# Multi-sensor approaches to assess the relationship between wetland deforestation and Amazon floodplain lake eutrophication.

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**Abstract.** The effects of wetland and wetland edge deforestation on Amazon floodplain water quality are investigated in this study**.** This paper presents the methods and results of a study devised to quantify the influence of deforestation on the environmental conditions of the Amazon wetlands lakes. In this investigation we used the following remote sensing data information: 1) PRODES deforestation area computed from Landsat ETM and TM data; 2) wetland area derived from JERS-1 GRFM mosaics; 3) Lake Chlorophyll concentration derived from MODIS images. Remote sensing information were gathered in a GIS environment and integrated to census data provided by the Brazilian Institute of Geography and Statistics to characterize deforested area land use at the municipality level. Results show that wetland deforestation for cattle grazing explains between 59% and 73 % the lake eutrophication in the municipalities under investigation. The integration of information derived from different sensors provided to be a good strategy to look into the relationship between lake water quality and wetland deforestation in regional scale.

**Palavras-chave:** multi-sensor, eutrophication, deforestation, wetland; multi-sensores, eutrofização, desflorestamento, áreas alagáveis.

## 1. Introduction

Land appropriation for agriculture poses a major threaten to the ecological state of the water environment in the present century. Early assessment of the water environment, however, is not a simple task because water properties vary widely in response to seasonal changes in the incoming radiation, climate, and hydrology.

This ever changing nature of aquatic system makes it difficult to unravel the influence of natural variation from anthropogenic disturbance (Chipps et al. 2006). This assertion is even sterner for floodplains lakes where the main driving force is the flood pulse (Junk, 1997). The floodplain lake shorelines oscillate between terrestrial and aquatic phases in response to the flood pulse and usually are used for settlement, agriculture and cattle ranching.

It is well known that the conversion from forest to pasture or cropland affects the movement of water and materials from terrestrial ecosystem to the aquatic system. In between those systems there are the wetlands which behave as a capacitor in the aquatic-terrestrial energy exchanges.

There are several researches carried out in the Amazonia aiming to understand the role of deforestation and land use changes on regional or global climate, hydrology and biogeochemistry (Coe et al., 2002; Keller et al. 2004). The focus of these researches, however, is on the Terra Firme land use change. The Amazon region, however, has a huge wetland zone, which is also undergoing land use changes which might have impacts on Amazon system functioning.

The Amazon River floodplain, locally known as *varzea* or *white water* floodplain, is one of the richest wetland systems in the Brazilian Amazonia, having a key role in the Earth system biodiversity (Junk, 1997). Recent studies, however, demonstrated that there are striking differences in the state of cover types along the Amazon River main stem (Hess et al. 2003). The main stem Amazon River floodplain, upstream the Madeira River confluence, is dominated by flooded forest whereas down streams, towards the lower Amazon River, the landscape is characterized by herbaceous vegetation. How much those differences are natural or human driven? It is well documented that the floodplain has being intensively used for cattle grazing in both Pará and Amazonas states (Ohly and Hund, 2000), and that Pará wetland might have been covered by flooded forests in earlier times. Assuming that as a fact, one could hypothesize that the floodplain lakes of deforested wetlands respond to this disturbance by changes in water quality.

Studies carried out in small watersheds (Neill et al., 2006) demonstrated changes in the interaction between terrestrial and aquatic system as a consequence of deforestation such as: reduction of soil hydraulic conductivity and increased overland flow. According to the authors this shunting of water into overland flow paths in deforested areas may be more significant than weathering in the delivery of cations from land into streams.

Those finds suggest that forest removal not only changes the amount of water flowing in the floodplain but it also affects its geochemistry. If the forest is removed and transformed in pasture land and intensively used for cattle during the low water season, one would expect even more intense changes in the nutrient availability in wetland lakes mainly in the falling and low water phases of the flood pulse.

Cattle grazing have several impacts on the wetlands. According to Steiman et al. (2003) those impacts can be either direct or indirect. Direct impacts include herbivory of aquatic vegetation, nutrient inputs via urine and fecal deposition and trampling of sediments. Indirect impacts include changes in macrophyte and algal species composition induced by nutrient loading and selective herbivory.

Studies carried out in lakes in the floodplain reach between Parintins and Almeirim (Novo et al. 2006) showed almost six month offset between the maximum water level and the maximum average weighed chlorophyll concentration. Barbosa (2005) in the Santarém region also showed the existence of extremely high chlorophyll concentrations. Those high concentrations are far above the base line levels (Melack and Forsberg 2001) and may suggest that those lakes might be undergoing severe eutrophication related to cattle ranching.

Eutrophication can be defined as the process of increase in primary production due to increased nutrient supply in aquatic systems. The increase in nutrient enhances algal productivity and accumulation of algal biomass. It also may increase, if light is not available, the spread of aquatic macrophytes. In the long run, eutrophication produces changes in community structure of flora and fauna threatening lake's biodiversity.

There are several eutrophication indexes, based on water chemistry (Total Phosphorus and Nitrogen concentration), water optics (turbidity) and water biology (Chlorophyll concentration, phytoplankton composition). Among them, chlorophyll concentration can be derived from remotely sensed data, in spite of the limitation of most of the algorithms available for Case I waters (Kampel and Novo, 2004). In fact, Novo et al. (2006) reported the use of MODIS images to map the spatial distribution of chlorophyll concentration in the Amazon floodplain lakes.

The availability of information on the spatial distribution of chlorophyll concentration can be used to derive an eutrophication index for the floodplain lakes which could be in turn related to deforestation.

Taking into account the availability of data, the objective of this paper is to report a study carried out to investigate the relationship between wetland deforestation and lake eutrophication, using the lake area occupied by chlorophyll concentration above the base level concentrations as an eutrophication index.

## 2. Study Area

The study area (**Figure 1**) was selected based on the following criteria: 1) the availability of chlorophyll distribution maps derived from MODIS data for the years 2002 and 2003; 2) the existence of wetland as significant part of their territory; 3) their spatial distribution along the Amazon River main stem at distances not larger than 300 km downstream and upstream Santarém, one of the highest population density spots in the east-west vector of growing human presence in the Amazon region (Kampel, 2003). The study area comprises 16 municipalities being 3 in the Amazon State and 13 in the Pará State.

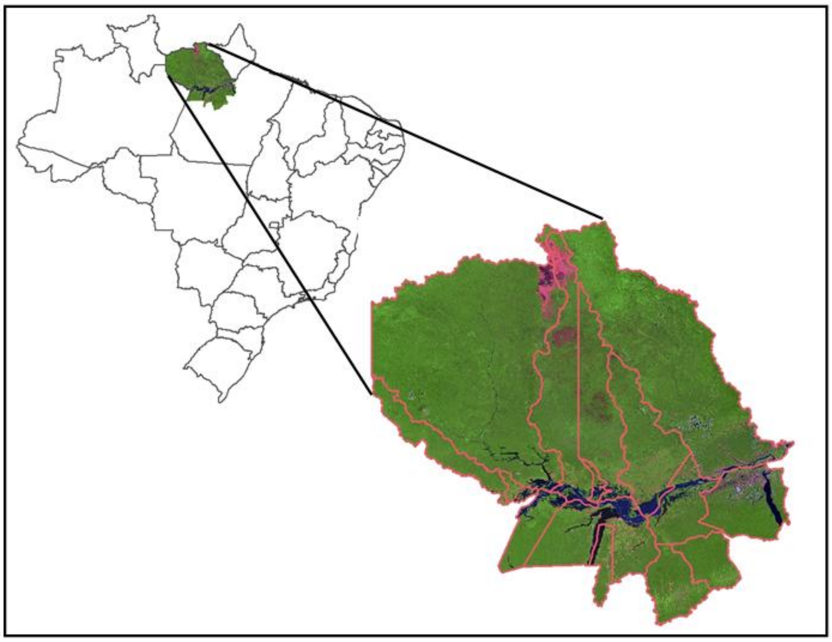

Figure 1: Study Area.

## 2. Methodology

In this investigation the following data sets were used: 1) deforestation area provided by INPE (2006); 2) the no-validated JERS-1 wetland mask (Hess et al., 2003; Melack et al, 2004); 3) Census data provided by the Brazilian Institute of Geography and Statistics (IBGE, 2006); 4) municipality digital maps (IBGE, 2006); 5) Chlorophyl distribution map derived from MODIS images (Novo et al. ; 2006); 6) chlorophyll concentration data derived from literature (Forsberg and Melack, 2001).

The first step was to integrate all the data set into a geographical information system environment, so as to derive the following information used in this study: a) wetland area; b) open water area; c) 2 km buffer area at the wetland margin; c) lake area with chlorophyll concentration larger than the base-line concentration; d) cloud cover area in the wetland. All this information was computed for each municipality under investigation. Details on the procedures applied to derive that information are fully described in Affonso et al. (2006). As the chlorophyll distribution maps were available at a monthly basis, subjected therefore to changes in the lake area in response to the flood pulse, whereas the deforestation data was available at a yearly basis. To overcome this problem, the Eutrophic Lake Index was defined as the summation of the lake area with chlorophyll concentrations above the base line during a certain period of time including the falling and low water states of the hydrological cycle (Barbosa, 2005). As the chlorophyll map was derived from MODIS images acquired from June 2002 to December 2003, the computation was limited to open water only. Areas covered by macrophytes, exposed lake bottom and cloud cover were gathered into a class named "others". **Figure 2** exemplifies the problem of variable cloud cover and lake area. Everything that was not open water at a given date was included in the class "others" which represents a mixture of wet areas ranging from exposed lake bottom to cloud-cover. The size of this class changes considerably from one date to the other. In order to take this into account, the area covered by this class was assessed for each municipality. The municipalities and dates at which this class covered more than 50 % of the municipality were disregarded in the analyses. This procedure was adopted to avoid comparing municipalities which at a given time were not significantly represented by open water, either because of cloud cover or infestation by macrophytes.

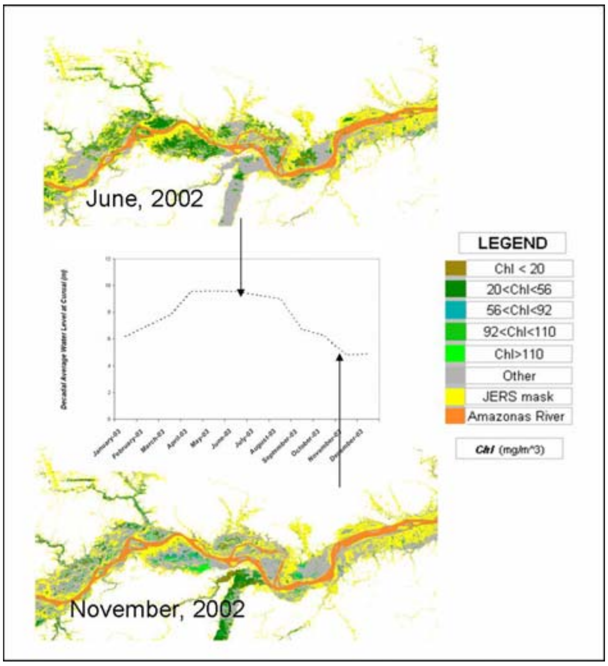


Figure 2: Seasonal changes in the open water area in response to changes in the flood pulse.

In the computation of the Eutrophic Lake Index, it was assumed that the baseline chlorophyll concentration as reported in the literature (Melack and Forsberg, 2001) varies from 1 mg/m$^3$ to 90 mg/m$^3$. The area occupied by chlorophyll concentration values larger than 92 mg/m$^3$ were then computed for each municipality and crossed with the information on the size of the class "others" present in the Novo et al. (2006) maps.

Two sets of data were derived for statistical analysis: Eutrophication Index _2002, Eutrophication Index_2003, Deforestation_2001, Deforestation_2002. This data set were submitted to an exploratory linear regression analyses in order to assess how much the lake eutrophication can be predicted from the wetland deforestation at municipality level.

## 3. Results and Discussion

**Figure 3** shows the results of the regression analyses for the Eutrophication Index derived from the chlorophyll distribution in 2002 and wetland deforestation computed for 2001. The rational for using one year lag between the two variables was that the impact of cattle on the floodplain would be sensed after its occupation for at least a hydrological year.

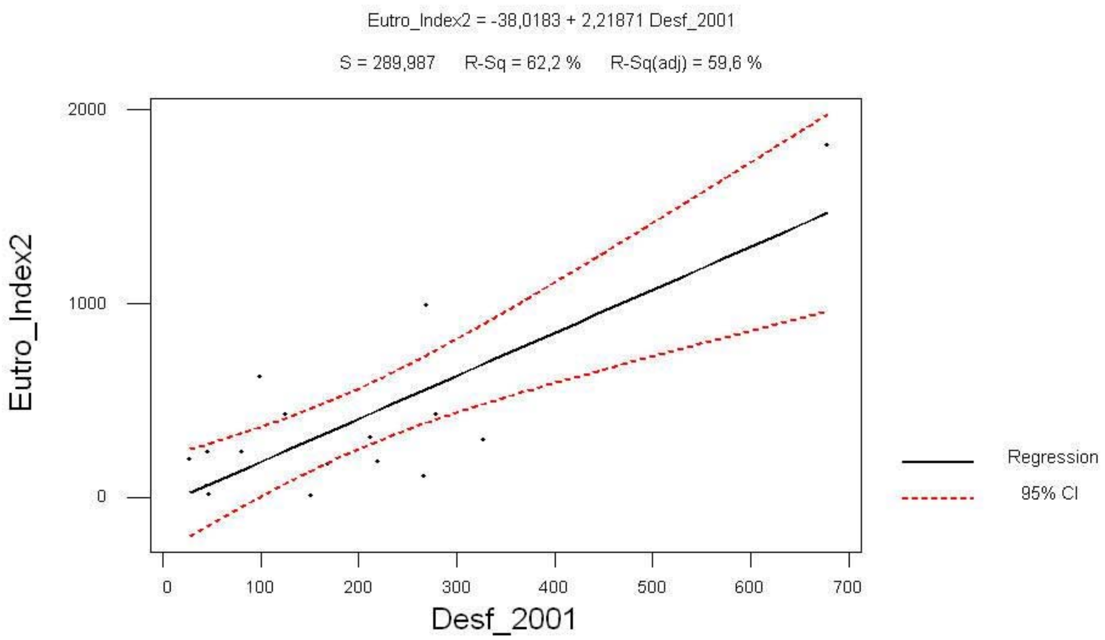


Figure 3: Regression model for estimating lake eutrophication in 2002 (Eutro_index2) as a function of wetland deforestation in 2001 (Desf_2001).

**Figure 4** shows the statistical results for the eutrophication estimated for 2003. The fact that for two successive years the regression model showed the same overall trend in the relationship between the proposed Eutrophic Lake Index and wetland deforestation suggests that there is a perceptible impact of the land use in the Amazon lake water quality.

The linear model in **Figure 3** (p-value = 0.000) provides a reasonable fit to the data. The R indicates that the area of deforested wetland in 2001 (Desf_2001) accounts for59,6 % of the variation in the lake eutrophic index (lake area with chlorophyll concentration above the region base line). The inspection of the plot reveals that the municipalities setting outside the 95% confidence limits fall into two groups: a) Santarém and Óbidos, where the deforestation maybe largely underestimated since the baseline wetland deforestation defined by PRODES (INPE, 2006) disregarded a great deal of forest removal in those areas prior to satellite monitoring have started; b) Monte Alegre and Almeirim, where the chlorophyll concentration maps did not reach the specified threshold for the class “others”. In this case, either because of cloud cover or lack of open water due to macrophyte infestation, the Eutrophic Lake Index was largely underestimated. Those methodological imperfections shall be tackled in future studies.

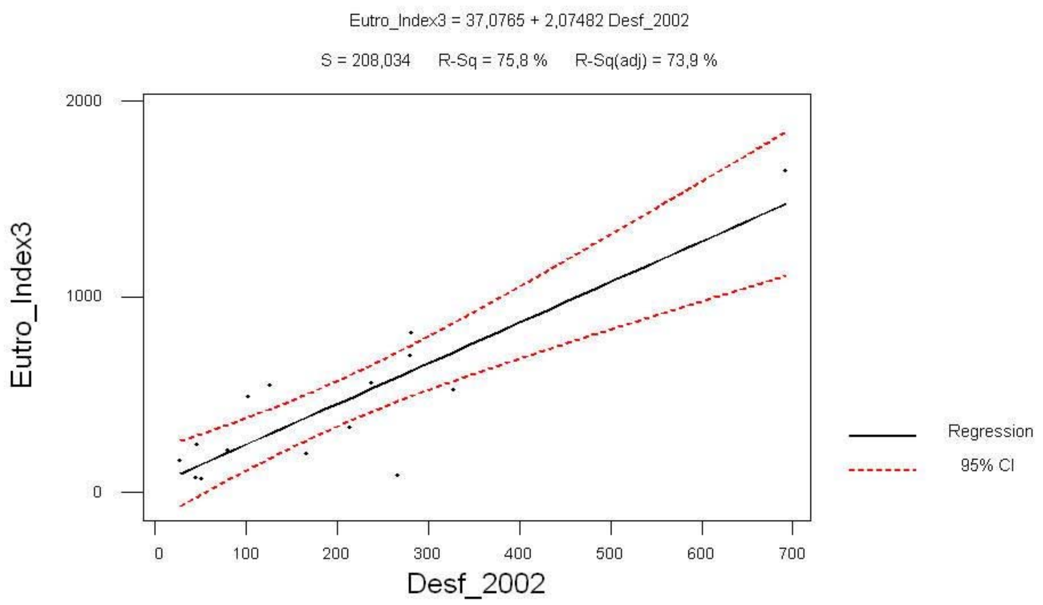


Figure 4: Regression model for estimating lake eutrophication in 2003 (Eutro_index2) as a function of wetland deforestation in 2002 (Desf_2001).

The linear model in **Figure 4** (p-value = 0.000) provides a much better fit to the data. The R indicates that the area of deforested wetland in 2002 (Desf_2002) accounts for 73.0 % of the variation in the lake eutrophic index (lake area with chlorophyll concentration above the region base line). The better fit maybe related to the fact that in 2003 most of the data available for estimating the Eutrophic Lake Index reached the specified threshold for the class “others”

In spite of the weaknesses of the data available, mainly because they were not produced aiming to answer the questions addressed in this study, they provide solid grounds to support the assumption that the wetland deforestation is responsible for a great deal of the Amazon water quality deterioration. **Figure 5** summarizes the connections between wetland deforestation, herd grazing and eutrophication. In the figure one can observe that, the red arrows (Eutrophication Lake Index above 500 km2 of chlorophyll concentrations larger than the regional base level) are located in municipalities characterized by very large herds. It is important to point out that in some municipalities the cattle is also raised in Terra Firme pasture land. Even so, some of these cattle can eventually spend some time in the floodplain, contributing to the deterioration of the lake water quality.

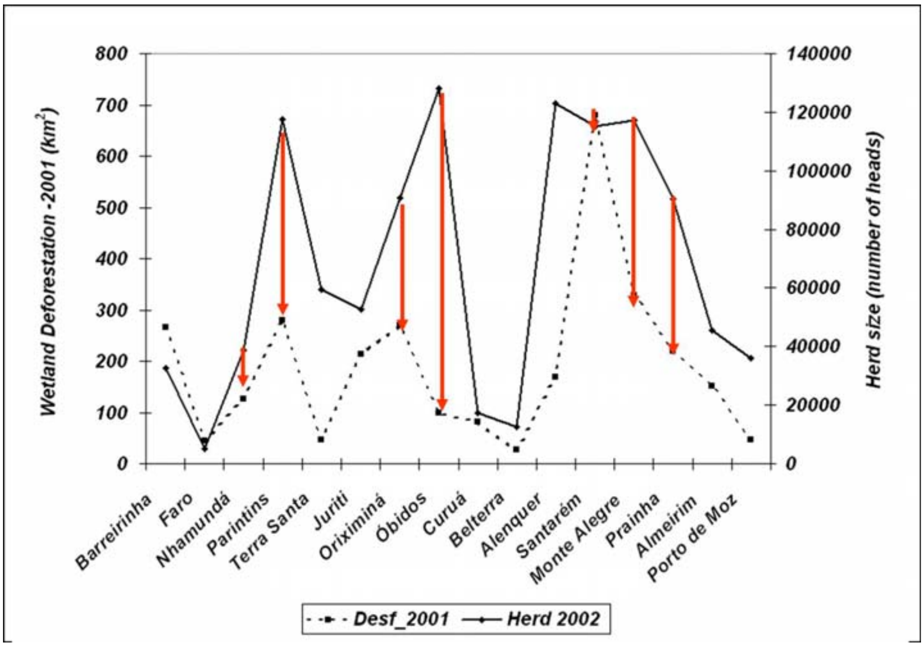


Figure 5: Connections among deforestation, cattle grazing and lake eutrophication. The red arrows indicate the municipalities with the largest Lake Eutrophication Indexes.

## 4. Conclusion

The results of this study points out to the importance of the information derived from several sensor systems which integrated into a geographical information system environment allowed to get a better understanding of the relationship between wetland deforestation and lake water eutrophication.

It is important to stress that in spite of the data available were derived for answer the specific question of this study, they were very useful and allowed to ascertain the fact that in the area under study wetland deforestation for cattle grazing is producing a great deal of environmental impact on water quality. The methodology used for this study should be perfected so as to derive not only explanatory models but predictive models that may act as sound support to sustainable development practices in the region.


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