PREDICTIVE MODELING OF TROPHIC STATUS OF A TROPICAL RESERVOIR USING GEOGRAPHICAL INFORMATION SYSTEMS

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This paper describes a method to assess the trophic status (TS) of a tropical reservoir. Barra Bonita reservoir is located in the Tiete River, SP state (22°29'S and 48° 34'W). Water quality variables were determined at 30 sample points in 18 dates. Data were stored using a Geographical Information System (GIS) software developed by the Image Processing Division at INPE, Brazil. The spatial distribution of the patches in the reservoir permitted to identify the areas where the inputs of nutrients are critical and to understand how the circulation patterns, depth and other environmental variables are affecting the system.

INTRODUCTION

Lakes change naturally from oligotrophic (nutrient-poor) to eutrophic (nutrient-rich) through time. In the modern society, however, human activities are accelerating this process (Tundisi and Matsumura-Tundisi, 1992). The excessive growth of plants can result in changes of odor and taste of the water, increasing the expenses in water treatment. There are also significant ecological consequences such as fishing kills, spread of parasitic diseases (Ryding and Rast, 1989), and increase in the methane emission to atmosphere (Bartlett et al. , 1988).

The International Cooperative Programme on Monitoring of Inland Waters provided boundary values of total phosphorus, total nitrogen, chlorophyll concentration and Secchi Depth for the trophic conditions of temperate zone lakes (OECD, 1982). Indexes used to classify the trophic level of aquatic systems in temperate regions can not be applied to tropical environments (Esteves, 1988). Because of that, it is recommended that the assessment of the trophic state of a given tropical system rely on a combination of indexes.

The objective of this paper is to describe a method to assess the TS of a tropical reservoir by combining several trophic indexes (TI) measured at various dates with the aid of a GIS.

STUDY AREA

Barra Bonita reservoir was selected as test site. It is located in the Tiete River, at 22°29'S and 48° 34'W. Tiete drainage basin has 32 330 km ^{2} encompassing the most populated and urbanized area in Brazil. Sugar cane plantation is the main agricultural activity. The reservoir surface area is around 300 km ^{2} most of the year. Although built up with the primary purpose of producing hydroelectricity, nowadays it is being exploited for navigation, recreation and fishing (Tundisi et al., 1991).

METHODS

Water samples were collected at 30 limnological stations located at every 2 km. The following variables were measured: total nitrogen (TN), total phosphorus (TP), and total chlorophyll (phaeophytin + chlorophyll a) (Chl). A data set of 18 different dates were stored in a georeferenced data base with the help of a GIS.

The data were submitted to the following processing: interpolation (Burrough, 1986); classification according to the OECD (1982) boundary (table 1); organization of a set of rules based on Boolean algebra. The following data sets were selected out of the 18 available: July 20, 1989; March 03, 1990; August 8, 1990 and November 11, 1990. Those dates represent typical Summer and Winter cases along two hydrological years (Novo and Braga, 1991).

Two problems were investigated in relation to the trophic state: 1 - given a single date, how the reservoir trophic state changes when more than a TI is applied; 2 - given a time series, how the reservoir trophic state changes when different sets of TI are applied. The basic assumption was that a given pixel (P) in the reservoir would be classified in a given trophic status (TS) in a single date if it met the following constraints:

$$P(TS) = TN(TS) \text{ and } TP(TS) \text{ and } Chl(TS) \quad (1)$$

This rule was applied for 4 different dates (two Summer data sets and two Winter data sets) and the final trophic status (FTS) of each pixel was obtained assuming that it would be defined by the length of time spent by the pixel in a given TS. The following constraints were then applied:

$$P(FTS) = TS1 \text{ and } TS2 \text{ and } TS3 \text{ and } TS4 \quad (2)$$

RESULTS

The TS of the reservoir changed from July, 1989 to November 1990 when Chl was used as TI (table 2). The reservoir TS represented by Chl is widely dependent on seasonally. In the Winter almost the entire reservoir is classified as Mesotrophic

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(75 % to 92 %). In the Summer, half of the area is turned into Eutrophic. When TP is used as TI, the seasonally does not affect the reservoir TS (table 3). The use of TN as TI puts the reservoir into the Eutrophic class most of the time (table 4). Except for July, when 67 % of the reservoir was Mesotrophic in terms of TN concentration, in the remaining dates, the reservoir was predominantly Eutrophic.

Table 5 shows that if both nutrients are used to determine the TS of the Barra Bonita waters, the area occupied simultaneously by the same trophic class is reduced. It means that high concentrations of TP and TN are not spatially coincident. During the Winter, 34 % of the area of the reservoir can be classified as Mesotrophic if both nutrients are used. It may be explained by the high hydraulic retention time which is responsible for the horizontal mixing of the reservoir. In the Summer the horizontal stratification of the reservoir increases the variability in the type and amount of nutrients on the reservoir surface. If the three TI are used (table 6). No common area can be classified as Eutrophic because in the specific case of Barra Bonita reservoir the areas with a given concentration of TN, TP or Chl are not spatially coincident.

The results in table 7 show that only 18 % of the area can be classified in a given trophic level in the period under study if the Chl is used as TI. It means that there is a very high spatial and time variability in the Chl concentration. If TP is used as TI, the reservoir is kept as Mesotrophic during the year, showing that the TP concentration is not as dependent as Chl on the seasonal and spatial changes in the forcing functions. When TN is used as TI only 21 % of the area of the reservoir is kept Eutrophic along the year.

Figure 1 shows the spatial distribution of the trophic classes derived from Chl used as TI in November,1990. Tiete inlet and Piracicaba inlet are predominantly Eutrophic. The central body of the reservoir, however, is Mesotrophic. When TP is used as TI (Figure 2) only the reservoir entrance is Eutrophic, indicating that the main source of TP for the system is the urban sewage coming from the urbanized catchment basin. The Eutrophic water corresponds to the transition zone of the reservoir (Thorton et al., 1990) where significant sedimentation occurs with increase in light penetration sufficient to promote primary production. The increase in primary production explains The decrease in TP concentration downstream.

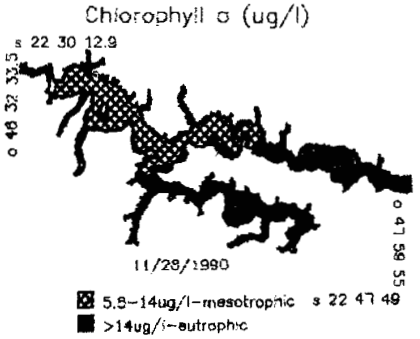

Figure 1

Barra Bonita TS Distribution when Chl is applied as TI.

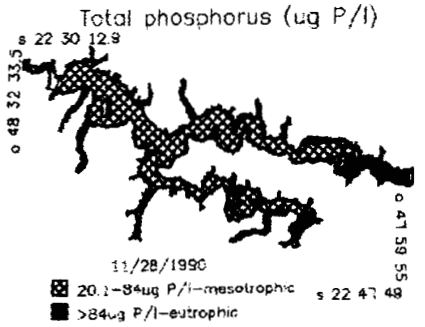

Figure 2
Barra Bonita TS defined when TP was used as TI

In the same date, the entire reservoir is classified as Eutrophic if TN is used as TI (Figure 3) showing that this nutrient is abundant and it is not completely depleted in the primary production processes.

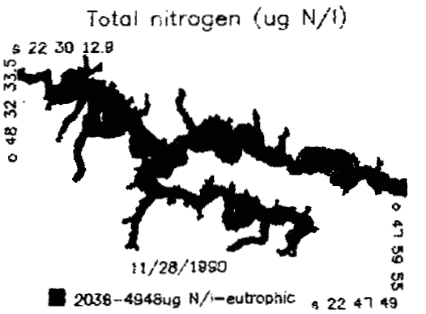

Figure 3
Barra Bonita TS defined by TN used as TI

As a consequence, in November, 1990, when the three limnological variables are combined (Figure 4) the Eutrophic waters are restricted to the entrances of the Piracicaba and Tiete inlets.

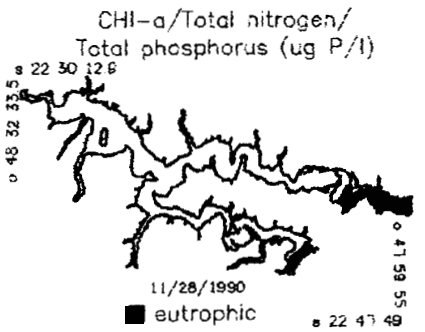

Figure 4
Barra Bonita trophic state TN&TP&Chl is used as TI

It is clear that a key action for eutrophication control in the Barra Bonita reservoir must emphasize the decrease in the TP input to the reservoir from the Tiete and Piracicaba rivers.

Their catchment basins have suffered in the last three decades an intensive process of land conversion. Land use is characterized by monospecific cultures subjected to intensive use of fertilizers. Economical deterioration also increased the input of waste water discharge without treatment (Tundisi and Matsumura-Tundisi, 1992).

Figure 5 shows the results when Chl is used as TI. There is a small region in the central body of the reservoir which remains Mesotrophic along time. The remaining area of the reservoir does not keep the same trophic level along time.

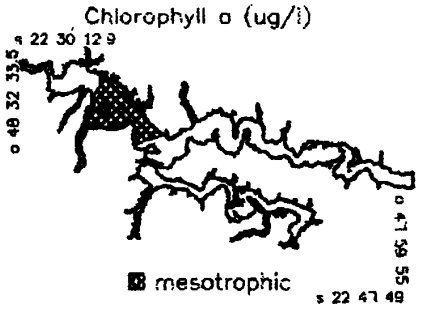

Figure 5
Barra Bonita TS when Chl is used as TI in four dates

If TP is used as TI, most of the reservoir is classified as Mesotrophic (Figure 6).

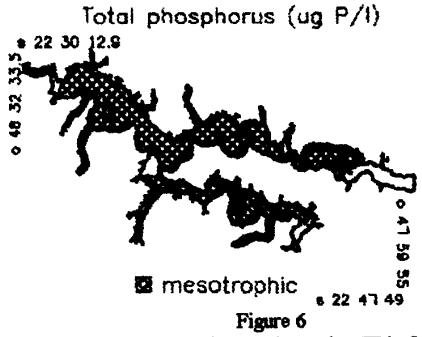

Figure 6
Barra Bonita TS when TP is used as TI in four dates

An Eutrophic region is identified when TN is used as TI, and it is restricted to the Tiete inlet (Figure 7). It indicates that this region is the most critical in the reservoir during the year. It keeps high level of nutrients favoring the undesirable growth of algae and macrophytes when the TP becomes abundant in the system.

When all three limnological variables are used as TI, however, the reservoir does not present a region which can be classified within a given trophic class.

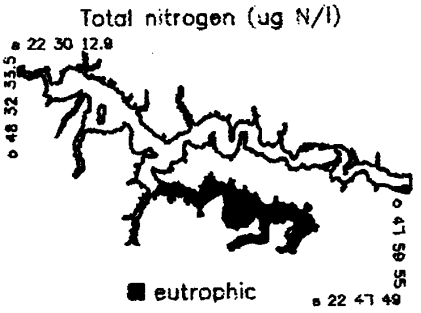

Figure 7
Barra Bonita TS when TN is used as TI in four dates

CONCLUSIONS

The results of this study show that the methods of predicting the trophic level of aquatic systems based on average values for the system as whole can lead to misclassification. Barra Bonita reservoir, for instance, could be classified as an Eutrophic reservoir if average values of TN, TP and Chl were used to represent the entire water body. During the period the average TN, TP and Chl values were most of the time far above the Eutrophic limits (Novo and Braga, 1993)..

The use of the GIS to manipulate spatially the samples proved the heterogeneity in the TS in space and time. To locate water masses with variable degrees of eutrophication in a given aquatic environment is a key factor to identify the strategies for controlling the nutrient inputs to the reservoir. The use of GIS should be stimulated among limnologist as tool to get a better understanding of the spatial variability of water properties in order to identify the main interactions between the aquatic and the terrestrial environment.

ACKNOWLEDGMENTS

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Table 1 - *OECD boundaries used to classify Barra Bonita reservoir into three trophic classes.*

Trophic level	Total Nitrogen	Total Phosphorus	Total Chlorophyll
Oligotrophic	$< 660 \mu g l^{-1}$	$< 8 \mu g l^{-1}$	$< 2 \mu g l^{-1}$
Mesotrophic	$660 - 1870 \mu g l^{-1}$	$8 - 84 \mu g l^{-1}$	$2 - 14 \mu g l^{-1}$
Eutrophic	$> 1870 \mu g l^{-1}$	$> 84 \mu g l^{-1}$	$> 14 \mu g l^{-1}$

Table 2 - *Area of the reservoir occupied by water with different trophic status when Total Chlorophyll is used as TI*

Total Chlorophyll	July 20 1989	March 17 1990	August 8 1990	November 28 1990
Oligotrophic	07.4%	00.0%	00.0%	00.0%
Mesotrophic	92.6%	41.0%	75.0%	52.0%
Eutrophic	00.0%	59.8%	25.0%	39.5%

Table 3 -- *Area of the reservoir occupied by water with different trophic status when Total Phosphorus is used as TI.*

Total Phosphorus	July 20	March 17	August 8	November 28
Oligotrophic	000.0%	00.0%	00.0%	00.0%
Mesotrophic	100.0%	97.2%	97.0%	87.8%
Eutrophic	000.0%	02.8%	03.0%	12.2%

Table 4 -- *Area of the reservoir occupied by water with different trophic status when Total Nitrogen is used as TI.*

Total Nitrogen	July 20	March 17	August 8	November 28
Oligotrophic	000.0%	000.0%	01.0%	000.0%
Mesotrophic	067.4%	000.0%	34.8%	000.0%
Eutrophic	032.5%	100.0%	66.0%	100.0%

Table 5-- *Area of the reservoir occupied by water with different trophic status when Total Phosphorus and Total Nitrogen are used as TSI.*

Total Nitrogen Total Phosphorus	July 20	March 17	August 8	November 28
Oligotrophic	000.0%	000.0%	00.0%	000.0%
Mesotrophic	032.2%	000.0%	34.0%	000.0%
Eutrophic	000.0%	001.0%	01.0%	010.0%

Table 6- *Area of the reservoir occupied by water with different trophic status when Total Phosphorus, Total Nitrogen and Total Chlorophyll are used as TSI.*

Total Nitrogen Total Phosphorus Total Chlorophyll	July 20	March 17	August 8	November 28
Oligotrophic	000.0%	000.0%	00.0%	000.0%
Mesotrophic	065.2%	000.0%	33.7%	000.0%
Eutrophic	000.0%	000.0%	01.0%	010.0%

Table 7 - *Trophic Status of the Barra Bonita Reservoir in four dates*

Four Dates	Chlt	TP	TN
Oligotrophic	000.0%	000.0%	00.0%
Mesotrophic	018.7%	086.5%	00.0%
Eutrophic	000.0%	000.0%	21.0%