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Mapping and characterization of vegetation units by means of Landsat imagery and management recommendations for the Pantanal of Mato Grosso (Brazil), north of Poconé

by

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Abstract

In the present study, remote sensing in the northern region of Poconé-MT was used to identify vegetation categories, which were then mapped and characterized. The goal in generating the map was to provide information needed to support sustainable use and to formulate conservation policies. Vegetation units were identified and classified using digital images that were taken in 1990 by the Landsat Thematic Mapper© Satellite and then processed using ERDAS software. First, the vegetation classes were systematically defined. In a preliminary interpretation of the image data, Landsat-TM bands that allowed the best visual differentiation of these classes were selected and the image was georeferenced. Routes for trips to the study area to collect ground truth data (training samples) for further supervised classification were then determined. These data were subsequently classified according to The System of Classification of Brazilian Vegetation (VELLOSO et al. 1991), which has been used in other physiognomic maps of the Pantanal, in order to make our results comparable to those from other mappings. In addition, some modifications of this system were made due to the particular characteristics of the Pantanal and the scale used for this map. Six classes and 16 subclasses were defined for part I of the vegetation map of Pantanal, Mato Grosso, Brazil, specifically, the area north of Poconé. A distinction was made between the vegetation units of the Paraguayan Depression and those of the Pantanal due to the different characteristics of the vegetation from these two regions, and particularly the role played by inundation. The phytoecological region savanna (cerrado) covers a large part of the total area (53.05 %) and consists of five sub-classes. Two forest classes were identified: seasonal semideciduous forest and seasonal deciduous forest. These two phytoecological classes occupied 16.21 % of the total mapped area; 14.45 % of the area has been strongly modified by humans (agriculture, pasture, gold mine, and construction); 0.80 % is covered during the dry season by perennial water bodies. Based upon ground truth data and regional field experience, ten eco-zones are

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proposed and suggestions for sustainable management and conservation measures are discussed.
Keywords: **Pantanal, wetland, flooded savanna, vegetation, map.**

Resumo

Neste artigo identificou-se e caracterizou-se as diferentes categorias de vegetação detectadas por sensoriamento remoto na região norte de Poconé-MT para subsidiar políticas de uso sustentável e de conservação. As unidades da vegetação foram separadas e classificadas usando imagens digitais do Landsat Thematic Mapper© data de 1990 e o tratamento da imagem foi executado usando o software ERDAS. Na interpretação preliminar dos dados selecionaram-se as faixas de Landsat-TM que permitiram a melhor diferenciação visual das classes. Para a classificação supervisionada foram realizadas viagens de campo para identificar unidades de paisagens suficientemente grandes e georeferenciadas para servir de área testes. Adotamos o Sistema da Classificação da Vegetação Brasileira (VELLOSO et al. 1991) que tem sido usado em outros mapas fisionômicos do Pantanal para fins comparativos. Algumas modificações deste sistema foram necessários devido às características do Pantanal e da escala trabalhada neste mapa. Seis classes e 16 subclasses foram definidas e mapeadas na Depressão Paraguaia e Pantanal de Mato Grosso, norte de Poconé MT (parte I), (em anexo). Nós diferenciamos a vegetação da Depressão Paraguaia e do Pantanal isto porque as características da vegetação são diferentes para as duas regiões. A inundação foi considerada o fator principal desta diferenciação. A classe Savana (cerrado) cobre uma parte grande da área total (53,05 %) com cinquo subclasses. Duas classes florestais foram identificadas, uma Floresta sazonal semidecidual e outra a Floresta sazonal decidual, estas duas classes ocupam 16,21 % da área total. 14,45 % da área são modificadas fortemente pelo homem (agricultura, pasto, mina de ouro, e construções) e 0.80 % são cobertos por corpos d'água perenes, mesmo durante a estação seca. Baseado nos dados e em experiências do campo, são sugeridas 10 eco-zonas e são propostas sugestões para a gestão e a o uso sustentável.

Introduction

The Pantanal of Mato Grosso is a large wetland in the central region of the South American subcontinent, in the triangle between Brazil, Bolivia, and Paraguay that is formed by the coalescent alluvial fans of the tributaries to the Paraguay River. It covers about 160,000 km^2, of which about 140,000 km^2 belong to Brazil, 15,000 km^2 to Bolivia, and 5,000 km^2 to Paraguay, but estimates of its size vary considerably. The present study and the resulting map represent a registration of the vegetation of the northern portion of the Pantanal in the year 1990 on a scale of 1:100,000. The map was generated in order to describe the actual conservation state and for use in future initiatives aimed at preserving the biodiversity of this wetland through the designation of conservation areas or areas for sustainable use.

The Pantanal of Poconé harbors a rich vegetation. EITEN (1982) and SARMIENTO (1983) described it as a hyperseasonal savanna with specific vegetation types and large periodically inundated areas. The term savanna was initially coined to describe vegetation in which grasses are dominant. Meanwhile, the term savanna is broadly used by botanists and geographers in reference to the physiognomy of an open grassland with single trees or groups of trees, or to define a specific type of vegetation according to its floristic composition and habitat components (EITEN 1982). According to MEDINA (1982), savannas in the tropics are characterized by a particular climate, soil conditions, and factors such as fire and human impact. Savanna is the most common vegetation type in the tropics and occurs in 65 % of southern Africa, 45 % of the southern part of South America, and 60 % of northern Australia (HUNTLEY & WALKER 1982). In South America, savannas are found on either side of the equatorial rain-forest belt. The main savanna region in the south is known as *cerrado* (SOLBRIG 1996).

Most savanna areas of the Pantanal are wetlands that are periodically flooded by rain water and/or river water of the Paraguay River and its tributaries. They show pronounced terrestrial and aquatic phases because of a monomodal and predictable flood pulse (HAMILTON et al. 1996; JUNK 1993; JUNK & WANTZEN 2004) and are covered by a specific flood-tolerant vegetation. In the periodically flooded savannas, there are dispersed elevations that extend above the flood level and are covered by different types of cerrado vegetation, with semi-deciduous and deciduous forests. The flood pulse and the unique climatic and biogeographic settings give rise to the characteristic biodiversity of the Pantanal wetland (Junk et al. 2006).

ADAMOLI (1982) and ALVARENGA et al. (1984) divided the Pantanal into different subregions according to local ecological characteristics and floodplain regions of tributary rivers. One of these subregions is the Pantanal of Poconé, which covers 11 % of the Brazilian Pantanal. LOUREIRO et al. (1982) and AMARAL et al. (1982) determined the vegetation of the Pantanal of Poconé as savanna and mapped the physiognomic vegetation units according to to the following vegetation formations: dense woody savanna (*savanna arborea densa*), park savanna (*savanna parque*), grassland-woodland savanna (*savanna gramineo lenhosa*), and open woody savanna (*savanna arbórea aberta*).

Specific vegetation types of the Pantanal were described by PRANCE & SCHALLER (1982), RATTER et al. (1988), NASCIMENTO & NUNES DA CUNHA (1989), POTT & POTT (1994), PRADO et al. (1994), DUBS (1994), NUNES DA CUNHA (1990, 1998), GUARIM-NETO et al. (1996), SCHESSL (1999), ZEILHOFER & SCHESSL (1999), NUNES DA CUNHA & JUNK (1999), POTT & POTT (2000), SALIS (2000). SILVA et al. (1998, 2000), NUNES DA CUNHA & JUNK (2001, 2004), DAMASCENO-JUNIOR et al. (2004), and DAMASCENO-JUNIOR et al. (2005). Thematic maps were i.a. developed by RADAMBRASIL (1982), and remote sensing studies at specific sites by SILVA (1985), RAWIEL (1993), THE NATURE CONSERVANCY & FBCN (1993), and FASSNACHT (1995). A current review on the state of the art in vegetation mapping is given by SILVA & ABDON (2006).

The history of man-made landscape changes in the Pantanal is relatively recent. Initially, humans had little impact on the vegetation cover because cattle-ranching was still unknown. Instead, the rich variety of wildlife and fishes provided the early hunter-gatherers with a steady protein supply. About 5,000 years ago, the inhabitants built elevated structures for flood protection. Cattle-ranching was introduced in the Pantanal by European settlers at the beginning of the 18th century. Grazing by the animals and pasture clearing by the ranchers modified the plant cover, increasing the area of open savannas (campos limpos) while maintaining habitat and species diversity in a nearly natural "Parklandschaft" (WILHELMY 1957) landscape structure. Since that time and extending into the present, cattle breeds and horses have become highly adapted to the periodic flooding and poor food quality of the Pantanal. The main economic activity has become the breeding of beef cattle, with the current herd size estimated to be three million. While this system has contributed to the overall conservation of the Pantanal (DANTAS 2004), regional overstocking has caused damage in some areas, especially due to soil compaction. Nonetheless, the traditional human population of the Pantanal has accumulated a vast knowledge of the region, and an equilibrium between traditional indigenous management and low-intensity ranching has been reached.

In spite of the fact that the Brazilian Constitution declared the inundated savanna of the Pantanal to be a national heritage site, it is currently threatened by various human activities (ALHO et al. 1988; JUNK et al. 2006). Only 2.5 % of the Upper Paraguay River basin is protected (HARRIS et al. 2005). In addition, the rising social and economic pressure in the Pantanal, and thus the interest in increasing beef production, have led to the accelerated conversion of forested areas into pasture, causing large-scale changes in the vegetation cover. SILVA et al. (1999) estimated that from the original naturally forested area (about 30 %), only 4.5 % remains forested. Of the two states in which the Pantanal is localized, about 66.9 % of the recent deforestation has occurred in Mato Grosso do Sul and 33.1 % in Mato Grosso (SILVA et al. 1998b). Moreover, while dike and road construction have locally modified the hydrological regime, even greater threats have come mainly from outside the Pantanal. The large-scale change of the cerrado into agricultural plots, mainly for soybean plantations, has resulted in soil erosion and the transport of suspended material into the Pantanal (COUTO 1990; HAMILTON et al. 1998; WANTZEN 2006). The subsequent deposition of sediments inside the Pantanal regionally modifies its hydrology and affects plant cover. Gold and diamond mining in catchment areas has also increased the sediment load of the tributaries and it leads to mercury contamination of plants and animals in those areas where the mines are located (HYLANDER et al. 1994; VON TÜMPLING et al. 1995; CALLIL & JUNK 2001). A hydroelectric power plant constructed on the Manso River has modified the regional hydrology, which provides the basis for the ecological processes of the region. The largest threat derives from the planned construction of the Paraná-Paraguay waterway (*hidrovia*), mainly for ship transport of soybeans from the cerrado belt to the Atlantic Ocean. The waterway will alter the hydrology and thus the flora and fauna of large parts of the Pantanal (PETERMANN et al. 1999; GOTTGENS et al. 2001). In 2000, the Brazilian Government retreated from the project; however, reactivation of the plans is currently being debated.

Changes in vegetation cover and land use in the Pantanal have already occurred and will most likely accelerate in the future. Quantification of these changes requires maps that describe the actual status of the vegetation cover and the extent of human occupation of the area. In the present study, different types of vegetation were identified by remote sensing in the region north of Poconé-MT. The information was then applied to construct a vegetation map, with the goal of providing a source of information to be used in formulating policies to support sustainable use and conservation of the area.

Geography, climate, and hydrology

The municipality of Poconé is situated between 56° and 58°W and 16° and 18°S. The northern border is formed by various low-elevation mountain ranges, the Serrana region, and the Serra da Campina; the Paraguay River is the western border and the Cuiabá River forms the eastern and southern borders (Fig. 1).

According to RADAMBRASIL (1982), there are two geomorphological regions in the Poconé municipality. The Paraguay River Depression covers the northern part and the Pantanal the southern part. The dry climate of this region has shaped and abraded the landscape into convex and tabular forms. It is drained by the Formiga and Guanandi streams and a large number of small tributaries. The dominant vegetation type is cerrado (savanna). The Pantanal region is situated south of the municipality and is a flood plain with a topographic slope varying between 0.3-0.5 m km^{-1} E-W and 0.03-0.15 m km^{-1} N-S. This extremely low declivity reduces the runoff of the Paraguay River and leads to periodic inundation of most of the area during the rainy season. There are a few hills in the floodplain area, so that the height of the region varies between 80 and 150 m above sea level. Different types of periodically flooded grassland (campos), shrubland (cerrado), deciduous and semideciduous forests, and semi-evergreen floodplain forest occur in patches or strips (NUNES DA CUNHA & JUNK in press).

The climate of the Pantanal of Poconé belongs to the A_w savanna subtype, according to the classification by KÖPPEN, and has monthly average temperatures of about 25 °C (RADAMBRASIL 1982). Temperatures below 20 °C (in extreme cases 4 °C) may occur several times during the southern winter. These "friagens" are caused by short-term (4-5 days) cold-air masses from Antarctica that may move as far north as the cities of Cáceres and Cuiabá (TARIFA 1986; VALVERDE 1972). The rain regime is tropical-seasonal, with well-defined dry and rainy seasons in July-August and October-April, respectively (RADAMBRASIL 1982). In the transitional periods between these seasons, rainfall is less intense. Annual precipitation decreases to 1,250 mm near Cáceres, in the north, to 1,089 mm near Corumbá, in the south. According to TARIFA (1986), another decreasing rainfall gradient occurs in the east-west direction. Climatic and hydrological seasons are distinct in the Pantanal. While the arid conditions in the dry season are caused by low rainfall and high evapotranspiration, flooding is provoked by the poor drainage of the soils, rainfall, and flooding by the rivers. The hydrological regime is unusual and is due to the unique geological and geomorphological features of the Upper Paraguay River basin (PONCE 1995). While rainfall and flooding periods coincide in the northern part of the Pantanal, the low declivity of the Paraguay River results in a slow southward migration of the flood peak, so that inundations occur 2-3 months later than in the northern region. Inundations of the sub-basins depend strongly on the discharge of the individual tributaries and the current water level of the mainstem, which may provoke back-flooding with high local and temporal variability (HAMILTON et al. 1996). Apart from this annual variability, there are multi-year cycles of greater rainfall or more severe drought (ADAMOLI 1982; NUNES DA CUNHA & JUNK 2004).

Landscape units

There are many physical landscape structures in the Pantanal and they support a wide variety of characteristic plant communities tolerant to different degrees of inundation and drought stress. In the following, we introduce the terminology of these landscape units, using the local names given by the traditional communities living in the Pantanal. These names will be used in the description of the results.

Natural *campos limpos* are flat, low-lying, seasonally flooded areas that are covered by grasses, sedges, and herbaceous plants during the terrestrial phase and by aquatic macrophytes during the aquatic phase.

Campos sujos correspond to campos limpos with respect to herbaceous plant cover but shrubs and single trees are also present. Elimination of undesired shrubs and trees by ranchers and by cattle grazing has led to the transformation of campos sujos into artificial campos limpos on higher ground. The carrying capacity of the different types of native pastures has been reduced mainly due to the invasion of woody plant species into campo limpo areas. In fact, many farms in our study area have already suffered the impact of these plants. Multi-year hydrological cycles and regional legislation of brush-cutting have been attributed as potential causes for the invasions (NUNES DA CUNHA & JUNK 2004; SANTOS et al. 2006). Depending on the prevailing tree species, there are different subgroups of campos sujos, e.g., campo sujo de Canjiquera

(*Byrsonima orbignyana* A. JUSS), campo sujo de Pombeiro (*Combretum* spp.), and campo sujo de Lixeira (*Curatella americana* L.) (NUNES DA CUNHA & JUNK in press).

Campos de murunduns are grasslands covered with small earth-mounds several square meters in size and about one meter in height, reaching above the mean flood level. The mounds were built, probably over periods of centuries, by termites as accumulations of clay particles and eventually became covered with species of cerrado, for instance, *Curatella americana* (NUNES DA CUNHA 1990; PONCE & NUNES DA CUNHA 1993). The area between murunduns is covered by herbaceous plants and is periodically flooded during the rainy season.

Cordilheiras are paleo-levees several kilometers in length and about 100 m broad that extend about 1.5 m above the mean flood level. They are covered by cerrado vegetation or deciduous or semideciduous forest with a stratum of *Bromelia balansae* on the ground, indicating permanent terrestrial conditions. The topographic variations of the cordilheiras affect its floristic composition (NUNES DA CUNHA 1990).

Capões are round or elongated remnants of degraded paleo-levees (PONCE & NUNES DA CUNHA 1993) that extend about 1.5 m above the mean flood level. They are covered by cerrado vegetation or deciduous or semideciduous forest, similar to cordilheiras.

Levees are elevated river banks formed by the deposition of recent sediments. They become flooded only during very high floods and are covered by deciduous or semideciduous forest.

Landis are shallow seasonal channels in the campos dos murunduns with a close connection to the groundwater table. They are covered by semi-evergreen flood forest (RIBEIRO et al. 1999).

Vazantes are temporary drainage channels at the lower part of the Pantanal plain. They are covered during the terrestrial phase by grasses and herbaceous plants and during the aquatic phase by aquatic macrophytes (ABDON et al. 1998).

Corixos are small floodplain channels that connect perennial lakes with each other and with the river channel. Periodically, they may be covered with aquatic macrophytes (RADAMBRASIL 1982; WANTZEN et al. 2005).

Brejos are swampy areas covered by perennial hydrophilous herbaceous plants, for instance, *Thalia geniculata*, *Cyperus giganteus*, *Aeschynomene* spp., and *Canna glauca*.

Lagoas and *baias* are lakes that are connected to the river system during high-water periods (ABDON et al. 1998). They are colonized by free-floating and submerged aquatic macrophytes that often show a concentric zonation (RADAMBRASIL 1982; POTT & POTT 2000, WANTZEN et al. 2005).

Salinas are lakes that are isolated from the drainage system over long periods of time (ABDON et al. 1998). They show increased concentrations of mineral salts because of high evaporation rates. Since salinas are isolated from the groundwater table (ABDON et al. 1998), their water levels fluctuate much less than those of lagoas. Aquatic macrophytes are absent and algae dominate, for instance, *Oscillatoria* spp., *Aphanothece* spp., and *Synoechoccocus elongatus* (MOURÃO 1989). Salinas occur mostly in the southern Pantanal but not in the studied area.

Inselberge (witness hills) are small isolated rocky outcrops in the floodplain near the slopes of the mountains surrounding the Pantanal. They are covered with deciduous forest and xerophyllous plants.

Aterros de índio, capão de aterro, aterros de bugre are artificial earth-mounds constructed mostly in pre-colonial times by the indigenous settlers of the region to provide protection during the annual flood season. Excavations reveal fragments of ceramics and other archeological remnants (PONCE & NUNES DA CUNHA 1993).

Batumes are large and dense communities of floating aquatic vegetation which accumulate organic detritus that can become colonized by shrubs and small trees (POTT & POTT 2000; WANTZEN et al. 2005). In the Baia Grande, a large floodplain lake, broad areas of organic material from floating aquatic vegetation (*batumes*) occur that can become confounded in the satellite image with bare soil, because the vegetation loses leaves during the dry season.

Materials and methods

Vegetation units were identified and classified using digital images that were taken in 1990 by the Landsat Thematic Mapper Satellite. The images were processed using ERDAS software. First, the classes to be mapped were defined. Bands 2, 3, and 4 (visible green light, near and middle infrared, respectively) of Landsat-TM allowed the best visual differentiation of these classes and were therefore used in a preliminary visual interpretation of the image data. Routes for trips to the study area to collect the ground truth data (training samples) for further supervised classification were determined and the Universal Transverse Mercator (UTM) coordinates of the different training-sample areas were extracted from the images.

The Landsat TM images were rectified and georeferenced to the UTM coordinate system. This was done using official topographic maps with a scale of 1:100,000 (DSG 1982). The satellite images were georeferenced using landmarks that could be identified in both the Landsat images and the topographic maps. These landmarks served as identical points in transformation of the Landsat image coordinate system into the UTM coordinate system of the topographic maps. In this way, the resulting vegetation map was in the same coordinate system as the topographic maps of the Diretoria do Serviço Geográfico Brasileiro (DSG). The training samples collected in the field were transformed into signatures that defined the characteristics of each of the classes. Each picture element (pixel, actual size 30 x 30 m) of the image was assigned to one of the predefined classes. Before classification, the signatures obtained were analyzed and the statistics of the sample areas were evaluated. The different training samples for a single class were merged into one signature. The resulting signatures were used to obtain a supervised classification by applying the maximum-likelihood method (SWAIN 1978; HABERÄCKER 1977).

Ground truth data were collected in field trips in which sufficiently large landscape units were identified with respect to their vegetation structure. These data were then georeferenced, identified in the digital Landsat TM images, and marked as polygonal areas. At sites where access by car was impossible, flights were undertaken to observe, recognize, and register the different phytophysiognomies of those areas and to register the geographic position of particular places located in them. In addition, some habitats were filmed and photographed. Surveying began at the beginning of the dry period in 1994, when access to most of the areas of interest was possible by car. A global positioning system (GPS, Magellan Inc., Santa Clara, California) was used to register the geographic position of the training samples and to verify the phytophysiognomic units.

The final results of the classification were examined, statistics were generated by comparison to control sample areas, and the vegetation classes were reevaluated accordingly. Classes of the same vegetation type that were separated, e.g., with respect to phytophysiognomy at different water levels, were merged into a single class. The results were verified and confirmed in the field.

The internationally recognized System of Classification of Brazilian Vegetation (VELLOSO et al. 1991), which has been used in other physiognomic maps of the Pantanal, was also adopted in the present study in order to allow comparison between our results and those of other studies. The following terminology was selected from VELLOSO's hierarchy, which is organized according to the ecological physiognomy of the particular formation:

* **Class** (*classe de formação*) refers to the type of vegetation (e.g., forest, scrubland, woodland).

* **Subclass** (*subclasse de formação*) is a subunit of the above term and is defined by the regional climate.

Whenever possible, the terms used for classes and subclasses were the same as those in VELLOSO'S original paper; however, some terms were modified to better delineate the formations of the Pantanal. The categories defined by VELLOSO below the level of subclass (*grupo de formação, subgrupo de formação*, etc.) were not used here since they could not be distinguished due to limitations in scale (1:100,000). Nonetheless, several plant communities have been identified within the subclasses. A more detailed description of these communities can be found in (NUNES DA CUNHA & JUNK in press).

In the past years, several new terminologies were introduced. In order to facilitate comparison of this study with later ones, a synopsis of the terminology based upon the physiognomic-ecological system of the Instituto Brasileiro de Geografia e Estatística (1992) and the terminology used in the Upper Paraguay River Basin Conservation Plan (PCBAP) of 1997 is provided (Table 1).

Results

Extent of vegetation classes

Consistent with the phytoecological units described by VELLOSO (1991), five classes of terrestrial vegetation and one classe of aquatic habitats were defined for the vegetation map of Pantanal, Mato Grosso, Brazil (Part I: North of Poconé) (Table 2):

1. Seasonal semideciduous forest, with two subclasses
2. Seasonal deciduous forests, with two subclasses
3. Savanna, with five subclasses
4. Transition system (ecological tension area), with two subclasses
5. Secondary systems, with five subclasses
6. Water bodies

In Table 2, the vegetation units of the Paraguay Depression and the Pantanal are listed separately because the characteristics of the vegetation in the two regions differ, mostly due to the degree of inundation. Thus, 53.05 % of the mapped area consists of savanna, 41.02 % being in the Pantanal and 12.03 % in the Paraguayan Depression. In the latter, seasonal semideciduous forest and seasonal deciduous forest are the most abundant (9.58 %). Since, at one time, these forests had a greater presence in the Paraguayan Depression, it is likely that most of the 10.03 % deforestation has occurred in the classes seasonal semideciduous forest and seasonal deciduous forest as well as in the class savanna forest.

Seasonal semideciduous forest (13.51 %) and seasonal deciduous forest (2.7 %) occupy 16.21 % of the total mapped area. Another forest formation, the seasonally flooded evergreen forest, was assigned to the class of formations influenced by natural dynamics, i.e., transition zone (transitional systems). This class includes pioneer forest formations subjected to periodic flooding, for instance, the *cambarazais* (stands dominated by *Vochysia divergens*), which covers 12.13 % of the mapped area, and floating aquatic vegetation. Savanna (cerrado) accounts for a large part of the total area (53.05 %). At the time that the satellite images (1990) were acquired, 14.45 % of the area had been strongly modified by humans (agriculture, pasture, gold mine, and constructions). Only 0.80 % was occupied by perennial water bodies; however, it must be noted that the satellite image was taken during the peak of the dry season.

The areas suffering from the impact of human activities were poorly visualized in the investigated region of the Pantanal. Generally, deforestations occur in areas that are not affected by inundation, such as the cordilheiras and capões, which have been transformed into pasture, subsistence farming plots, or homesteads. These landscape units are so small that, in most cases, it was not possible to indicate them within the scale chosen for the map. Likewise, areas of former campo sujo vegetation, in which woody plants were removed, could not be shown on the map. During the data sampling period, the majority of the deforested areas belonged to only three or four large farms. Areas with a high density of cattle had denuded soil surfaces and were thus considered to be areas of deforestation in the Pantanal.

Some landscape units are found in only one of the two sub-areas. Floating aquatic vegetation (batumes) and permanent water bodies (baías) occur only in the Pantanal, while sugar-cane plantations, gold mines, and cities are located only in the Paraguayan Depression.

Different types of grassland were included in the savanna subclasses, i.e., parkland savanna, woody grassland savanna, and seasonally flooded grassy-woody savanna. They are very important for cattle-ranching in the Pantanal. The predominant grassland types are Mimoso characterized by *Axonopus purpusii* (MEZ) CHASE, *Hemarthria altissima* (POIR) STAPF & HUB. and *Paspalum almum* CHASE, Macega branca, mostly *Paspalum plicatulum* MICHX., and Pacova, with *Thalia geniculata* L. The latter type covers the lowermost areas of the floodplain, such as seasonal swamps. Other grass-dominated areas with scattered scrub, low trees, or palm vegetation are: Cambará scrub savanna (*Vochysia divergens* POHL), and Pombeiro grassland (*Combretum lanceolatum* POHL). These woody species are subject to brush-cutting by farmers, who consider the invasive species to be competitors of the (desired) grasslands. Consequently, many areas are kept free of woody vegetation by human activities.

Vegetation classes and subclasses

1. Class: Seasonal semideciduous forest (*Floresta estacional semidecidual*)

1.1. Subclass: Lowland seasonal semideciduous forest (*Floresta estacional semidecidual de terras baixas*)

In the Paraguayan Depression, seasonal semideciduous forest is represented by the subclass semideciduous forest. It occurs at lower altitudes (around 200 m asl). Near the city of Poconé, only small patches remain between deforested areas because the soil that supports this type of forest is also appropriate for agricultural use (sugar cane, manioc) and as pasture. The remaining patches represent 7.28 % of the area and occur primarily in the hills in the northern section of the study area, outside the boundaries of the municipality. This subclass is characterized by a tree stratum about 10-30 m in height, with a dense canopy formed by *Aspidosperma cylindrocarpon* MÜLL. ARG., *Protium heptaphyllum* (AUBL.) Marchand, *Chrysophyllum gonocarpum* (MART. & EICHLER ex MIQ.) ENGL., and other tree species. Bamboo (*Guadua* sp.) forms the lower stratum of the forest. In general, lianas and epiphytes are also present.

1.2. Subclass: Alluvial seasonal semideciduous forest (*Floresta Estacional Semidecidual Aluvial*)

In the Pantanal, seasonal semideciduous forest is represented by the subclass seasonal semideciduous forest of the lowlands. This type of forest is encountered on the high levees along the shores of the Paraguaizinho and Bento Gomes Rivers, which are inundated only during extreme flood periods, and on cordilheiras. The trees shed leaves in the dry season during July to September, and the intensity and duration of the dry season determine the deciduous period. *Astronium fraxinifolium* SCHOTT ex SPRENG., *Enterolobium contortisiliquum* (VELL.) MORONG, *Tabebuia roseoalba* (RIDL.) SANDWITH, and *Scheelea phalerata* (MART. ex SPRENG.) BURRET are characteristic species of the tree stratum, with emerging specimens being about 20 m in height. The lower stratum is formed by young individuals. The soil is covered with a dense litter layer during the dry period. Bamboo is absent. Semi-deciduous forest is found on capões, cordilheiras, and levees with *Tabebuia* spp. and *Scheelea phalerata* (cordilheira de mata, capão de mata).

2. Class: Seasonal deciduous forest (*Floresta estacional decidual*)

2.1. Subclass: Lowland seasonal deciduous forest (*Floresta estacional decidual de terras baixas*)

In the Paraguayan Depression, seasonal deciduous forests occur at lower altitudes (around 200 m asl). Small patches are found on the hills and in the interfluvial zone. Drought stress determines the amount of leaf shedding, which can reach 100 % in very dry years. These forests are present in flat areas of soils with elevated organic matter content. Many such areas have been converted to pasture because the trees can be easily accessed and removed by machines. Seasonal deciduous forests represent 1.8 % of the vegetation of the Paraguayan Depression. *Anadenanthera colubrina* (VELL.) BRENAN, *Calycophyllum multiflorum* GRISEB., *Astronium urundeuva* (ALLEMÃO) ENGL., and *Sterculia striata* A. ST.-HIL. & NAUDIN are important species in the tree stratum. The height of emerging species is about 15-20 m. Lianas occur frequently. The floristic composition is similar to that of the seasonal semideciduous forest, but the level of leaf shedding is more pronounced (about 90 % of the leaves are usually shed).

2.2. Subclass: Alluvial seasonal deciduous forest (*Floresta estacional decidual aluvial*)

In the Pantanal, mapping of the forests was impossible because the patches were too small. Typically, the plant communities are dominated by a single species, e.g., deciduous forest by *Callisthene fasciculata* MART. (*carvoal*) and deciduous forest in *cordilheiras, capões*, and *levees* by *Sebastiana brasiliensis* SPRENG. and *Seguieria paraguayensis* MORONG (*Cordilheira de mata, capão de mata*).

3. Class: Savanna (*Cerrado*)

3.1. Subclass: Savanna forest (*Savana florestada = Cerradão*)

In the Paraguayan Depression, savanna forests are characterized by the dense tree vegetation. Due to intensive deforestation, very few such areas remain. Occasionally, savanna forest floristically resembles semideciduous forest. The tree stratum contains characteristic savanna species, such as *Caryocar brasiliense* CAMBESS., *Qualea grandiflora* MART., *Vatairea macrocarpa* (BENTH.) DUCKE, and *Diptychandra aurantiaca* TUL., which are typically 7-12 m high. In the Pantanal floodplain area, different communities can be distinguished, for example, dense low tree savanna, which is restricted to the non-flooded areas of *cordilheiras* and *capões*.

3.2. Subclass: Low tree and shrub savanna (*Savanna arborizada*)

This subclass can be observed throughout the Paraguayan Depression. The vegetation is characterized by nanerophyte species, such as *Anemopaegma arvense* (VELL.) STELLFELD ex DE SOUZA, *Cochlospermum regium* (SCHRANK) PILG., and

Anacardium humile A. ST.-HIL. It also includes areas of secondary vegetation (capoeira) that in the satellite images could not be distinguished from the natural low tree shrub savanna. For the Pantanal region, open cerrado and community types of *campo sujo* are included in this subclass, for instance, *Campo sujo de canjiqueira* (*Byrsonima orbignyana* A. JUSS.), *Campo sujo de paratudo* (*Tabebuia aurea* (SILVA MANSO) BENTH. & HOOK. F. ex S. MOORE), and *Campo sujo de cambará* (*Vochysia divergens* POHL). Low tree scrub woodland and seasonally flooded savanna parkland occur mainly in interfluvial areas, which are less flooded. Formerly, these areas were intensively managed and covered by grassland.

3.3. Subclass: Parkland savanna (*Savana parque*)

This subclass occurs in small patches in the Paraguayan Depression and as large extensions in the Pantanal. In both regions, parkland savanna has been used for centuries as natural pasture. This subclass is also designated as seasonally flooded parkland savanna because there is shallow flooding during the rainy season. The herbaceous stratum of parkland savanna in the Paraguayan Depression is characterized by *Axonopus* spp., *Paspalum* sp., *Echinolaena inflexa*, (POIR.) CHASE, *Ichnanthus procurrens* (NEES ex TRIN.) SWALLEN, *Syngonanthus* sp., and *Hyptis crenata* POHL ex BENTH., while in the Pantanal it is highly variable and depends on the position of the savanna within the flooding gradient (see detailed studies by PRADO et al. (1994) and SCHESSL (1999).

There are four physiognomic types of parkland savanna, each of which occurs under specific geomorphological conditions or is characterized by dominant plant species.

In the transition zone between the Pantanal and the Paraguay Depression, there is one type of parkland savanna; it consists of large numbers of small earth-mounds made by termites, the *Campos de murundus* (termite savannas) described above. At the borders of the *murundu* earth-mounds, *Annona pygmaea* W. BARTRAM, *A. dioica* ST.-HIL., and *Anacardium nanum* A. ST.-HIL. normally occur, while in the centers of the mounds the most frequent species are *Curatella americana* L., *Bromelia balansae* MEZ and *Simarouba versicolor* A. ST.-HIL.

The other common types of parkland savanna only occur in the Pantanal. There are also two types of parkland savannas with monospecific stands of either *Tabebuia aurea* (SILVA MANSO) BENTH. & HOOK. F. ex S. MOORE (*Paratudal*), which covers large areas near the Paraguaizinho River, or *Tabebuia heptaphylla* (VELL.) TOLEDO (*Piuval*). The fourth parkland savanna type consists of grassland vegetation with interspersed forested islands (*capões*). The tree vegetation of the capões is not made up by a single species, but by an assemblage of, e.g., *Astronium fraxinifolium, Dipteryx alata*, and *Sterculia striata*. These savannas differ considerably from one another and from other types of parkland savanna with respect to floristic composition, which varies according to soil type, inundation, and management. For example, the occurrence of large numbers of the palm *Scheelea phalerata* (*acuri*) is an indicator of anthropogenic alteration. These altered forests are locally called *Capões com acurizal*.

The inner parts of the vegetated islands are often densely covered with the bromeliad *Bromelia balansae* MEZ. The characteristic herbaceous species of the outer borders of the capões, which become flooded, include *Cyperus haspan* L., *Cyperus luzulae* (L.) ROTTB. ex RETZ., *Eleusine indica* (L.) GAERTN., *Panicum laxum* SW., *Setaria parviflora* (POIR.) KERGUÉLEN, *Hymenachne amplexicaule* (RUDGE) NEES, *Pas-*

palidium paludivagum (HITCHC. & CHASE) PAR., and *Leersia hexandra* SW.

3.4. Subclass: Woody grassland savanna (*Savana-gramíneo-lenhosa = Campo limpo de cerrado*)

VELLOSO et al. (1991) established a vegetation class called *Savana-gramíneo-lenhosa* to designate a group of vegetation types dominated by grassy vegetation and including a variable contribution of woody life forms (hemicryptophytes and geophytes). In the Paraguayan Depression, woody grassland savannas occur mainly on hills with shallow soil depth or even on stony outcrops (*afloramentos*). This type of vegetation suffers from annually recurring campfires. However, many plant species have adapted to survive fire, e.g., densely growing tussock grasses in which the central (green) part or geophytic growth of the meristemal parts is protected. The trees are characterized by thick, fire-protecting barks, tortuous growth forms (due to recurrent regrowth from protected meristems), xylopodia, and leaf flush/flowering/fruitification that is timely adapted to the fire season. Reviews on fire adaptations can be found in COUTINHO (1977, 1982). This subclass does not occur in the Pantanal.

3.5. Subclass: Seasonally flooded grassy-woody savanna (*Savana-gramíneo-lenhosa sazonalmente inundável*)

In analogy to the previous vegetation subclass, which occurs exclusively in the Paraguayan Depression, we established a subclass of woody grassland savanna that becomes annually flooded in the Pantanal. This subclass was not previously described by VELLOSO (1991). The contribution of woody plants is minimal. Areas with higher contributions of woody plants belong to the subclass "Low tree shrub savanna" (3.2.).

The most prominent representative of this subclass is the *campo limpo inundado* (inundated grassland), which is typical for the deeply flooded parts of the Pantanal. During the terrestrial phase, it is dominated by low grasses that produce large amounts of biomass within a short time and which are thus important in cattle-ranching. At the scale used in our map, a distinction between the most typical plant communities was not possible. However, ground truth analysis revealed that the most important communities for cattle-ranching are: *Mimoso grassland* (*campo de mimoso*), dominated by the species *Paratheria prostrata* GRISEB., (capim mimoso), *Reimarochloa brasiliensis* (SPRENG.) HITCHC., *Panicum laxum* SW., *Axonopus purpusii* (MEZ) CHASE, and *Paspalum almum* CHASE, and *Macega branca* grassland (*campo de macega branca*) with *Paspalum plicatulum* MICHX.

This subclass is characteristic of deeper inundated areas and therefore the corresponding vegetation dominates those areas along the lower section of the Bento Gomes and Paraguaizinho Rivers and the area near the Paraguay River. The majority of the deforested areas has been transformed into grassland and is found near ranch houses and in intensively managed areas.

Within the extensive areas of these grass-dominated fields, there are round or linear localized depressions. These remain water-filled during the dry season and harbor rapidly growing, moisture-requiring species, such as *Thalia geniculata* L., (*pacova do brejo*), that occur in drainage channels or swamps (*brejo*). Campos with a few individuals of *Ipomoea fistulosa* MART. ex CHOISY (*algodoeiro*) and *Combretum lanceolatum* POHL ex EICHLER (*pombeiro*) are also included in this class, although these species may be invasive (see discussion on *campo sujo* above). This physiognomic type occurs mainly in areas flooded by the Paraguaizinho and Bento Gomes Rivers.

4. Class: Formations influenced by natural dynamics = Transition systems (*Formações influenciadas por dinâmicas naturais*)

VELLOSO's et al. (1991) vegetation system did not take into account formations of vegetation that are strongly influenced by natural dynamics, e.g., riverine dynamics and fire cycles. The term in his system that comes closest to describing this situation is *Sistema Edáfico de Primeira Ocupação = Formações pioneiras*, referring to recent establishment of pioneer vegetation. In the map, we have denominated this type of formation as "transition zone". This class comprises vegetation types that are influenced by short-term changes in the environment, especially the change between dryer and wetter years within multi-year cycles. For example, the sequence of wetter years after 1973 favored the development of hygrophilous plant species. Major areas representative of this class are found along the rivers Bento Gomes, Paraguaizinho, Rio Claro, and Cassanges as well as along paleo-river channels.

4.1. Subclass: Seasonally flooded brevi-semideciduous forest (*Floresta brevi-semidecidua sasonalmente inundada*)

This subclass is represented by dense monospecific forests of *Vochysia divergens* (cambarazais). The characteristic reflection pattern of the leaves due to their waxy surface and the widely recognizable yellow inflorescence that is present at the beginning of the dry season (RAWIEL 1993; FASSNACHT 1995; SILVA et al. 2000) allow recognition of the cambará trees (*Vochysia divergens*) despite the coarse scale of the satellite image that was used (pixel size 30 x 30). Near the rivers Claro and Pinxaim and between the Cassange and Alegre Rivers cambarazais cover large areas. This species shows specific patterns of expansion and reduction (Fig. 2) and may invade natural grasslands in the Pantanal during pluri-annual wet periods. During such periods, the species becomes restricted to moist areas as it does not tolerate fire stress (NUNES DA CUNHA & JUNK 2004).

4.2. Subclass: Floating aquatic vegetation (*Batumes*)

This subclass is characterized by aquatic macrophytes and grasses that create dense mats with their rooting and stolonization structures. Aquatic macrophytes such as *Eichhornia crassipes* (MART.) SOLMS, *Paspalum repens* P.J. BERGIUS, *Pistia stratiotes* L., *Salvinia auriculata* AUBL. and especially *Oxycarium cubense* POEPP. & KUNTH. cover the shores of rivers, lakes, and drainage channels (corixos). These species fix dead organic material with their roots and form dense organic carpets, locally called *batumes* or *baceiros*, which in permanently flooded areas become colonized by herbs, shrubs, and eventually trees. Plant species show a characteristic succession with increasing age and thickness of the carpets (POTT & POTT 2003). During the high-water season, the *batumes* can become fragmented and moved around the lakes by wind action and water currents; during the dry season, they may become stranded and their organic matter oxidized and mineralized. Multi-annual cycles strongly influence the occurrence and thickness of these organic-matter layers; for example, due to the high water level in 1973, the *batumes* in the Baia Grande were much larger than before (WANTZEN et al. 2005; see schematic view in Fig. 3). *Batume* herb species are not adapted to fire and thus their seed banks can be destroyed by it. In very dry seasons occurring after longer wet periods, large amounts of organic matter fall dry on areas where the batumes have become stranded. If fires then occur, they have deleterious effects because they burn for a very long time. Moreover, fires may creep unperceived below the vegetation mats and are therefore very difficult to combat (analogous to peat areas).

5. Class: Secondary system (*Sistemas segundários*)
This class comprises different types of man-made systems.

5.1. Subclass: Artificial pastures and areas of subsistence agriculture (*Pastagens artificiais e áreas de agricultura de subsistência*)
Only about 20 % of the area of the municipality of Poconé (17,261 km^2 (CNM, 2006) belongs to the Paraguayan Depression and is not seasonally inundated. This area has been systematically transformed into pastures or areas of subsistence agriculture. During the inundation season, cattle herds of the Pantanal are transported to these dryer areas.

On large farms of the Pantanal region, accelerated deforestation of *cordilheiras* and *capões*, locally called "field clearing" (*limpeza do campo*), has been used to increase the amount of pasture. The affected areas are relatively small and scattered, and most are too small to have been included in the map. However deforestation of the *cordilheiras* negatively and severely impacts the ecosystem because it destroys important breeding and shelter areas for wildlife as well as shelter for cattle during inundations.

5.2. Subclass: Sugar-cane plantations (*Canaviais*)
Sugar-cane plantations represent 0.23 % of the mapped area and are situated near an alcohol factory located on the road between Poconé and Cáceres. Sugar cane (*Saccharum officinarum*) was introduced for sugar and alcohol production in the early days of Portuguese colonization, and sugar factories in the Pantanal date back to the late 19th century. The plantations are strictly monospecific due to the use of pesticides. Sugar-cane plantations have recently become a political issue because they are an essential part of the Brazilian biofuel program, and several other countries are likely to adopt this program. However, there is public concern about the effects of pesticides used in sugar-cane cultures on the brooks and tributaries of the Pantanal wetland, so that initiatives have been introduced to prohibit sugar mills (usinas) in the vicinity of the Pantanal (RIOSVIVOS 2006). An accident at the sugar mill Usina Santa Olinda in Sidrolândia (MS) in 2003 led to the release of toxic substances into the Canastrão and Cachoeirão streams and caused mass mortalities of fish. In addition to large amounts of oxygen-consuming organic matter, high concentrations of phosphorous and nitrogen were measured. Only the small size of the mill averted an even larger ecological disaster.

5.3. Subclass: Gold mines (*Mineração de ouro*)
Gold mines and depositions of mining residuals cover 0.2 % of the mapped area. The tailings represent a many-fold problem. In addition to their content of mercury residues, which are low in concentration but high in their total amount (VON TÜMPLING et al. 1995), the deposited sediments are extremely fine-grained and low in nutrients. Since hardly any pioneer vegetation grows on tailing material, affected areas have a devastated appearance, resembling a "lunar landscape". Reclamation projects to enable natural plant growth involve substantial efforts of transporting fertile soil, irrigation, and planting.

Gold mining in the Poconé area began in the 18th century and was followed at the beginning of the 1980s by a period of intensive exploration of superficial gold deposits, which required the use of heavy machinery and mercury to extract the gold from the sediments (NOGUEIRA et al. 1997). This activity increased the sediment load of the affected streams and rivers and provoked the contamination of organisms, including humans, with mercury. In recent years, mercury release has decreased considerably because the superficial gold deposits are depleted. However, the presence of about 2 t of mercury, deposited mostly in metallic form in the environment, remains of concern (JUNK et al. in press).

5.4. Subclass: Roads and dikes (*Estradas e aterros*)

The Pantanal Highway (*Transpantaneira*) and the connecting side-roads constructed on dikes to avoid flooding during the rainy season form a steadily increasing "fishbone" system. Several ranches have also built dikes to protect against flooding. Roads and dikes comprise a relatively small area but their effect on the Pantanal is large because they facilitate human access to the area and interrupt the natural pathways of the water. Although the Pantanal Highway was initially constructed without any bridges, periodic flooding, which broke the dike at over 130 sites over a length of 137 km, eventually led to bridge construction. Still, the damming effect of the dike-associated road has been enormous; for example, the Bento Gomes River has changed its flow and now back-floods large areas in the northernmost section of the Pantanal.

Discussion

Vegetation mapping in the Pantanal - a survey of research efforts

The vegetation of the Pantanal has yet to be mapped in proper detail, and all existing maps, including the one produced in this study, have to be regarded as single stones in a mosaic - an attempt to obtain a better total picture of the distribution and dynamics of the component vegetation. The first set of maps covering the Upper Paraguay Basin, including the Pantanal, was elaborated by the Ministry of Internal Affairs (MINISTÉRIO DO INTERIOR) as part of regional development planning, including protection of the Pantanal (Brasil 1979). Later, the Radam Brasil Project (RADAMBRASIL 1982) in conjunction with the Ministry of Mining and Energy (Ministério de Minas e Energia) produced a set of maps covering the geology, geomorphology, vegetation, soils, and land use of this region. Currently, these maps are the most comprehensive documents about the area; however, their scale of 1:1,000,000 is very coarse.

Recently, the Ministry of the Environment (Ministério de Meio Ambiente) elaborated an environmental zoning plan, as part of the broader Upper Paraguay River Basin Conservation Plan (PCBAP). This zoning took into account thematic, physical, biotic, social, economic, institutional and legal aspects of the basin, and included the production of maps, at a scale of 1:250,000 that described the vegetation, soils, and geomorphology of the region. The basin was divided into 44 areas the potentials and fragilities of which were defined. Major contributions were quantification of the level of deforestation (Brasil 1997) and the PCBAP vegetation maps, which were based on the maps of Radam Brasil. Both approaches used the classification system of VELLOSO et al. (1991). The map of the IBGE (1993) included the Pantanal in the bioma cerrado, but the IBGE (2004) recently produced a map of Brazilian biomes (*Mapa de Biomas do Brasil*), at a scale of 1:5,000,000, in which the Pantanal is considered as a distinct biome (*Bioma Pantanal*) covering 1.76 % of Brazilian territory. A map in which aerial survey was used to quantify the vegetation classes of the entire Brazilian Pantanal and to determine their distribution (SILVA et al. 2000) revealed 16 such classes based on phytophysiognomic aspects, the most important being grassland (31.1 % of the entire area), *cerradão* woodland (22.1 %), *cerrado* (14.3 %), marshes (7.4 %), semideciduous forest (4.0 %), gallery forest (2.4 %), and floating mats (2.4 %). These maps provide very valuable large-scale information about the vegetation and serve as a basis for assessing large-mammal populations and their migrations.

Several local studies were carried out in the Pantanal with the goal of producing thematic maps: for instance, geo-ecological characterization of the northern Pantanal (ZEILHOFER 1996), the distribution of cambará forests (*Vochysia divergens*) (FASSNACHT 1995), human impacts (RAWIEL 1993), the Pantanal National Park (PONZONI et al. 1989), Fazenda Nhumirim (SILVA et al. 1998a), Fazenda Bodoquena (BOOCK et al. 1994; SILVA et al. 1998a), and part of the Nhecolândia sub-region (ABDON et al. 1998). The last four of these maps were made in the Pantanal of Mato Grosso do Sul. Most of these maps have not been published.

Methodological constraints in this map

The map produced as part of this study covers the northern Pantanal, including part of the non-flooded Paraguayan Depression, at a scale of 1:100,000. The pixel size of the satellite images upon which the map was based was 30 x 30 m. Analysis of the images confirmed the field observations, which revealed a small-scale mosaic of different habitats. Elaboration of the map required combining the pixels into major classes such that small peculiarities disappeared. For example, *capões* and many small swamps and patches of deciduous forests cannot be visualized on the map. In the Pantanal of Mato Grosso, vegetation type and community structure can change within a distance of a few meters depending on the topography, which determines the amplitude and duration of flooding by rain water and/or river discharge during the flood period. Soil type, humidity, fire stress, and grazing intensity are other important factors affecting vegetation cover and habitat diversity.

In a detailed analysis of a vegetation transect crossing a levee along the Cassange River, NUNES DA CUNHA & JUNK (2001) differentiated eight forest communities over a distance of 440 m. They concluded that woody species of the Pantanal are distributed along a topographic gradient according to their tolerance of periodic flooding and drought. The elevated number of species found on rarely flooded habitats can be explained by the proximity of the permanently non-flooded savanna (cerrado) bordering the Pantanal. It supports drought-tolerant semideciduous species, which are also tolerant to short and shallow flooding. An analysis of the 85 most common woody species in the Pantanal of Poconé revealed that 30 % are restricted to high-lying areas that are rarely flooded, while 65 % have a wide range of distribution, and only 5 % occur in areas subjected to long-lasting inundation (NUNES DA CUNHA & JUNK 1999, 2001).

As noted above, this study was conducted during the dry period. During the flood period, the landscape reveals different patterns that were not taken into consideration in this map, but must nonetheless be studied for future land-use planning.

Landscape zones detected in this map: a basis for conservation planning

An advantage of simplifying the vegetation units is that larger zones appear more clearly, which can be attributed to biogeographic units or ecoregionalization projects. An overarching principle of the mostly planar landscape of the Pantanal is the erosional and depositional pattern of the river systems, which rework recent and old sediments. A few centimeters difference in the height of the landscape or the water level can decide the flow direction of rivers. Secondary floodplain channels are often observed to change flow direction depending on where riverine or rainwater has caused higher flooding. Even the dislocation of plant carpets (batumes, see above) can change the river flow or block river channels completely (WANTZEN et al. 2005). Therefore, in this map particular attention was paid to the patterns of recent river floodplains, inactive floodplains, and emerging terraces in order to delineate major landscape zones (Fig. 1).

Current use of the northern Pantanal and recommendations for its future use based on the landscape zones established in this study

The vegetation map covers a region of the Pantanal that is subject to intensive landscape changes. Large areas have been deforested, the vicinity of the Paraguay Depression facilitates the shifting of cattle from native pastures in the Pantanal to terra firme uplands during flood periods, and the Transpantaneira highway (which is entirely built on dikes) has locally blocked the natural course of flood waters. Plans for both conservation and sustainable management are urgently needed, and in this respect the current map provides a practical tool that can be readily used by regional authorities and NGOs. An overall goal should be to maintain the high regional habitat diversity found in the Pantanal. The natural drivers for the coexistence of different successional stages of the vegetation are the annual flood patterns, multi-year hydrological cycles, and the effects of fire during dry phases. The main human activities shaping the vegetation are deforestation, introduction of exotic grass species, cattle-ranching, and dike construction. More recently, the flood pattern of the northern Pantanal has been changed by the construction of dams in tributaries, such as the Rio Manso dam, which influences 25 % of the discharge of the Cuiabá river. While extensive cattle-ranching has had a positive influence on some aspects of biodiversity (by maintaining highly diverse grasslands), more recent activities have tended to reduce habitat diversity and thus the biodiversity of the flora and fauna. As a preliminary attempt to formulate a regional sustainable management plan, we have outlined recommendations for the distinct zones in the study area, which can be summarized by their similar characteristics, environmental problems, and conservation needs.

1 - Shallow floodpains between the Cuiabá Depression and Rio Paraguaizinho

This area is only shallowly inundated (max. 50 cm), with greater inundations (if any) limited to a few days. The small streams flowing into this area carry low freights of sediments and have little erosional force; therefore, this zone is relatively stable and allows fewer invasions by plants than other areas of the Pantanal. The vegetation is parkland savanna, dominated by the tree *Tabebuia aurea* and extensive native pastures. This area is currently used as low-intensity cattle rangeland, which is compatible with the carrying capacity of the ecosystem. During the inundation phase, cattle are moved to permanently dry areas. We recommend maintaining this type of management without increasing the number of cattle.

2 - Transition zone between the Paraguay Depression and Rio Paraguaizinho

This zone includes both elevated areas of the Pantanal that become only slightly inundated and several terra firme zones. The vegetation is characterized by seasonal deciduous forest and seasonal semi-deciduous forest. Currently, there are several settlements in the area. The intensive home-garden culture of the settlers has overused the carrying capacity of the soils. Various campfires and illegal poaching activities by settlers have been observed. These activities are especially harmful as they affect well-preserved habitats at the Rio Paraguaizinho that have large population densities of rare species (hyacinth macaw, jaguar) and which offer large roosting and breeding sites for aquatic birds (*ninhais*, see JUNK et al. 2006). This area should be better-protected and settlements that are incompatible with the regional conditions should be removed.

3 - Transition zone between the Cuiabá Depression and Rio Bento Gomes (both sides)

These areas are affected by shallow inundations. The savanna vegetation (subclasses: parkland savanna and woody grassland savanna) tends to become invaded by the *canjiqueira* tree (*Orbigna* sp.). The recommendation for the sustainable use of this zone is to maintain the original tree vegetation. Invasive species may be carefully removed locally, applying the techniques explained in SANTOS et al. (2006).

4 - Interfluve between the Rio Paraguaizinho and Rio Bento Gomes

The interfluve is annually flooded at moderate levels (about 1 m). Its vegetation comprises savanna forest and low tree and scrubland savanna. Since the recent change in the Pantanal from drier to wetter conditions (after 1974), the vegetation has quickly developed towards a more forest-like appearance. Species of the cerrado, such as *Tabebuia aurea, Callisthene fasciculata*, and *Astronium fraxinifolium*, have spread rapidly, covering large areas previously used as cattle rangeland. The invasion process is called "cerradification" (*cerradificação*). Farmers are regionally combating these invasions by brush-cutting and replanting the areas with exotic grass species (*Brachiaria* spp.) because the seed banks of native grass species have been degraded. These activities are legal when the "legal reserves", i.e., a certain percentage of the original woody vegetation, is maintained. Our recommendation is to preserve a system of corridors and patches of different successional development stages of the cerrado, so that the migration of bird, reptile, and mammal species between "cerradificated" zones and the original savanna forest patches is possible. It is very important to delineate the capões and cordilheiras in these areas and to fully protect their vegetation. Detailed studies of this zone are needed to analyze the causes behind the spread of cerrado species, the effects of brush-cutting, and alternatives for the sustainable coexistence of ranching and natural landscape dynamics.

5 - Interfluve between the Paraguaizinho, Bento Gomes, and Paraguay Rivers

This area is annually flooded at high levels (more than 1 m). The Paraguay River strongly influences the hydrological regime of these seasonally flooded grassland savannas and accounts for the many natural pastures (campos) that are found in this region. Currently, shrub species such as *Combretum laxum* and *Combretum lanceolatum* tend to invade and build up monospecific stands called "pombeiral" (NUNES DA CUNHA & JUNK in press). We recommend locally removing these invaders to maintain the native pastures, according to the techniques explained in SANTOS et al. (2006).

6 - Interfluve between the Bento Gomes and Claro Rivers; areas affected by the Transpantaneira highway

The construction of the Transpantaneira highway has strongly interfered with the natural flooding regime, as it crosses the discharge pathways of overland flow during the flood period. The first result of construction of the 130-km-long dike was that the road blocked the water on its eastern side and reduced flooding on its western side. Soon after the construction in the 1970s, the dike broke due to the force of the water current at many sites that were bridged by wooden bridges. The concentration of flow near the bridge deepened the floodplain channels locally, so that currently the situation is a complex mixture of areas that are drier or wetter than before the dike road was constructed. Consequently, there is a mosaic of very different vegetation patches. Two different types of plant invasions have subsequently taken place. First, in the dry, more elevated areas, which now receive more water than prior to construction of the dike road, cerradification, as described for zone 4 (interfluve between the Rio Paraguaizinho and Rio Bento Gomes), has occurred. This process has also affected areas that used to be shallowly flooded but which fell dry for most of the year. Second, in low-lying moist areas that now receive even more water than before, there has been an invasion of *Combretum* species, as described for zone 5 (interfluve between the Rio Paraguaizinho, Rio Bento Gomes, and Paraguay Rivers). This very heterogeneous area needs further study in order to develop a sound, scientifically based management concept. At the moment, we recommend reducing the invasive species at smaller patches in order to regain natural pastures; however, on a larger scale, it is useless to struggle against the dynamics of the natural hydrology-driven vegetation. The remaining patches of tall woody vegetation should be fully preserved.

7 - Interfluve between the Bento Gomes and Claro Rivers; areas not affected by the Transpantaneira highway

A relatively small patch of the interfluve has not been strongly influenced by the Transpantaneira highway, because the Bento Gomes River has been bridged since its construction, so that flood waters have largely maintained their natural dynamics and plant invasions have been controllable. In this area of medium inundation (about 80 cm), there are many native pastures with high carrying capacities for cattle-ranching. Here we suggest maintaining the traditional management scheme, without intensification of the stock size.

8 - Interfluve between the Claro and Cassange Rivers

This zone is influenced by the hydrodynamics of these two rivers as well as by the inundations of the nearby Cuiabá River. The result is a medium to high level of inundation (1-1.5 m) and relatively high, hydrodynamically driven, natural patch dynamics of the physical habitats. Various natural floodplain channels are found here; these may develop high erosional forces due to variations in the water levels between the three rivers during the rainy season. The habitat dynamics create a natural mosaic of different vegetation types (see map), although large areas with high-quality native pastures are also found. During the post-1974 years, many of those areas were invaded by flood-tolerant woody species, such as *Vochysia divergens*, *Licania parvifolia*, and *Combretum* spp. Our management recommendations are the same as those for zone 6.

9 - Interfluve south of the Cassange River
This area reveals a highly dynamic habitat structure due to riverine influences. It is dominated by low-diversity, nearly impassable scrubland with *Mimosa pellita, Combretum* spp., and *Ipomoea carnea* ssp. *fistulosa*. Little is known about this area and its highly dynamic vegetation structure, which makes its successful management unlikely. We therefore recommend maintaining this area as it is.

10 - River corridors and active floodplains
Along the courses of the rivers, at erosional as well as depositional sites, pastures of high carrying capacity are found; however, these zones have been strongly influenced by the rapid successions that have taken place subsequent to recurrent hydrodynamic restructuring. Depending on the size of the river, a marginal stretch of 100-200 m is protected by law (see WANTZEN et al. 2006 for a review of the legislation).

Due to the scale of the map, small landscape units, some of which deserve full protection, have not been shown. Nonetheless, they may be located in the regions mentioned below. The following habitats need to be fully protected independent of their location (see also HARRIS et al. 2005, and JUNK et al. in press, for considerations about conservation):

* *Aterros de indio, capão de aterro, aterros de bugre*: Cultural sites.
* *Rocky outcrops and Inselberge*: Steep sharp gradients in habitat conditions, ranging from flooded to arid, that provide habitats for rare and partly unknown flora and fauna. Due to their dryness, these habitats are extremely sensitive to fire but they also provide important shelter for terrestrial fauna during rapidly rising floods.
* *Ninhais, poleiros*: Breeding and roosting sites for large populations (several thousands of individuals) of birds. Apart from species conservation, these large bird accumulations have important structuring effects on the nutrient supply of the region (ABDO & DA SILVA 2004).
* *Corixos*: Small floodplain channels that harbor the greatest diversity and biomass of aquatic invertebrates. They also serve as important feeding and reproduction sites for fish in the Pantanal (WANTZEN et al. 2005; MARCHESE et al. 2005).
* *Brejos*: Hot spots of propagules and seed and egg banks.

Hydrological effects on a multi-year scale
Inundation is the major driving force for the distribution and community structure of plant species. The map shows this indirectly in terms of vegetation classes and subclasses, which are distributed according to long-term hydrological conditions. Annual herbaceous plants react quickly to hydrological changes (PRADO et al. 1994; SCHESSL 1999) whereas trees show considerable resilience to changes in hydrology (NUNES DA CUNHA & JUNK 2004). Therefore, the occurrence of a specific cerrado or forest type represents the mean hydrological conditions of the last decades or even the last century.

The strong impact of pluri-annual changes in hydrology can best be demonstrated by comparing the size of permanent lakes (bahias) as shown in satellite images of different years. For instance, the size of Baia Piuval, near Fazenda Ipiranga and Baia Grande at the lower course of the Paraguaizinho River, increased about five-fold after the change from a drier to a wetter phase in 1973/1974. The area covered with water during the extensive dry period of 1966 is shown on the map in dark blue and can be compared to the area covered by water during the low-water period of 1990, which is shown in light blue.

Pluri-annual changes also affect the distribution of vegetation classes. The class Transition systems (14.7 %) comprises large areas of shallowly flooded savannas recently colonized by the flood-adapted tree *Vochysia divergens* (cambará). A study of the age structure and species composition of these communities showed that the stands started to spread into the savanna area after the last pluri-annual dry period, during the 1960s. The cambará has been favored by the wet conditions that have dominated the Pantanal during the last 35 years. (NUNES DA CUNHA & JUNK 2001).

Human impacts on a landscape scale

During and after the large flood of 1974, ranchers suffered enormous economic losses. Increasing competition with cattle-ranching in the uplands led to further economic constraints. This resulted in a decrease in pasture management and a shift from man-made grasslands to campo sujo. Since the 1970s, the cambará tree (*Vochysia divergens*) has "invaded" pasture areas, reducing the carrying capacity of the farms. Clearing of the pastures by cutting the trees is currently practiced by ranch owners on a large scale and often in violation of environmental legislation.

Despite the low human density and extensive management approaches, a considerable but not quantifiable part of the vegetation types is of anthropogenic origin, as noted above. Exclosure experiments on Fazenda Ipiranga, near Poconé, indicated that many grass savannas would change within a few decades to low tree and shrub savannas if grazing by cattle would be inhibited (NUNES DA CUNHA & JUNK unpubl.).

Small-scale man-made vegetation changes, such as some mining activities and the deforestation of *capões* and *cordilheiras*, are also not indicated on the map. These changes affect rather small patches and the total affected area is also relatively small. However, since these types of impacts occur in large numbers, their ecological consequences can be large. Moreover, deforestation of key habitats has a disproportionately negative impact on biodiversity, and for this reason the affected areas deserve special attention regarding conservation. Capões, cordilheiras, and levees substantially increase and maintain species diversity. During floods, they provide vitally important refuges for many terrestrial species and essential corridors and stepping stones for migrating wildlife. Large animals, including jaguar, deer, and rhea, migrate between the Pantanal and permanently dry areas (Paraguayan Depression and Serra das Araras) during the terrestrial period. Cordilheiras and capões are also breeding sites for caimans (*Caiman crocodylus yacare*). Artificial earth-mounds constructed within inundated areas by the indigenous population before the arrival of Europeans (*aterros de bugre*) are places of high fertility and provide important refuge areas for animals and cattle during the wet period (WANTZEN et al. 2005). However, large-scale deforestation of these landscape units has been documented in the northern Pantanal (RAWIEL 1993). From an ecological point of view, it is extremely important to recognize, identify, and map these habitats of the Pantanal and to include them in conservation policies. An analysis that addresses such details would require maps of a scale of 1:10,000.

Human impact is increasing mainly with respect to deforestation for purposes of cattle-ranching and to a lesser degree to agriculture and road construction. Other types of land use causing deforestation are sugar-cane (alcohol production), manioc (starch production), and banana plantations, subsistence cultures, and gold mining. As a result, natural habitats have become fragmented and inhospitable for the original species. The fragmentation of habitats and the isolation of communities were discussed by LOVEJOY et al. (1986), BIERREGAARD & LOVEJOY (1989) and STOUFFER & BIERREGAARD (1995) as reasons behind species extinction. Aside from ecological considerations, animals inhabiting these habitats have become more exposed targets for hunters.

Road construction opens the way for terrestrial plants to reach remote places inside the Pantanal, as shown by the many plants that grow along the Transpantaneira highway that are not flood-adapted. Invading species may also be favored by the overgrazing and trampling of cattle. This causes bare soil surfaces that create favorable germination conditions for invasive plants (POTT 1995). Alterations in the vegetation cover may also occur in response to anthropogenic changes in the local hydrological regime. RAWIEL (1993) reported that after the construction of a new dike in the Porto Jofre region the vegetation cover changed.

Conclusions

Our map provides information regarding current vegetation cover and economic activities in a part of the municipality of Poconé-MT. It can be used as basis for future regional land-use planning, decision-making with respect to environmental conservation, ecological studies, and impact analyses of major man-made and natural environmental changes because it covers a characteristic portion of the northern Pantanal. For specific areas and purposes, we recommend the application of new techniques; for instance, radar images to determine the extent of flooded areas, and the combined use of different types of sensors such as air-photography and satellite imagery.

The municipality of Poconé serves as a model for environmental planning. The geomorphological gradient between the inundation-free Paraguayan Depression and the periodically inundated Pantanal has given rise to a large habitat diversity that is still conserved by traditional land-use techniques and various reserves (National Park of the Pantanal, Ecological Station of Taiamã, SESC reserve, Ecological Station Serra das Araras, not on the map, but see HARRIS et al. 2005). Major changes in vegetation cover are expected to occur in at least part of the study area because of the construction of the reservoir for hydroelectric power generation at the Manso River, which will modify the flood regime and, in the medium-term, the vegetation cover.

Following construction of the Transpantaneira highway, secondary roads, and many dikes, severe and in part unexpected impacts on the vegetation cover were documented. Problems arose because the hydrological characteristics had not been monitored. It is a challenge for conservationists and decision-makers to define standards and rules that take into account the ecology of the region as well as the socio-economic requirements and economic needs of the municipality, while maintaining the major structures and functions of the Pantanal landscape for the benefit of the local population. The present map indicates major vegetation classes related to inundation. However, it is not enough to delineate the local drainage system that has to be maintained in order to avoid major changes in the local hydrological regime.

The vegetation of the Pantanal is subjected to continual changes because of natural and human disturbances, e.g., annual and pluri-annual changes in precipitation and hydrology, erosion and sediment deposition, fire stress, grazing pressure, and deforestation. The potential vegetation of the Pantanal cannot be attributed to a single climax stage. Due to annual and multi.annual flood cycles, the system oscillates between dry and humid climax stages. Therefore, sustainable management strategies cannot be made without considering the extreme dry and moist conditions in the Pantanal.

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Appendix

Six vegetation maps with separate explanations.

Table 1: Synopsis of the different terms based upon the physiognomic-ecological system of the IBGE (1992) and the terminology used in the 1997 PCBAP.

Paraguayan Depression	**Pantanal**	**IBGE (1992), PCBAP (1997)**
Seasonal semideciduous forest	Seasonal semideciduous forest	Floresta estacional semidecidual aluvial Floresta estacional semidecidual de terras baixas (Pantanal) Floresta estacional semidecidual submontana (Paraguayan Depression)
Seasonal deciduous forests	Seasonal deciduous forests	Floresta estacional decidual aluvial Floresta estacional decidual de terras baixas (Pantanal) Floresta estacional decidual submontana (Paraguayan Depression)
Savanna forest	Savanna forest	Savana florestada
Low tree and scrub woodland	Low tree and scrub woodland	Savana arborizada
Savanna parkland	Savanna parkland	Savana parque
Wood grassland savanna		Savana gramíneo lenhosa
	Seasonally flooded grass-wood savanna	Savana gramíneo lenhosa
	Seasonally flooded forest evergreen	Vegetação pioneira. Vegetação de influencia fluvial e fluvio-lacustre
	Floating aquatic vegetation	Vegetação pioneira. Vegetação de influencia fluvial e fluvio-lacustre

Table 2: Relative amount of land (%) covered by the phytophysiognomic classes and sub-classes of the study area. Classes and subclasses were defined according to VELLOSO et al. (1991) and following recent adaptations defined for the Pantanal and the adjacent Paraguayan Depression. For subclass 1.2, the areas were too small to be registered by satellite image.

Class	Paraguayan Depression	Pantanal
1. Seasonal semideciduous forest		
1.1. Lowland seasonal semi-deciduous forest	7.28	6.23
1.2. Alluvial seasonal semi-deciduous forest		
2. Seasonal deciduous forest		
2.1. Lowland seasonal deciduous forests	---	0.40
2.1. Alluvial seasonal deciduous forest	2.30	---
3. Savanna		
3.1. Savanna forest	2.40	1.00
3.2. Low tree and scrub woodland	0.91	20.60
3.3. Savanna parkland	5.52	7.50
3.4. Wood grassland savanna	3.20	---
3.5. Seasonally flooded grass-wood savanna	---	11.92
4. Transition Systems (Ecological tension area)		
4.1. Seasonally flooded evergreen forest	---	12.13
4.2. Floating aquatic vegetation	---	2.57
5. Secondary systems		
5.1. Deforestation	10.03	3.29
5.2. Sugarcane plantations	0.23	---
5.3. Gold mines	0.20	---
5.4. Cities	0.50	---
5.5. Roads	0.20	---
6. Water bodies	---	0.80
	32.77	66.44

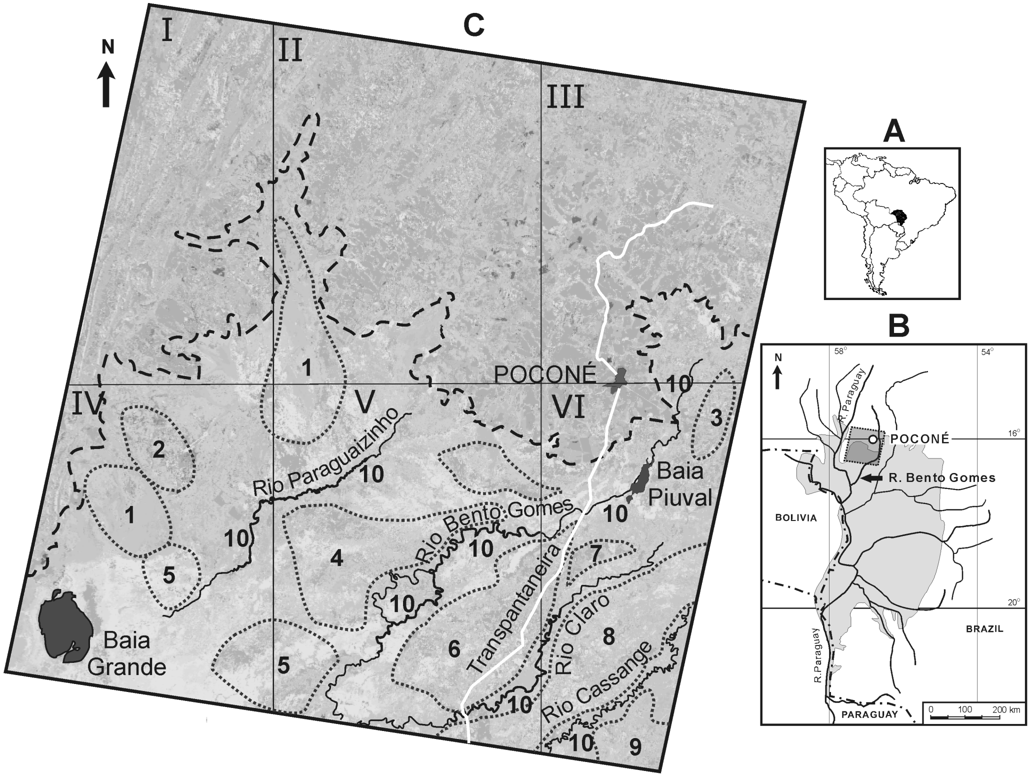

Fig. 1:
Map of the Upper Paraguay River Basin and the investigation area. (**a**) Localization of the Pantanal within South America. (**b**) Position of the study area within the Pantanal (shaded). (**c**) Position of the individual maps (I-VI), borderline between the Paraguay Depression and Pantanal wetland (stippled line), and designation of the ecozones (1-10). See text for description of the latter.

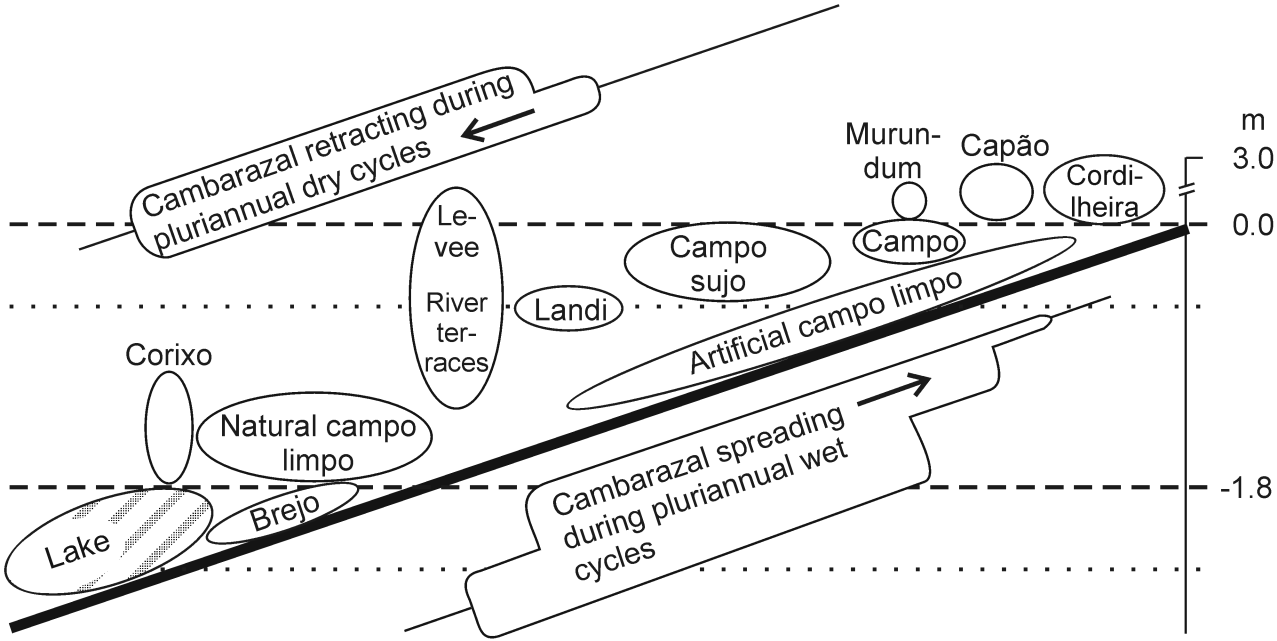

Fig. 2:
Changes in cambarazal communities due to water-level changes and fire cycles. (Modified from NUNES DA CUNHA & JUNK 2004).

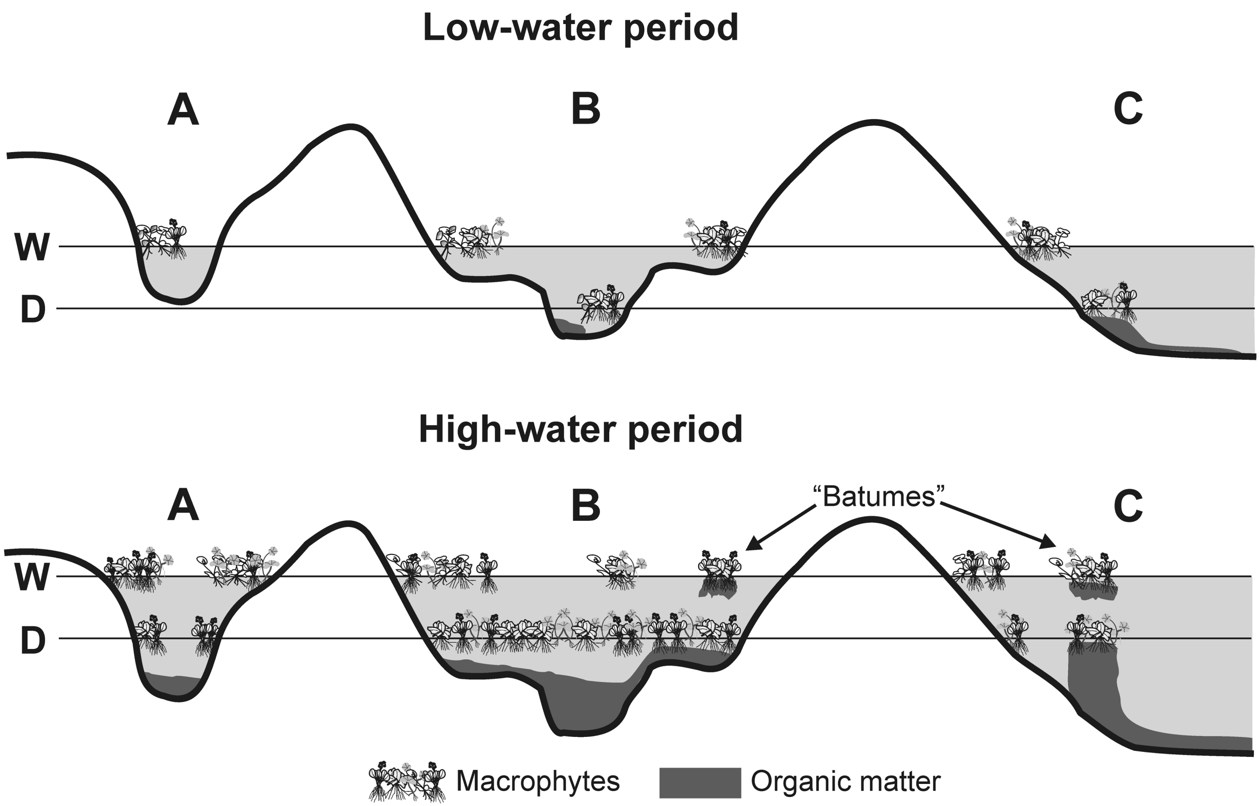

Fig. 3:
Effects of multi-annual cycles of dry (above) and wet (below) periods in the Pantanal on the development of floating vegetated islands (batumes). **W** = wet season, **D** = dry season water level. Types of water bodies: **A** = temporary pond (becoming permanent during high-water periods) **B** = shallow depression lakes with limited permanent areas, **C** = permanent lakes. (Modified from WANTZEN et al. 2005).

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