SPATIAL AND LIMNOLOGICAL CARACTERIZATION OF THE PARAGUAI RIVER FLOODPLAIN AREA, SOUTHERN PANTANAL, WITH EMPHASIS ON THE '*DECOADA*' PHENOMENON

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Abstract

The objective of this study is to contribute to improve understanding of the '*Decoada*' phenomenon', the local term for the seasonal alteration of limnological parameters, including depletion of dissolved oxygen that can cause natural fish kills, in the Pantanal Wetlands (Mato Grosso do Sul State, Brazil). Two water bodies, adjacent to the Paraguay River (Baía Tuiuiú and Bracinho) were studied over a hydrological period (April 2008 to February 2009). The sampling plan was prepared using GIS tools. In each environment a grid of 2 per 12 square cells of 70 meters side was created. It was positioned in its center to guide the sampling during rising and flood phases as well as in the drainage and low-water phases. The bimonthly sampling included ten randomly selected sample points. The measured limnological variables were ordinate, using a PCA for each studied site. A strong influence of the flood pulse was observed on them, with particular changes occurring during the 'decoada' phenomenon.

Keywords: Pantanal Wetland. Floodplain. Decoada. Dequada. Fish kills. Limnology. Paraguay River.

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Resumo

Caracterização espacial e limnológica de área de inundação do rio Paraguai, Pantanal Sul, com ênfase no fenômeno da 'decoada'

Este estudo buscou contribuir para uma melhor compreensão do fenômeno da "decoada", um termo regional para a alteração sazonal dos parâmetros limnológicos, incluindo a depleção do oxigênio dissolvido que pode causar a mortalidade natural de peixes na planície de inundação do rio Paraguai, Pantanal Sul (Mato Grosso do Sul, Brasil). Dois corpos d'água adjacentes ao rio Paraguai (Baía do Tuiuiú e Bracinho) foram estudados durante um período hidrológico (abril/2008 a fevereiro/2009). O delineamento amostral foi organizado utilizando ferramentas SIG. Em cada ambiente foi criada uma grade de 2 por 12 células quadradas de 70 metros de lado, que foi posicionada no centro do corpo d'água para orientar as amostragens de forma padronizada, realizadas nos períodos de enchente/cheia e vazante/seca. Cada coleta bimestral foi realizada em dez pontos amostrais selecionados aleatoriamente. As variáveis limnológicas obtidas foram ordenadas através de uma análise de componentes principais (PCA) para cada local estudado. Observamos uma forte influência do pulso de inundação sobre elas, com alterações expressivas ocorrendo durante a "decoada".

Palavras-chave: Pantanal. Planície de inundação. Decoada. Dequada. Mortandade de peixes. Limnologia. Rio Paraguai.

INTRODUCTION

The yearly cycle of flood and drought is the most important ecological phenomenon in the floodplain of a river, because it controls its structure and functioning, performing a primordial role in nutrient recycling and water availability, providing a highly productive environment for aquatic macrophytes, algae, bacteria, protozoa, invertebrate and fishes (JUNK et al., 1989; RESENDE, 2006, p.1).

In the Pantanal wetland, the seasonality of flood and drought, also known as "flood pulse" (JUNK et al., 1989, p.111), annual and multiannual, is one of the factors that rule the Pantanal biodiversity, since it sometimes favors both the animal and plant species related to the dry phase, and sometimes the species related to the flood phase (CALHEIROS; FERREIRA, 1997). Moreover, according to the annual hydrological regime, changes may be observed in limnological parameters, whereas in the flood phase, when such changes are stronger, they are called locally as '*decoada*' (or '*dequada*').

Decoada is a natural phenomenon which occurs mainly in the early phase of hydrological flood, when the flood waters resulting from rainfall in the headwaters of the Pantanal basin overflow the riverbeds, invading the fields and lowland areas and coming into contact, particularly, with the terrestrial organic matter developed during the dry period from the previous year, but also with aquatic vegetation from the previous flood.

This phenomenon is characterized by water with a black tea color, due to the dissolved organic compounds, from organic matter decomposition, besides the rising value in electric conductivity, alkalinity and carbon dioxide, as well as a decrease in dissolved oxygen (with values close or inferior to 1,0 $mg.L^{-1}$) and a small decrease in pH and transparence by Secchi disk (CALHEIROS; FERREIRA, 1997, p.30).

This phenomenon requires an in-depth investigation, since, depending on its magnitude, it may provoke death to hundreds of tons of fishes, due to changes in the water quality (CALHEIROS; FERREIRA, 1997), and also because the energy supply for the aquatic food chain depends on it (CALHEIROS, 2003), as it is the natural control of the Golden Mussel, an invasive exotic species (DOURADO et al. 2010, 2011). Its occurs at the beginning of the flood phase (from January to March, sometimes until April or May), in all the flooding area of the large rivers in the Alto Paraguay Basin, especially at the junction of the Paraguay and Cuiabá Rivers, where the initial formation of *Decoada* water masses to the Southern Pantanal occurs. These water masses move downstream, coalescing with other waters, already impaired locally, due to the decomposition phenomenon in the adjacent flooded areas, until the main stream (locally known as "*Corixos*") bed and the downstream rivers are reached again (OLIVEIRA et al., 2013; CALHEIROS et al., 2000; OLIVEIRA; CALHEIROS, 2000; CALHEIROS; HAMILTON, 1998; HAMILTON et al.,1997; CALHEIROS; FERREIRA, 1997). Several reasons justify the efforts to better understand the *Decoada* phenomenon, especially the assessment of its environmental impact (CALHEIROS; FERRREIRA, 1997; OLIVEIRA et al., 2010, 2011, 2013), besides the negative economic aspects related to the periods of inactive fishing, for the professional fishermen and for the tourism sector, activities of great importance for the local economy.

Considering the ecological and economic importance of the *Decoada* phenomenon for the Pantanal ecosystem, the need to better understand its influence on the structure and dynamics of the aquatic biota, and its distinctive characteristics in the functioning of the Pantanal floodplain, the present study is a contribution to improve understanding of this phenomenon. The limnological characteristics of two water bodies from the Paraguay River plain during a hydrological period are presented, emphasizing the changes caused by *Decoada*. Moreover, further studies are suggested, in order to help its monitoring and to predict its occurrence, using remote sensing techniques.

MATERIAL AND METHODS

Area under study

The choice of two study areas adjacent to the Paraguay River, *Baía Tuiuiú* – a marginal lake to the river in oxbow shape – and the *Corixo Bracinho,* was done because both water masses are characteristic ecosystems of the floodplain, where the *Decoada* phenomenon can be observed every year, in major or smaller magnitude, depending on the hydrologic conditions. The drought level of the previous phase, the amount of rainfall at the headwaters of rivers and, consequently, the water level reached and its duration, the velocity of water rising in the floodplain in the subsequent flood phase, these are important factors for determining the expression of this phenomenon (CALHEIROS, 2003; CALHEIROS; FERREIRA, 1997). In this regard, consultations with experienced local fishermen and researchers of the Pantanal ecosystem were essential to determine the most appropriate sites for this study.

Baía Tuiuiú

Baía Tuiuiú is an abandoned meander of Paraguay River, the main water collector from the Pantanal. Esteves (1998) remarks that these water bodies are usually named "Oxbow Lakes", given that it is a marginal lake formed by the meander isolation through natural processes of erosion and sedimentation at/on its margins, resulting from the dynamics of river geomorphology.

Such permanent or temporary waterbodies, which may or may not maintain connectivity with the river during the dry phase, are named locally as "*baías*" (bays).

Baía Tuiuiú is located upstream of the city of Corumbá, Mato Grosso do Sul, close to the Brazil/Bolivia border (21k 0430268/7919547 UTM). It is approximately 6.5 km long, with circular shape and is characterized by well preserved riparian vegetation to the West, and to the East by an extensive bank of aquatic macrophytes. It is connected to the Paraguay River, even during periods of low water. Regarding the water flow, *Baía Tuiuiú* shows behaves as semi-lotic environment, which may alter sometimes the water flow direction: from the river towards the lake (flood) and on the opposite (ebb) direction, depending on the hydrological phase of the system.

Bracinho

The denomination '*Bracinho*' (little arm) reveals its nature: it is a drainage channel, an arm of the Paraguay River, approximately 29 km long (21k 0441337/ 7900517 UTM). It is narrower in its upper section, to the North of the Corumbá City, remaining almost entirely pervaded by aquatic macrophytes, during almost the entire year. Regarding the flow, it shows characteristics of lotic environments, particularly in periods of flood and ebb, being responsible for the drainage of a large extent of the floodplain upstream.

Data Sampling

In order to ensure the standardization of data collection from the same sites throughout the duration of the study, reference points were established, with the use of landmarks, whose geographical coordinates were recorded using a GPS equipment (12 Garmin® Personal Navigator®). This strategy allowed more accuracy for the analysis of the temporal evolution of limnological parameters, avoiding the inclusion of parameter variations due to failure on the location sampling points.

The data collection plan was developed using the software ArcGis 9.3, in order to create a grid of 02 per 12 square cells, from the landmarks with geographical coordinates, for the two environments in the floodplain. LANDSAT 7-TM images from June 2007 (Orbit/Point 227/73) were used to establish the grid and position it at the centre of the water body and thus, to guarantee the most accurate sampling, in both seasons: flood/rise and ebb/dry. Besides that the proximity to the places close to the river banks and subject to a great variation of the water body level, due to flood conditions throughout the year, was avoided.

The geographical coordinates of each cell centroid were used to locate the sampling points in the field. Each cell in the grid measured 70 meters side, avoiding overlapping of points was avoided due to possible GPS location errors.

From the grid design, identical for each environment, among the twenty four cells for each grid, ten were selected randomly for the achievement of the sampling. At each time, the sampling points were selected again randomly, and the randomly selected points in previous collections were again part of the sample universe. The coordinates of the cell centroids chosen to perform the sampling, were located utilizing a GPS equipment.

The sampling was done every two months, during the months of April, June, August, October and December 2008 and February 2009, always in the morning, between 7 am and 12 pm. The '*Decoada*', specifically in this hydrological year, occurred in April/2008 (flood phase), although local fishermen reported that a less significant phenomenon, "a mass of rotten water", had been observed in August (ebb phase) in *Baía Tuiuiú*.

A sampling unit of the bottom sediment was taken from each randomly selected point for granulometric analysis, to determine the fractions of organic matter, silt, sand and clay. Therefore, a modified Petersen type dredge was used, with a volume of 03 liters and an area of 0.0345 m^2. The granulometric analysis followed the method described in the Embrapa's Soil Analysis Manual (EMBRAPA, 1997).

Water samples were collected using a Van Dorn bottle, at half a meter above the overall site depth and measured, *in situ*, depth values (m) (depth gauge Speed Tech Instruments), water speedy (m/s) with a Marsh-McBirney flowmeter, Flo-Mate Model 2000), water transparency with a Secchi disk (m), besides pH, electric conductivity ($\mu S/cm^{-1}$), water temperature (°C) and dissolved oxygen (mg/ L^{-1}), utilizing a properly calibrated YSI portable potentiometer.

In the Limnology Laboratory of Embrapa Pantanal/Agricultural Research Center of the Pantanal, the Free CO_2 values ($mg.L^{-1}$), Chlorophyll-a ($\mu g.L^{-1}$), Alkalinity ($meq.L^{-1}$, total nitrogen ($\mu g.L^{-1}$), total phosphorus ($\mu g.L^{-1}$) and total suspended material (MST) (mg,L^{-1}) was determined.

Data analysis

Due to the presence of a large number of descriptor variables of physical and chemical water conditions, ordering techniques were used for a multivariate statistical analysis. Therefore a Principal Component Analysis (PCA) was performed, considering the Euclidian distance between the sampling points (SYSTAT 10.2 version) (SPSS, INC. 2000). The PCA was done with a correlation matrix of 16 variables, namely: Dissolved oxygen, Electric conductivity, Water temperature, Depth, Secchi-disk transparency, pH, Organic matter, Total Sand, Silt, Clay, Dissolved CO_2, Total alkalinity, Chlorophyll-a, Total nitrogen, Total phosphorus and Total suspended matter.

RESULTS AND DISCUSSION

According to data provided by the *Serviço de Sinalização Náutica do Oeste* (Western Nautical Signal Service), from the 6th Naval District of the Brazilian Navy (Ladário, MS) related to the variation of rainfall level at the Paraguay River, the flood peak occurred in June/2008, whereas the drought peak occurred in December in that hydrologic cycle.

Temporally, expressive and inversely proportional variations for the O_2 and CO_2 values were observed in both environments. In *Baía Tuiuiú* and *Bracinho*, the highest CO_2 values and the lowest O_2 values were recorded in the periods of high water (flood/flow), corresponding to April-June-August/2008. Conversely, the lowest CO_2 values and the highest O_2, were registered in the low water period (ebb/dry), corresponding to October-December-February/2008-2009. As for the Chlorophyll-a, in both environments, the highest values were recorded at the drought peak, i.e. December 2008, a time when also the highest values for MST and the lowest for water transparency were observed.

The results of the Principal Component Analysis suggest that there is a clear seasonal hydrologic pattern of variation in the limnological parameters analyzed in both environments (Figure 1).

As for *Bracinho*, it was found that 66% of data variation was explained by the two first PCA axes, the first one being correlated mainly with depth, Secchi-disk transparency and Free CO_2 concentration, with a positive correlation showing higher values of these variables in the flood period. On the other hand, the samples collected during the dry season showed higher pH values, water temperature, nitrogen, and phosphorus concentrations. On the second axis it was confirmed that the gradient found highlighted the variation in the sediment composition, separating samples with higher concentration of total sand from those with higher silt and organic matter concentration.

Concerning *Baía Tuiuiú*, the first two PCA axes explained 58% of the data variation. Similarly at *Bracinho*, the first axis clarified predominantly the seasonal variation of the analyzed variables, the samplings performed during the flood season showed higher values of depth and transparency, whereas the samplings executed in the dry season presented higher values of water temperature, dissolved oxygen and pH. At the second axis, the identified gradient was the result of the interaction between spatial variation in sediment composition (silt and sand) and the water quality parameters (conductivity and alkalinity). So the samplings performed during the months of April and October showed higher values of electric conductivity, alkalinity and silt, while the samplings collected during the months of June, February and December displayed higher sand concentration.

Regarding April/2008, the month with the "*Decoada*" phenomenon occurrence, the samples appeared grouped in both analyzed areas, as it was observed for the other months of collection. It is interesting to emphasize that they were grouped between the months of higher waters phase and those related to the lower waters stage, behaving differently.

The fluctuation of the water level in the rivers of the *Pantanal Mato-Grossense* is due to geomorphologic and climatologic features, which result in the annual and inter-annual flood pulse, which is reflected in the lakes and marginal water bodies. Marginal lakes and other water bodies of the floodplains present correlation with the hydrodynamics of the main river (RODRIGUES, 1998). So the depth of the two sites studied, show higher values for the months June and August, contrary to what would be expected in the dry months, but in accordance with the Paraguay River variation, due to the Pantanal floodplain geomorphology.

It is important to highlight that the flood peak (May to July) and the drought peak (October to December) in the studied region, are lagged from the rain periods (October to March) and drought (August to September), respectively. On the contrary, in the plateau region of the Alto Paraguai Basin, the beginning of river flood period and the rainfall period coincide due to the geomorphologic features of the system. This is due to the fact that in the northern Pantanal region, located in Mato Grosso State, the high waters occur during the rainy season (October to March), reaching Corumbá and its southernmost region only three months later, when the rains cease (May, June and July), by virtue of the slow Pantanal drainage (DA SILVA; ESTEVES, 1995; CARVALHO, 1986).

The Principal Component Analysis showed that in *Bracinho*, the higher CO_2 L values were observed in the months of high waters, whereas in *Baía Tuiuiú* the highest dissolved oxygen concentrations are strongly related to the low water months. Such results demonstrate somehow the same situation: during the high water period, an increase of O_2 consumption in the decomposition process of flooded organic matter by the aerobic organisms, results in a greater liberation of Free CO_2. This was also observed by Hamilton et al. (1997); Calheiros and Hamilton (1998); Oliveira and Calheiros (2000) and Calheiros (2003).

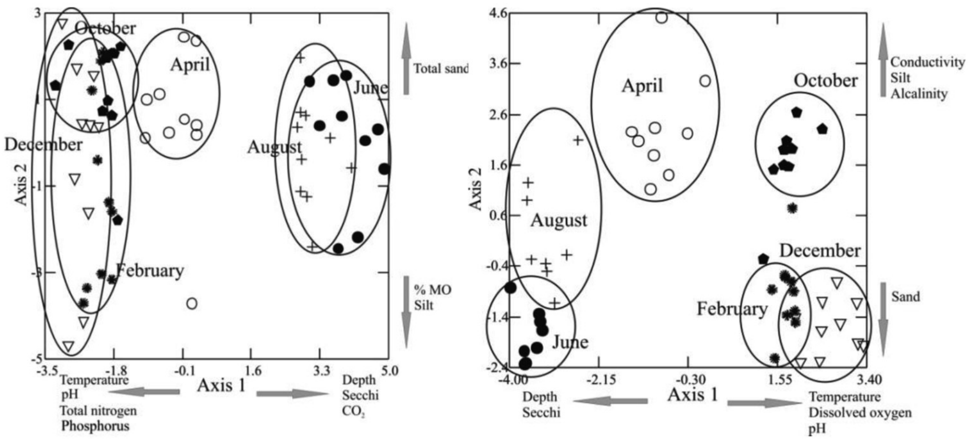

Figure 1 - Principal Component Analysis (PCA), listing the 16 limnological variables, for the collecting months (○: April/2008; ●: June/2008; +: August/2008; ⬟:October/2008; ▽: December/2008; ✱: February/2009) in Bracinho (left graphic) and Baía Tuiuiú (right graphic), near Corumbá/MS

In the Pantanal, in spite of a pattern related to the hydrodynamics, each hydrological cycle presents its own special features. Calheiros & Ferreira (1997) observe that the water flow direction in the large "*baías*" depends on the hydrological phase, heading for the river in the ebb/dry stage and reversing the flood during the flood phase, "and it may return again to run to the river, already in full flood, after the coalescence with the whole system".

The areas chosen for this investigation, present in generally differences related to the flow, being *Bracinho* a place whose water speed is higher when compared to *Baía Tuiuiú*, especially during the ebb stage, in the year studied. It is however necessary to improve understanding on the functioning of the environment through long-term research, to apprehend how the variation in water velocity occurs during different hydrological years.

The highest values for water transparency were recorded in June/2008, the month of highest depth and low flow; the lowest values for December/2008, in the dry phase, with smaller depth values in both environments. Similar results observed in flood areas are easily found in the literature (HAMILTON; LEWIS JR., 1987). Da Silva and Esteves (1995) argue that higher depths of Secchi disk in the flood period may be attributed to sedimentation of organic and inorganic compounds. Oliveira & Calheiros (2002) indicate the aquatic macrophytes as important elements for sedimentation of the suspended material, enabling a stronger penetration of light in the water column.

The highest values for water temperature are related to the warmer season, the summer. Considering that this period coincides with that one of low water, it is natural to expect higher temperatures, since the water bodies are shallower. Therefore, a negative correlation between depth values and water temperature was highlighted.

Values of organic matter and silt emerged as important factors in the disposal of the months December and February in *Bracinho*. For these variables, it was observed in the PCA graph, that there is a greater distance between the points. It is essential to note that for the months in which the points appear more scattered, rainfall was registered on the eve of the collection in the region studied (December/2008 = 4.6 mm; February/2009 = 1.2 mm), which could justify changes in the concentrations of silt and organic matter.

The analysis of the PCA results allow to observe that samples from the different months are grouped according to the phases of high and low water, except for samples from April, when the *Decoada* phenomenon occurred, and which were completely different from the other months (Figure 1). It is known that this analysis highlights the most significant factors for ordering the months; considering however, the set of the chosen variables, in this case, 16 variables. Therefore, it is interesting to note this isolation in both environments and compare it with the average parameters. The lowest values of dissolved oxygen (O_2) were obtained in April/2008, close to a complete anoxia condition and values considered high for Free CO_2, (maximum = 48.3 mg L^{-1}). Other studies conducted in the Pantanal registered the same situation (HAMILTON et al., 1997; HAMILTON et al., 1995; CALHEIROS; HAMILTON, 1998), recording values above 100 mg.L^{-1}, showing that this combination of high Free CO_2 values with low values of O_2 can be fatal to the biota, especially for fish, since the dissolved CO_2 causes direct interference in ability to entrainment of O_2 by hemoglobin (SMART 1981).

The total nitrogen values, electrical conductivity and alkalinity were highest in April, the month of the '*Decoada*' phenomenon occurrence.

The high values of electrical conductivity may be explained by the entry in large quantities of dissolved ions carried on from the newly flooded system, which starts to receive the waters that "wash" and carry the leached from the living or dead plant material developed in flooded fields of the previously dry plain, as well as the contribution of the material resulting from the decomposition of submerged vegetal organic matter and from interaction with the water bodies which underwent evaporation during the dry phase. The results obtained are corroborated by those found by Da Silva; Esteves (1995), Calheiros and Hamilton (1998) and Oliveira & Calheiros (2000). Other works carried out in the Pantanal, also show an increase in electrical conductivity and alkalinity values during the occurrence of *Decoada* (CALHEIROS; FERREIRA, 1997; HAMILTON et al 1997; OLIVEIRA, 2009). High values for electrical conductivity and alkalinity may be related to the decomposition of organic matter (PNMA, 2004) or to leaching of ash and debris, to the major interaction between rocks and water, besides leaching of plant debris and washing of water bodies previously isolated, whose dissolved salts have been concentrated by evaporation during the isolation phase, as well as the increase in concentrations of Free CO_2 derived from the increase in decomposition, common processes during the phenomenon studied. Further investigations in other flood environments also revealed similar results (RODRIGUES, 1998; SOUZA-FRANCO et al., 2009).

The same can be mentioned to explain the high values of total nitrogen, related to nitrogen forms which enter the system by water, from the decomposition of submerged terrestrial vegetation and aquatic macrophyte debris, in addition to faeces and urine of animals.

For chlorophyll-a, suspended solids and water transparency, the amounts recorded in the dry peak coincide with the results found by Oliveira & Ferreira (2003). These authors suggest that the concentration/dilution factor is more active than light for the observed pattern. However, they stress that in the period of higher chlorophyll concentration, there is a greater availability of phosphorus and soluble reactive silicate, nutrients which promote algal development. In this study a high availability of phosphorus (total) in the environment was also found.

The results suggest that there are gradual seasonal changes in physical and chemical characteristics of water during the year, except for the *Decoada* period which shows a dramatic alteration in the water characteristics. As *Decoada* is associated to the beginning of the flood phase, the intensity of this phenomenon may present a spatial and temporal variation in the Pantanal, showing areas where the phenomenon occurs earlier and with major intensity and others where the phenomenon may occur later and with lower intensity (DE AZEVEDO MACEDO et al., 2014).

Due to the great extension of the Pantanal ecosystem, the use of field sampling to detect the *Decoada* phenomenon in the different regions, and particularly, to monitor the displacement of the *Decoada* "plume" over time becomes economically impossible. In this context, the use of remote sensing techniques for monitoring water quality in very large regions may be a viable alternative for the study of the *Decoada* phenomenon. Studies have shown that it is possible to monitor the variation of some water quality parameters using remote sensors (HADJIMITISIS et al., 2006; JULIAN et al, 2008; SONG et al, 2011). Among the parameters liable to be monitored by satellite images are turbidity and total organic matter content (e.g. SONG et al., 2011), which lie among the features that vary throughout the year and especially during the *Decoada*, suggesting a great potential for the use of satellite images to better understand and predict the occurrence of this phenomenon.

Initially it will be necessary to establish a relationship between the physical and chemical characteristics of the water in the different regions of the Pantanal and the spectral response captured by satellite images with the use of statistical models.

To generate and calibrate these models, it is suggested to sample the variations of limnological conditions throughout the year, including the *Decoada* phenomenon, correlating them with the images. It is also recommended to adopt sampling at fixed points over the hydrological year, representing different positions in the sampled water bodies, ranging from the most upstream to further downstream areas, with points at the most marginal as well as at the most central regions. By maintaining the sampling at the same points throughout the cycle, it will be possible to identify not only the evolution of the parameters along the temporal gradient, but also the spatial gradient of water bodies. Furthermore, with the sampling at fixed points in different areas of the water bodies, it will be possible to detect the *Decoada* phenomenon moving with different intensities over time. Another important factor is to schedule the field sampling for the exact dates or at least close to the dates of satellite image acquisition, so that the information collected in the field represents the water body conditions at the time of the satellite image acquisition.

Once the field samplings throughout the year or years are performed, it will be possible to establish and calibrate mathematical models, so it is possible, in the following years, to use only the reflectance values of satellite images to monitor the limnological characteristics of the water bodies.

Once the models are well calibrated, besides allowing to estimate the conditions of water quality, it will also be possible to analyze the evolution of the *Decoada* phenomenon in a spatially explicit form, identifying with great accuracy the location of the regions affected by this phenomenon (SONG et al. 2011) and, depending on the temporal resolution of the sensor used, it will also allow a more detailed monitoring of the *Decoada* plume displacement by water bodies and floodplain, enabling more accurate predictions about the time when the different regions will be affected when the phenomenon begins. In this way it will be possible to incorporate detailed information on the effect of land use/land cover, as well as climatic factors such as rainfall and temperature, and on the beginning of the *Decoada* phenomenon. Additionally, with the appropriate prediction of occurrence and displacement of *Decoada*, the responsible institutions for economic activities most affected by the phenomenon, such as fishing, fish farming in ponds and tourism could be informed in advance about it, planning in a few days in advance the displacement its areas of performance to avoid losses.

The use of remote sensing and mathematical models for monitoring limnological conditions will also allow studies on possible effects of changes in climatic conditions and land use on the frequency of occurrence and intensity of the *Decoada* phenomenon, which, in turn, is directly related to the extra availability of carbon for the aquatic food chain in the Pantanal (Calheiros 2003).

CONCLUSIONS

This work showed that the limnological variables are influenced by the flood pulse which present particular values during the occurrence of the *Decoada* phenomenon. To improve understanding of these special features, it is of fundamental importance to implement long-term projects with multidisciplinary teams, enabling monitoring of limnological conditions for more than one hydrological period, as well as monitoring these areas by remote sensing data, aiming the generation of mathematic models to improve comprehension of essential ecological processes which command functioning of the Pantanal ecosystem, in order to base public policies for its conservation, as determined by the Federal Constitution, Article 225 (Brazil, 1988), as well as future forecasts about possible changes in limnological conditions associated to land use, changes in hydrodynamics (waterways, dams for hydroelectric generation) (Calheiros et al. 2009) in addition to climatic conditions.

REFERENCES

APHA, AWWA, WPCF. **Standard methods for the examination of water and wastewater**. American Public Health Association, Washington: American Water Works Association, Water Environmental Federation. 20 ed. 1998. 1268p.

AYRES, M. M. et al. **BioEstat 5.0**: Aplicações Estatísticas nas Áreas das Ciências Biológicas e Médicas. Belém: Sociedade Civil Mamirauá, 2005.

BRASIL. **Estudos hidrológicos da bacia do Alto Paraguai**. Rio de Janeiro, DNOS/MI, 1974. v.1.

BRASIL. **Constituição da República Federativa do Brasil.** Brasília: Senado Federal (Centro Gráfico), 1988. 292 p.

CALHEIROS, D.F. et al. **Influência de usinas hidrelétricas no funcionamento hidro-ecológico do Pantanal Mato-grossense - Recomendações.** Corumbá: Embrapa Pantanal. Série Documentos 2009. (DOC 102). 21p. Disponível em: http://www.cpap.embrapa.br/publicacoes/online/DOC102.pdf. Acesso em 11 fev. 2013.

CALHEIROS, D. F.; FERREIRA, C. J. A. Alterações limnológicas no rio Paraguai ("Dequada") e o fenômeno natural de mortandade de peixes no Pantanal Mato-grossense - MS. **Boletim de Pesquisa e Desenvolvimento**. Corumbá: EMBRAPA Pantanal, 1997. 48p.

CALHEIROS, D. F.; HAMILTON, S. K. Limnological Conditions Associated with Natural Fish Kills in the Pantanal Wetland of Brazil. **Verhandlungen Internationale Vereinigung fur Theoretische und Angewandte Limnologie,** v. 26, n. 5, p. 2189-2193. 1998.

CALHEIROS, D. F.; SEIDL, A. F.; FERREIRA, C. J. A. Participatory research methods in environmental science: local and scientific knowledge of a limnological phenomenon in the Pantanal wetland Brazil. **Journal of Applied Ecology**, v. 37, n.8, p. 684-696. 2000.

CARVALHO, N. O. Hidrologia da Bacia do Alto Paraguai. In*:* SIMPÓSIO SOBRE RECURSOS NATURAIS E SÓCIO-ECONÔMICOS DO PANTANAL, 1, Corumbá,1986. **Anais...** Brasília: EMBRAPA-DDT, 1986. p.43-49.

DA SILVA, C. J.; ESTEVES, F. A. Dinâmica das características limnológicas das baías Porto de Fora e Acurizal (Pantanal de Mato Grosso) em função da variação do nível da água. **Oecologia Brasiliensis**, v.1, p. 47-60, 1995.

DE AZEVEDO MACEDO, H. et al. Distribuição e classificação da intensidade do fenômeno de dequada no Pantanal. In: SIMPÓSIO DE GEOTECNOLOGIAS NO PANTANAL, 5, Campo Grande, MS 2014. **Anais...** Embrapa Informática Agropecuária/INPE, 2014. p. 721-730.

EMBRAPA. Serviço Nacional de Levantamento e Conservação de Solo**.** Manual de métodos de análise de solo. Rio de Janeiro: Embrapa, 1997, 212p.

ESTEVES, F. A. Fundamentos de Limnologia, Rio de Janeiro: Interciência, 1998. 602p.

GRAN, G. Determination of the equivalence point in potentiometric titrations, Part II. **Analyst**, n. 77, p. 661-671. 1952.

HADJIMITSIS, D. G. et al. Determination of turbidity in Kourris Dam in Cyprus utilizing landsat TM remotely sensed data. **Water Resources Management,** n. 20, p. 449-465. 2006.

HAMILTON, S. K.; LEWIS JR., W. M. Causes of seasonality in the chemistry of a lake on the Orinoco River floodplain, Venezuela. **Limnology and Oceanography**, Washington, v.6, n.32, p. 1277-1290. 1987.

HAMILTON, S. K ; SIPPEL , S. J.; MELACK, J. M. Oxygen depletion and carbon dioxide and methane production in waters of the Pantanal wetland of Brazil. **Biogeochemistry**, Netherlands, n.30, p. 115-141. 1995.

HAMILTON, S. K. et al. An anoxic event and other biogeochemical effects of the Pantanal wetland on the Paraguay River. **Limnology and Oceanography**, Washington, n.42, p. 257-272. 1997.

JULIAN, J.P. et al. Optical water quality in rivers. **Water Resources Research,** n.44, p. 1-19. 2008.

JUNK, W. J. The flood pulse concept in river floodplain systems. p. 110-127 In: DODGE, D. P. **Proceeding of the international large Symposium** (LARS). Canadian Special Publications of Fisheries and Aquatic Sciences, Ottawa, 106 p. 1989.

JUNK, W. J.; DA SILVA, C. J. O Pulso de Inundação: base para o manejo do Pantanal. In: SALES, V. C. (Org.). **Ecossistemas Brasileiros:** Manejo e Conservação. v.1, p.179-188. 2003.

KEMPE, S. Long-term records of CO_2 pressure fluctuations in fresh waters. **Mitt. Geol. Palaont. Inst. Univ. Hamburg**, SCOPE/UNEP Sonderband. v.52, p. 91-332. 1982.

KRUG, F. J. et al. Zone trapping in the injection analysis. Spectrophotometric of flow level of ammonium ion in natural waters. **Analytica Chimica Acta**. v.151, p. 39-48. 1983.

MACKERETH, F. J. H.; HERON, J.; TLLING, J. F. Water analysis: some revised methods for limnologist. **Freshwater Biological Association.** Scientific Publications nº 36. Wilson & Son Ltda. Kendall, 117 p. 1978.

MARKER, A. F. H. et al. The measurement of photosynthetic pigments in freshwaters and standartization of methods: Conclusions and recomendations. **Arch. Hydrobiol. Beih. Ergebn. Limnol.** v.14, n.1-2, p. 91-106. 1980.

OLIVEIRA, M. D.; CALHEIROS, D. F. Transporte de nutrientes e sólidos suspensos na bacia do rio Taquari (Mato Grosso do Sul). **Acta Limnologica Brasiliensia**, v. 10, p. 35-45. 1998.

OLIVEIRA, M. D.; CALHEIROS, D. F. Flood pulse influence on a phytoplankton community in south Pantanal floodplain, Brazil**. Hydrobiologia**, v. 427, p.101-112. 2000.

OLIVEIRA, M. D.; CALHEIROS, D. F. Características e Alterações Limnológicas na bacia do rio Taquari, MS. **Documentos**. Embrapa Pantanal, v. 1, p. 1-5. 2002.

OLIVEIRA, M.D. et al. Oxygen depletion events control the invasive golden mussel (Limnoperna fortunei) in a tropical floodplain. **Wetlands**, v.30, n.4, p.705-716. 2010.

OLIVEIRA, M. D. et al. Abiotic factors controlling the establishment and abundance of the invasive golden mussel Limnoperna fortunei. **Biological Invasions**, v. 13, p. 717 -729. 2011.

OLIVEIRA, M.D.; FERREIRA, C.J. Estudos Limnológicos para monitoramento da Bacia Hidrográfica do Rio Miranda, Pantanal Sul. **Boletim de Pesquisa e Desenvolvimento**. Corumbá: Embrapa Pantanal, 2003. 61 p.

PNMA. **Aperfeiçoamento do Monitoramento da Qualidade das Águas da Bacia do Alto Curso do Rio das Velhas**. Brasília: Programa Nacional do Meio Ambiente, 2004, 110p.

RESENDE, E. K. **Interpretações inadequadas e equívocos no manejo da pesca no pantanal**. Corumbá: Embrapa Pantanal, n. 104, p.1-5. 2006.

RODRIGUES, L. C. **Estrutura da comunidade fitoplanctônica de uma lagoa marginal do rio Ivinhema (lagoa dos Patos, planície de inundação do alto Rio Paraná) em diferentes períodos do ciclo hidrológico**. 1998. Dissertação (Mestrado). Universidade Estadual de Maringá. Maringá, 1998.

SMART, G. R. Aspects of water quality producing stress in intensive fish culture. In: PICKERING, A.D.; (Ed.). **Stress and Fish**. London: Academic Press, p. 277-293. 1981.

SONG, K. S. et al. Water quality monitoring using Landsat Thematic Mapper data with empirical algorithms in Chagan Lake, China. **Journal of Applied Remote Sensing,** v. 5, s/p. 2011.

SOUZA-FRANCO, G. M.; ANDRIAN I.; FRANCO, R. M. Comunidade de insetos aquáticos associados à Eichhornia azurea (Schwartz) Kunth, em uma Lagoa de várzea na planície de inundação do Alto rio Paraná, Mato Grosso do Sul, MS, Brasil. B**iológico.** v. 71, n. 1, p. 83-91. 2009.

SPSS, INC. **SYSTAT** version 10.2, standard version. Chicago: SPSS, Inc. 2000.

VALDERRAMA, J. C. The simultaneous analyses of total nitrogen and phosphorus in natural waters. **Mar. Chem**. n. 10, p. 109-122. 1981.

WETZEL, R. A.; LIKENS, G. E. **Limnological analyses.** New York: Springer. 2001. 391p.

ZAGATTO, E. A. G. et al**. Manual de análises de plantas e águas empregando sistemas de injeção em fluxo**. Piracicaba: Universidade de São Paulo/CENA, 1981. 45p.