that have been estimated for various ecosystems: US$ 8498 ha^{-1} yr^{-1} for rivers and wetlands, US$ 969 ha^{-1} yr^{-1} for forests, and US$ 232 ha^{-1} yr^{-1} for grasslands (Constanza et al., 1997). In the past, highly industrialized countries such as the USA and European countries have invested large amounts of money to "valorize" their wetlands by using them for agriculture and the construction of infrastructure, industries, and housing. Negative economic and ecologic side effects now force the USA government to spend many billions of US$ to recover parts of the Everglades and the Mississippi floodplain to benefit, in the long term, economically from the associated wetland values that are now highly appreciated (Abramovitz, 1996; TNC, 1996). Similar efforts have been taken by France, Germany, and the Netherlands to recover parts of the Rhine River floodplain (Nienhuis et al., 1998). These examples show that (1) economic benefits of wetland destruction are often overrun by the costs of negative side effects, (2) the economic framework changes quickly and modifies cost–benefit analyses of development projects, often in favor of the values of an intact wetland, (3) only parts of the former wetland area can be recovered to near-natural conditions with very high costs, and (4) maintenance of wetlands is always much less expensive and more effective than rehabilitation after degradation.

Several international conventions have set up a framework for the conservation of the Pantanal as a globally important wetland, e.g., the Ramsar Convention, the Convention on Biological Diversity, the Convention on Climate Change, the Convention on Migratory Species, and the World Heritage Convention. These conventions stress the importance of non-commercial values of ecosystems and allow the inclusion of the Pantanal in international networks with similar goals that facilitate exchange of information and access to international funding and political support.

The political decisions made in the near future will determine in which direction the Pantanal will develop.

One option is cautious development avoiding drastic changes, respecting the dynamic behavior of the ecosystem (Jansson and Jansson, 1994), and prioritizing sustainability when using the natural resources of the Pantanal. This option would consider the importance of the Pantanal as a hydrological buffer system for downriver areas, a regional climate buffer, a valuable area for water retention and purification, and a center of maintenance of biodiversity. Cattle ranching is a weak economic basis for the ranches, but the scenic beauty of the landscape and its diverse flora and fauna in combination with traditional extensive ranching is very attractive for different forms of ecotourism and sport fishing. Large-scale marketing campaigns for local "green" products such as for beef with a recognized label of "free roaming sustainably managed Pantanal cattle" could increase the profitability of the ranches. The viability of such concepts is shown in Bonito, a city at the southern edge of the Pantanal. Several small rivers with transparent water, a diverse fish fauna and a large variety of aquatic plants attract many tourists.

The other option is the well-known approach of short-term, profit-oriented, non-sustainable stimulation of agriculture and intensified cattle ranching by large-scale road construction and flood control, and stimulation of industrial production by the construction of large hydroelectric power plants, canalization of the Paraguay River for large ship traffic, and other measures to improve infrastructure. This option would strongly affect and in part destroy one of the largest and best-preserved wetland systems of the world, and the economical return is questionable. Globalization of the markets will further increase the economic pressure and accelerate development projects in the Pantanal. Of special concern is the "tyranny of small decisions" because small steps taken are not very apparent to the public, but their sum can have a considerable negative effect. These seemingly small, but important steps should be carefully monitored and controlled by the environmental organizations.

For example, the disastrous consequences of the construction of the *hidrovia* on the Pantanal have been discussed by various authors (Ponce, 1995; Huszar et al., 1999; Gottgens et al., 2001). The construction requires meanders of the Paraguay River to be cut off, the river channel to be deepened, buildings to be constructed along its shores, and, most strikingly, rocky outcrops in the river channel to be removed, these serving as a sequence of natural impoundments and thus regulating the extent of the inundation (Ponce, 1995). Changes in hydrology would be irreversible.

Hamilton (1999) has conservatively estimated that a lowering of the river channel depth by 10 or 25 cm could reduce the flooded area by 11.7 or 31.4%, respectively. Willink et al. (2000) concluded that with the elimination of the northern Pantanal wetlands e.g., by the construction of the *hidrovia*, areas with high fish species diversity containing species of high economic value would be destroyed and 40–60% of the species could be eliminated. However, despite a judgment to stop any activity until a final decision about the *hidrovia* has been made, large vessels are used on the Upper Paraguay River. They recurrently become stranded, damage the ecosystem and increase the pressure on the population to vote in favor of channel deepening and harbor construction (Wantzen et al., 1999).

Another example is the settlement of landless people from the "Movimento Sem Terra" (MST, Movement of Landless People) in the Pantanal. Periodical flooding does not allow the application of traditional land-use techniques and makes the Pantanal an unsuitable place for subsistence farming. Settlers of the "Movement of Landless People" in the area cannot rely on traditional agriculture, and ranchers report of poaching and bushfires caused by these people who are not accustomed to the conditions in the Pantanal. Daily and Ehrlich (1992, 1996) define "carrying capacity" as "the maximum population size of a given species that an area can support without reducing its ability to support the same species in the future". Of course, humans can increase the carrying capacity through adequate management methods; however, it must be admitted that the natural carrying capacity of the Pantanal for humans is low.

In a letter of 13 April of 2004 to Mrs. Marina Silva, Minister of the Environment, the NGO's Ecologia e Ação (Ecology and Action, ECOA) and Organização de Cultura, Cidadania e Ambiente (Organization of Culture, Citizenship and Environment, OCCA) expressed their deep concerns about plans to establish a metallurgical and gas-chemical complex in combination with a highly polluting thermoelectric power plant operating with natural gas from Bolivia in the city of Corumbá. Supporters of the project reinforce their argument citing economic development and the creation of jobs for the local population. But there are certainly much better options for job creation in environmen-

tally friendly activities in such a unique and sensitive wetland than the establishment of a highly polluting industry with heavy negative impact on environment, human health, tourism, fishery and other activities. Once the industrial complex is established, there is no return to former near-pristine conditions in the area. On the contrary: it will call for other polluting industries and accelerate destructive activities.

4. Summary and recommendations

In a world with intensifying intercontinental economic links and with the countries lying partly within the Pantanal having growing economies and an increasing human population with changing requirements for a standard of living, an appeal to keep the Pantanal untouched would be unrealistic. However, any developmental planning should carefully analyze whether the proposed developmental projects make sustainable use of the specific "natural capital" of the Pantanal, how the projects could suffer from ecosystem restrains, how the projects affect the living standard of the local population, and to what extent they could negatively affect or irreversibly destroy major wetland structures and functions.

The "natural capital" of the Pantanal consists of its unique landscape and its high biodiversity, including large populations of charismatic animals, some of which are in danger of extinction elsewhere. Some very important ecosystem services are periodic water storage and release, stabilization of the regional climate, water purification, and sediment trapping.

Various features of the Pantanal act as limiting factors for its agricultural development, such as the high ecosystem fragility, and heavy natural stress factors, e.g., low nutrient status, periodic flooding, periodic drought, and fire. These lead to variable, but generally low to moderate natural productivity (Junk and Da Silva, 1999; Junk, 2000). Natural plant and animal communities compensate for these constraints by high nutrient-use efficiency and strong fluctuations in population density. However, the surplus that can be sustainably collected by humans is rather small, as shown by the adjacent Amazon basin. In just a few centuries, a small number of European immigrants reduced the formerly large populations of river turtles, manatees, caimans, otters, and capybaras to very low levels or even to near extinction (Junk and Da Silva, 1997).

There is no doubt that natural limiting factors to a certain extent can be compensated by adequate management methods (Goodland and Daly, 1996). However, conventional methods often fail in floodplains because of specific ecosystem behavior. For instance, improving productivity of soils by application of fertilizers during the low-water period is uneconomical because the periodic flooding lixiviates the nutrients. Furthermore, flooding coincides with the rainy season and hinders the planting of non-aquatic crops. Elimination of the impact of flooding by large-scale dike construction is not advisable because it would destroy the specific character of the ecosystem, negatively affect the adjacent floodplain areas, and diminish or threaten wetland ecosystem services. Early attempts to enclose areas of the Pantanal in the Camargo de Correia Island with dikes led to a prolonged moisture period within the dikes (rather than keeping the water out as expected) and a subsequent growth of woody weeds, which made a large area unusable for cattle ranching. There are many other examples of failed attempts to drive the wide amplitude of environmental variables of seasonal wetlands into the range where they could support agroindustrial systems. From these experiences, it would seem to be wise to develop a "floodplain-friendly" philosophy and to collect knowledge for a strategy that profits from the unique adaptations and life strategies of the organisms that have thrived successfully in these wetlands over the long course of evolution.

Sustainable development includes the maintenance of vital ecosystem structures and functions for the benefit of future generations. For instance, major modifications of the flooding regime, such as those predicted if the *hidrovia* is constructed, would lead to dramatic large-scale modifications of the Pantanal (Hamilton, 1999) and certainly do not fit within the concept of sustainable development. Economic benefits of the *hidrovia* are already today questionable and might vanish in the future because of a quickly changing global economy and the arising national transport alternatives; Pantanal degradation, however, is irreversible (Huszar et al., 1999).

Over the past two centuries, low-intensity cattle ranching has proven to be a sustainable management approach that maintains structures, functions, biodi-

versity, and the beauty of the landscape and is one of the very few examples of sustainable management of a tropical ecosystem introduced by Europeans. However, increasing economic pressure in the last decades requires changes in the traditional management concepts. Possibilities to increase the economic return of the ranches by amplifying pasture area through deforestation or through increasing animal density per unit area are limited. Viable alternatives are emerging, for instance, by the stimulation of a well organized ecotourism that benefits the local population, better exploitation of the little-used stocks of iliophagous fish species for human consumption, export of ornamental fishes, cultivation of game animals (e.g., caimans and capybaras), and a better marketing of local products under a "green" label that indicates environmentally sound production. The detailed analysis of developmental alternatives should lead finally to the formulation of an integrated master plan for the sustainable development of the Pantanal and its catchment area.

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