ANTHROPOGENIC FACTORS AFFECTING WATERS OF THE PANTANAL WETLAND AND ASSOCIATED RIVERS IN THE UPPER PARAGUAY RIVER BASIN OF BRAZIL

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RESUMO

Este estudo apresenta uma análise dos principais fatores que estão provocando alterações ambientais no Pantanal e nos rios associados. A agricultura intensiva, as pastagens cultivadas, a agroindústria e os efluentes urbanos concentrados no planalto constituem-se nas atividades de maior impacto e que têm gerado contaminação do sistema por agrotóxicos e metais pesados, incremento no aporte de sedimentos e poluição orgânica. As obras hidráulicas são, também, fatores de alteração ambiental, especialmente no Pantanal, pois, em geral, não contemplam as potencialidades produtivas baseadas no aproveitamento sustentado dos recursos naturais em suas avaliações de custo/benefícios. A sazonalidade climática definida e os pulsos de inundação condicionam parte das atividades produtivas e, ao mesmo tempo, interagem com os resíduos gerados, potencializando ou minimizando seus efeitos. A ocorrência de períodos plurianuais de cheia e de seca, dependendo da intensidade e da duração, interfere na utilização dos recursos naturais e nos efeitos decorrentes das atividades impactantes.

ABSTRACT

The principal factors that cause environmental alterations in the Pantanal and associated rivers of the upper Paraguay river basin are analysed in this paper. Intensive agriculture, cultivated pastures, mining, agroindustry and urban effluents, which are concentrated in upland areas adjacent to the Pantanal, are the principle causes of environmental

contamination in the form of agrotoxins and heavy metals, increased erosion and sediment transport, and organic pollution with high oxygen demand. Hydraulic projects constitute another form of environmental modification that is especially important in the Pantanal. Such projects are generally short-term solutions to development problems that may ignore the long-term, sustainable use of natural resources. The marked climatic seasonality throughout the basin and the seasonal inundation of the Pantanal regulate productive activities and, at the same time, interact with the wastes generated by those same activities, increasing or minimizing their environmental effects. The occurrence of multiyear periods of flooding or drought, depending on their intensity and duration, interferes with the exploitation of natural resources and affects the negative impacts of antropogenic activities.

INTRODUCTION

The drainage basin of the upper Rio Paraguay covers an area of 496,000 km^2, of which 393,600 km^2 lies in Brazilian territory; the remainder being in Bolivia and Paraguay. Within this basin is an extensive, relatively flat region known as the Pantanal, occupying 36% of the Brazilian portion and lying between 16-22°S and 55-58°W. Elevation in the Pantanal ranges from 80-150 m, and much of the area is subject to seasonal inundation (FIG. 1). The upland regions (> 250 m elevation), bordering the Pantanal in Brazilian territory, are known as the "planaltos", and include plains as well as low mountain ranges. These upland areas are important sources of runoff to the Pantanal (BRAZIL, 1974, 1979). The "planaltos" are the site of most of the human settlement in the region, as well as most of the agricultural, mining and industrial activities. Because these areas drain into the Pantanal, the rivers and floodplains receive substantial amounts of urban, agricultural, mining and industrial wastes.

The maintenance of an ecological equilibrium in productive systems, the capacity for self-purification of polluted waters, and the process of environmental contamination are all influenced directly or indirectly by the hydrological and climatic conditions of the ecosystem. In this paper, data are presented on existing and potential

environmental problems that affect the waters of the Pantanal and the rivers of the surrounding uplands, and the relationship between these problems and the hydrological and climatic conditions of the region are discussed.

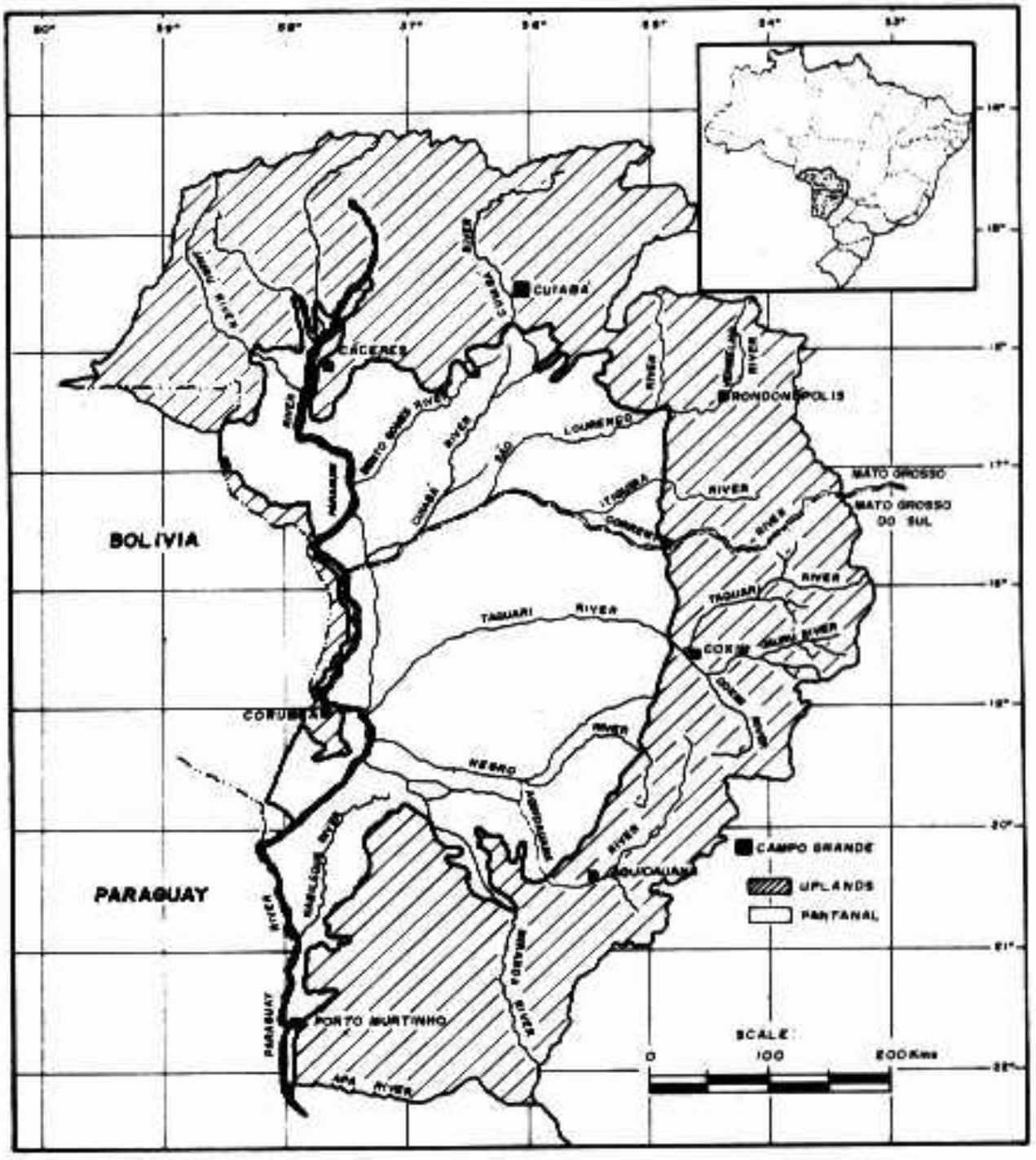

Fig. 1. Upper Paraguay basin of Brazil, showing the Pantanal, the bordering uplands and principal rivers.

CLIMATE

Spatial and seasonal variability in the climate of the upper Paraguay river basin results from interactions between air masses of equatorial continental origin and those originating from the Antarctic region, from the high solar radiation, and from the topography of the basin. Using the Köppen system, climate may be classified as Type Aw, with wet summers and dry winters, presenting a megathermic character on the floodplains and, in general, a mesothermic character in the uplands (BRAZIL, 1974; TARIFA, 1986). Although the precipitation regime is markedly seasonal throughout the basin (falling mostly between October-March), CADAVID GARCIA & RODRIGUEZ CASTRO (1986) used data from 81 meteorological stations to subdivide the basin into five subregions based on the months of greatest rainfall and on the average rainfall during dry months. They noted that the southern part of the basin has a more uniform distribution of rainfall throughout the year.

The total annual rainfall varies considerably between years, displaying deviations from the long-term mean that range from a minimum annual rainfall of 62% of the mean to a maximum rainfall of 152% of the mean. Consequently, the annual water balance is variable and may show either substantial water deficit or excess in particular years. Groups of dry or wet years, which may be defined as those in which the total rainfall deviates more than 15% from the long-term mean, may last up to 10 years (BRAZIL, 1974; CADAVID GARCIA & RODRIGUEZ CASTRO, 1986).

HYDROLOGICAL REGIME

Runoff resulting from summer rains, which are often concentrated in a 2-3 month period, initially results in discharge peaks of short duration in the rivers of the upland areas. Drainage of this runoff and of the rain water falling onto the floodplains is retarded due to the small slope of land surface, resulting in inundation of the floodplains. Spatial variation of inundation in the floodplains is explained in part by the geomorphology of the river beds and their adjacent levees. The large

capacity for water storage in floodplain areas results in a time lag of approximately six months for the passage of the flood wave across the Pantanal. Maximum water levels in the Rio Paraguay typically occur in the northernmost reaches during February-March, reaching Corumbá in April-May and the southernmost areas (e.g., Porto Murtinho) in July-August (BRAZIL, 1974; ADÁMOLI, 1986).

Examination of a 92-year time series (1900-1992) of the water level of the Rio Paraguay at Ladário (near Corumbá) reveals multi-year periods of particularly low or high water levels. These periods reflect interannual variation of rainfall in the basin (CADAVID GARCIA, 1984). In some floodplain areas, particularly in some parts of the extensive alluvial fan of the Rio Taquari, local rainfall appears to determine the extent of flooding, while in other areas surface flow of water originating from nearby rivers appears to be more important. Close to the border between the floodplain and the uplands, short-term inundation resulting from high rainfall events is commonly observed (BRAZIL, 1974).

INTERFERING FACTORS OF ANTHROPOGENIC ORIGIN

In the upland areas, activities that could potentially result in environmental degradation include deforestation; intensive agriculture; cultivation of pastures in unfit soils; and hydraulic projects. Problems originating in the upland areas are frequently propagated into the floodplains of the Pantanal. Within the Pantanal, additional problems include deforestation, sedimentation, hydraulic projects, introduction of exotic fish species, and uncontrolled tourism. There are also two large-scale projects currently under consideration: construction of a waterway (the "Hidrovia" project) by hydraulic alteration of the Rio Paraguay (as well as the Rio Paraná), and the construction of a large steel mill in the vicinity of Corumbá. These projects would have major environmental impacts on the region that must be studied carefully before their approval.

AGRICULTURE AND LIVESTOCK

The most important crop in the region is soybean, which is grown in intensive monoculture, followed by rice, corn, beans, cotton, sugar

cane, and wheat. These crops are grown mainly in upland areas; agriculture within the Pantanal comprises a very small proportion of the total.

The first impact of agriculture is the removal of the natural vegetation cover. Due to the characteristics of the climate and hydrological regime and the lack of soil conservation measures, this results in the erosion of topsoil and, consequently, sedimentation of downstream watercourses. Such sedimentation has even affected major rivers within the Pantanal, asphyxiating and destroying habitats of aquatic organisms and making navigation more difficult or impossible in some reaches.

Municipalities located in the upper part of the Miranda river basin use 80% of the land area for agriculture and livestock. Concentrations of suspended solids in the upper part of the river can reach 250 mg/l, although they have not yet been measured during the peak discharge periods, which are of short duration but may result in heavy sediment transport (BRAZIL, EMBRAPA, 1991).

Erosion of soils in the upper part of the Rio Taquari basin and subsequent transport of this material onto the floodplains of the Taquari fan has been documented (BRAZIL, 1974, 1982). The rio Taquari displays a divergent drainage pattern in its alluvial fan. Sedimentation in the lower reaches has elevated the river bed, impeded navigation and caused lateral levees to break and allow river water to inundate previously dry areas. In an attempt to resolve these problems, the local ranchers whose property had been damaged by extensive flooding have sought to close off the new openings in the levees. There are three questions related to the negative effect of such modifications. Fishery may suffer a reduction in fish production if reproductive migration routes are impeded or the period of flooding is reduced. Closure of levee breaks may result in further elevation of the river level because of its inability to carry the discharge, leading to new breaks in other parts of the levees. The third question concerns runoff retention and will be discussed further below.

The situation of the rio Taquari is especially serious because the possibility exists that sedimentation is accelerating long-term changes in the geomorphology of the river bed and its floodplain,

particularly at its confluence with the rio Paraguay, which may result in shifts in the course of the river in the future. It is also possible that hydrological changes will increase sedimentation at lower reaches of the rio Taquari as a result of the backwater flooding of the rio Paraguay in the vicinity of the Taquari fan.

Agricultural activities in the upland areas use large quantities of biocides. The total use of biocides in the portion of the upper Paraguay river basin within the state of Mato Grosso do Sul in the years 1985-87 was estimated by YAMACIRO (1989) to be 765,520 l and 115,427 kg (biocides are sold in either liquid or solid form). Most of the biocides used are herbicides, which are applied primarily on soybeans, rice, corn, wheat and beans. Herbicides are used mainly in the upland areas, although when they are used on crops on the floodplains, applications tend to be heavier on an areal basis, mainly on soybean and rice crops. In the Miranda river basin during 1985-86, the total consumption of biocides amounted to 52,608 l and 14,752 kg (BRAZIL, EMBRAPA, 1991), of which the most commonly used compounds were the herbicides Trifluralin and Alachlor and the organophosphates Monocrotofos and Methyl Parathion. In this period 938 l and 5,053 kg of chlorates were used, of which Mirex comprised 90%. The data presented here reflect only official acquisiton of products via agronomists, and are considered to be underestimates; the estimates provided here may be only 10% (YAMACIRO, 1989) to 30% (BRAZIL, EMBRAPA, 1991) of the true consumption in the region.

Pastures represent the sixth most important crop in terms of biocide use (YAMACIRO, 1989), and these are cultivated largely in the uplands. In addition, pastures have been cultivated on areas that were appropriate only for native pastures, destroying the native vegetation and thereby increasing erosion on uplands and the consequent sediment loads to downstream areas.

DOMESTIC AND INDUSTRIAL EFFLUENTS

The largest cities and most of the human population are concentrated in the upland areas bordering the Pantanal. Since the

1970's, most urban centers have experienced population increases while rural populations have remained stable or decreased.

The lack of basic sanitation, especially the collection and treatment of urban sewage and of solid waste, results in significant contamination of surface and subsurface waters that can increase the incidence of waterborne diseases, particularly among people living on the river margins. GOMES & SHIMADA (1985) investigated the effects of urban wastes originating in Cuiabá (Mato Grosso), the largest city in the region, on downstream reaches of the rio Cuiabá. They estimated that domestic and industrial effluents were responsible for a 20% reduction in the concentrations of dissolved oxygen and for a mean abundance of 1,553 fecal coliforms/100 ml in the river, which is well above the coliform limits allowed by Brazilian's law for water to be consumed without treatment (absence of fecal coliforms/100 ml), requiring conventional treatment for its consumption. For the state of Mato Grosso do Sul, population data (BRAZIL, ANUÁRIO ESTATÍSTICO DO ESTADO DO MATO GROSSO DO SUL, 1987) were used to estimate that the organic waste load for the Paraguay river basin results in a total biological oxygen deman of 12,083 kg/day, of which 75% originates from the city of Corumbá and from the basin of the rio Miranda.

Agroindustry presents a strong potential source of contamination of waters in the basin because waste treatment systems are not always established for their residual water, and because agroindustrial activities are often located close to urban centers. The principal agroindustries in the region include alcohol distilleries, slaughterhouses and meat processing plants, and milk plants. According to CADAVID GARCIA (in prep.), in the northern part of the basin the production capacity of the alcohol distilleries is about 1,500,000 l/day, with a corresponding waste discharge of 27,800 m^3/hour. These distilleries are located 30-162 km from the inundatable floodplains of the Pantanal. In the Miranda river basin, there are currently three milk plants, three meat processing plants, and a slaughterhouse in operation, producing an organic waste load that creates a biological oxygen demand estimated at 1,820 kg/day (BRAZIL, EMBRAPA, 1991). Of these, only one of the meat processing plants has a waste treatment

system. There is also an alcohol distillery with a capacity to produce 120,000 l/day.

MINING

Industrial exploitation of iron and manganese reserves is concentrated at the Urucum area, an inselberg formation located near Corumbá, where mining contributes significantly to the total production of these metals in Brazil. The environmental effects of this mining are mostly localized; however, they affect agricultural areas near Corumbá that are important for supplying products to the local population. Although there is no available scientific literature on the environmental problems associated with this mining, it degrades the scenic beauty of the area, appears to cause changes in the direction of groundwater flow, and, in streams draining the area, it results in contamination with iron and manganese as well as sedimentation problems. The most serious problems occur when dams that contain the mineral wastes generated by mining activities break during heavy rains, releasing material that affects extensive natural areas as well as agricultural sites downstream; such events have been registered.

Gold mining currently presents the greatest risks for contamination of waters in the upper Paraguay river basin. Gold mining activities are concentrated in the Mato Grosso state, situated in the upper reaches of the rio Paraguay drainage network. The extraction of gold-bearing ores by open-pit mining results in degradation of the landscape. Metallic mercury is mixed with sediment bearing gold to amalgamate the gold, then the mixture is heated to effect the separation, after which mercury is released to the atmosphere by vaporization and is not recovered. Mercury in the atmosphere is readily dispersed and eventually reaches land and water surfaces, where it becomes incorporated into food chains and displays the classic phenomenon of biomagnification at each successive trophic transfer. VIEIRA (1991), measuring total mercury in sediments, mollusks, fishes, and birds in the rio Bento Gomes near Poconé as well as in the rio Cuiabá and in the rio Paraguay near Corumbá, documented biomagnification of mercury through the food chains. The greatest

contamination was evident in the rios Bento Gomes and Cuiabá, where the frequency of individuals of eight fish species with mercury levels above 0.5 μ g/g of wet weight in muscle tissue varied from 25-43% (15-22% for liver tissue). VIEIRA (1991) also noted that the mercury levels in birds were high enough to affect their behavior and reproductive success. LACERDA (1990) analysed "piranhas" from the Poconé region, finding levels of mercury in their muscle tissue ranging between 0.06 μ g/g wet weight for *Serrasalmus nattereri* and 0.10 μg/g wet weight for *Serrasalmus* sp.; VIEIRA (1991) reported concentrations ranging from 0.05-10.25 μ g/g wet weight in samples of *S. nattereri* from the same area.

HYDRAULIC PROJECTS

Studies on the feasibility of hydroelectric impoundments in the region (BRAZIL, 1979; ALVARENGA et al, 1984) have considered only the demand for electricity, the benefits and problems of the reservoirs and the flood control aspects; little or no consideration was given to the negative effects of these projects on the flood regime in downstream ecosystems of the Pantanal. The reservoir constructed on the rio Manso, a tributary of the rio Cuiabá, stimulated a discussion of the advantages and disadvantages of such projects, bearing in mind that the conservation and sustainable use of resources is most appropriate for the Pantanal. Fish species suffered immediately with the closure of the dam, which impeded the migratory routes that are necessary for their reproductive cycles (LIMA, 1987; BRAZIL, EMBRAPA, 1991).

Impoundment or alteration of surface drainage patterns, whether by dam construction or by modification of lateral levees (elevation of dikes and closure of levee breaks), can bring serious problems not only for natural resources but also for production systems. According to CAMPOS (1991), the reproductive success of caimans is dependent on the availability of adequate nesting sites in floodplain aquatic habitats. ALHO et al. (1987) showed that the aquatic environments are an important component of the habitat of the capibara (*Hydrochaeris hydrochaeris*). In the regions of Nhecolândia and

Paiaguás (Taquari fan), pastures of higher nutritional value occur in areas known as "vazantes" which are drainage channels that carry water temporarily during inundation of the floodplain (POTT, 1988).

In floodplain areas such as Nhecolândia, water for human and livestock consumption is generally obtained from small lakes (locally called baías). Water sources in this area include local rainfall as well as inundation by water of the rio Taquari and by regional rainfall waters, which are carried by distributary channels (*corixos* e *vazantes*). The availability of surface water results from the balance of the water sources and losses and is locally affected by edaphic aspects and evapotranspiration. Given the high interannual variability of rainfall and the tendency for water deficits during much of the year, sometimes lasting all year or several years (BRAZIL, 1974), the maintenance of surface waters may be impossible in dry years if the rio Taquari floodwaters are impeded from reaching the floodplain areas because of impoundments.

Feasibility studies of the Paraná-Paraguay Waterway (*Hidrovia*) have revealed the importance of the Pantanal in maintaining navigable depths in the river channels downriver throughout the year. However, in the reach of the rio Paraguay between Cáceres and Corumbá, the studies indicated that it will be necessary to rectify or dredge the channel in parts in order to improve navigation during low water (BRAZIL, INTERNAVE, 1990). If river beds were lowered by 0.5-1.0 m, the area of floodplain waterbodies might be reduced in much of the floodplain upriver, which now floods only to depths of < 1 m, and negative impacts on those environments would likely result.

THE FLOODS

Discussions concerning the exploitation of the Pantanal, whether through use of natural resources, livestock rearing, agriculture, or tourism, use the floods as a point of reference. It is necessary to clarify that a large part of this exploitation is made possible by the existence of the process of inundation of the floodplain. Negative effects are

caused, in reality, by exceptionally high floods or exceptionally low water levels (droughts), occurring on an annual or multi-year basis. Studies have shown that some elements of the natural environment can be damaged in high water situations, such as the loss of caiman nests (CINTRA, 1985; CAMPOS, 1991), restriction of habitats for capibaras (ALHO et al, 1987), natural fish kills (RESENDE et al, 1990), and livestock rearing (ADÂMOLI, 1986; ANTUNES, 1986). In contrast, fishes could benefit from the increase in area for feeding and the reduction of risks of predation (BRAZIL, EMBRAPA, 1991). Conversely, extreme droughts may result in the disappearance of surface waters from extensive floodplain areas, imposing hardship on domestic and wild animals and greatly restricting the area of aquatic habitats. The natural biota of the Pantanal is resilient to such cycles and tends to recover rapidly, whereas introduced crops and livestock are much less so. It is therefore necessary to consider the role of exceptional as well as "normal" cycles of inundation and desiccation in maintaining the Pantanal Ecosystem and in ameliorating or intensifying environmental problems in the ecosystem.

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