AMAZONIANA XIII(1/2): 17 - 32 Kiel, Dezember 1994

Zooplankton community density in relation to water level fluctuations and inorganic turbidity in an Amazonian lake, "Lago Batata", State of Pará, Brazil*

by

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(Accepted for publication: September, 1993).

Abstract

This research concerns the patterns of variations in the zooplankton community density in Batata Lake, State of Pará, Brazil. Four collections were made during one year at distinct phases of the regional hydrological cycle. Together with the zooplankton community density, the water temperature, transparency, pH, concentration of suspended solids, chlorophyll-a and dissolved oxygen were determined. The chief objectives of the work were the observation of the spatial and temporal variations of the zooplankton community density and their relationships to the ambient variables measured; and the identification of the possible influence on these organisms of the fine particulate clays, tailings from bauxite processing, that have been discarded into the lake for ten years. The temporal fluctuations and the reduction in plankton density observed in the affected area of the lake are discussed, considering factors such as water level fluctuation and changes in the quantity of suspended inorganic matter and the direct consequences for the zooplankton, as well as effects through interactive mechanisms with other ambient variables such as phytoplankton primary production.

Keywords: **Zooplankton, density, water level, inorganic turbidity, Amazonian lake.**

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* Research funded by Mineração Rio do Norte S.A.

Introduction

Variations in the density of zooplankton communities under natural conditions are difficult to explain fully because of the existence of a large number of potential biotic and abiotic factors that may cause these variations directly or indirectly. Among these factors is turbidity, which increases in the complexity and diversity of its effects in proportion to its action upon the zooplankton community.

By absorbing and deflecting solar photons, turbidity may modify drastically the quality and quantity of subaquatic radiation, consequently changing the thermal characteristics and the primary production of a body of water. At the same time, particles in the water provide a substantial surface area upon which a variety of phenomena can occur (KIRK 1985). The presence of high quantities of inert particles interferes in the filtration mechanisms of zooplanktonic organisms and alters the nutritional value of their food (PAGGI & PAGGI 1974; ARRUDA et al. 1983). This fact becomes significant for the processes of energy transfer in the food web, to the extent that the inorganic suspended matter reduces the rate of feeding and the assimilation efficiency of the zooplankton, decreasing their production (McCABE & O'BRIEN 1983). At the same time that they may interfere negatively, clays can in certain circumstances, because of their capacity to adsorb organic compounds, become an important potential nutritional resource for the zooplankton filter-feeders (AVNIMELECH et al. 1982; ARRUDA et al. 1983).

Moreover the role of the zooplankton community must be considered, as under certain conditions zooplankters can control the abundance of suspended particles by the process of biosedimentation (GLIWICZ 1986; G-TÓTH et al. 1986).

Predation as much as competition, which according to HART (1988), among others, are in general the two principal interactive determinants of community structure, are influenced by turbidity. The presence of suspended clays reverses the usual competitive dominance of cladocerans over rotifers, freeing rotifer populations from competition (KIRK & GILBERT 1990). In a similar manner, turbidity can represent a refuge from predation (VINYARD & O'BRIEN 1976; McCABE & O'BRIEN 1983; GEDDES 1984).

Consequently, turbidity has been shown to be a highly significant ecological factor in some environments where it acts usually on zooplankton community composition (GEDDES 1984; HARDY 1989), or where human influence has modified natural conditions, directly or indirectly creating highly turbid environments (ARRUDA et al. 1983; ESTEVES et al. 1990; BOZELLI 1992).

The present study therefore investigated changes in the zooplankton community density in Batata Lake, considering aspects related to the action of the bauxite tailings entering the lake which have, among other consequences, altered the turbidity of the water.

Study area

Batata Lake is located between 1°25' - 1°35'S and 56°15' - 56°25'W, near Porto Trombetas in the Municipality of Oriximiná, State of Pará, Brazil (Figure 1). The lake is situated on the right bank of the Trombetas River and is about 2100 ha in area.

However, the lake surface area changes greatly during the year because of large variations in water level. Like the Trombetas River, the water of the elongate, dendritic Batata Lake is clear according to the classification of SIOLI (1950). River and lake remain interlinked throughout the year. This interlinkage intensifies when the water level rises above the shoreline dikes at various places. Batata Lake is surrounded by a vegetation formation which according to PRANCE (1980) should be termed seasonal igapó, since it undergoes periodic inundation.

Batata Lake is distinct from other lakes of the region in having received for ten years (until November, 1989) a byproduct of bauxite processing. Bauxite began to be mined in the region with the operations of the Mineração Rio do Norte Company in the Serra do Saracá mountain range in 1979. Waste materials, together with water used in washing were pumped into the upper part of Batata Lake in volumes of about 18 million m^3 annually. Seven to nine percent of these tailings are finegrained particulate solids, mainly aluminum oxide (21 %), silicates (4 %) and iron oxides (LAPA & CARDOSO 1988). According to SILVA (1991) the tailings spread into about 30 % of the lake area. This value is presently considered an underestimate since the tailings are becoming more widely distributed in the lake.

Sample collections were carried out at intervals of three months over a one-year period. The intervals were planned to take into account the different phases of the regional hydrological cycle: drawdown (water level decreasing - September, 1988); dry (lowest water level - December, 1988); filling (rising water level - March, 1989); and flood (highest water level - June, 1989). Six collection stations were established, stations 4, 5, and 6 being located in the area of the lake totally covered by the bauxite tailing clays. Station 3 was located in an area considered as in transition, showing some indications of the presence of tailings. During the dry phase, no collections were made at stations 5 and 6 because this part of the lakebed became totally dry.

Material and methods

Water temperature was determined with a FAC 400 electronic thermometer, and water transparency by a SECCHI disc. Water samples were collected with a Van DORN bottle, at the surface and just above the bottom. During periods of thermal stratification, water samples were also taken at intermediate depths. For determinations of oxygen concentration the procedure described by GOLTERMAN et al. (1978) was followed. pH was determined using a portable Digimed brand meter and the quantity of total suspended solids was determined by gravimetry. To estimate chlorophyll-a, known water volumes were filtered through GF/C membranes that were then analyzed in the laboratory according to the methods described by GOLTERMAN et al. (1978).

Zooplankton samples were collected in vertical tows through the entire water column, using a conical 68 µm-mesh net. The concentrated sample was fixed in a 4 % commercial sucroseformaldehyde solution (HANEY & HALL 1973).

Rotifers and nauplius larvae were counted in 1.0 ml subsamples made with an automatic pipet after homogenization of the sample. These subsamples were counted in SEDGWICK-RAFTER chambers using an American Optical microscope at 100 x magnification. At least 250 rotifers and 250 nauplii, and not less than three subsamples were counted per sample. Only rotifers of the Superorder Monogononta (KOSTE 1978) were counted. Nauplii were differentiated into cyclopoids and calanoids. Other microcrustaceans were sampled with an automatic pipet after homogenization of the sample. Subsamples of 1.0 to 10.0 ml were counted using a ZEISS/Jena stereomicroscope at 40 x magnification. At least 250 individuals and not less than three subsamples were counted per sample. Samples with low densities of individuals were counted entirely. Cladocerans of the Families Chydoridae and Macrothricidae were not counted. The results for density of organisms are presented as ind. m^{-2} in order to facilitate comparisons (BOTTRELL et al. 1976) and minimize the problem of large differences in depth between stations and season of sampling (MARLENE ARCIFA, pers. commun.). Calculations were made according to the area of the mouth of the plankton net and the quantity of organisms collected in a vertical haul referent to this area was extrapolated to m^2.

The relationships between zooplankton community density and environmental variables were elucidated using Stepwise Multiple Regression analysis (SOKAL & ROHLF 1981).

The regression coefficients were standardized. Suspended solids were not used in the regression to avoid interpretation mistakes, because zooplankton is already included in suspended solids.

Results

The maximum variation in the level of the Trombetas River during the study period was 8.36 m (Fig. 2). There was a distinct rhythm of rise and fall which was reflected in Batata Lake, since both systems remained interlinked during the entire year. This permitted characterization of different seasons according to the hydrological characteristics of the study area.

The thermal profiles and dissolved oxygen concentrations in the water are shown schematically in figure 3. Station 1 showed thermal stratification during all four seasons. During the drawdown and filling phases the water also showed stratification in regard to concentrations of dissolved oxygen, with a large deficit in the deeper parts. Station 2 showed thermal stratification during the drawdown, filling and flood phases, with stratification of dissolved oxygen concentration during drawdown and filling. Stratification of temperature and dissolved oxygen concentration was also observed during drawdown and filling at station 3. However at station 4, thermal stratification appeared only during drawdown, and the water was thermally and chemically unstratified at the other periods. At stations 5 and 6 no strafification was detected during the two phases at which samples were taken.

In table 1, pH values at the surface of the water column are presented. There appears to be little evidence of effect of the tailings on pH values, however station 6 showed some of the lowest values measured during this study. The correlation between pH and zooplankton density was not statistically significant. Over time the lowest values were observed during the dry and flood phases.

The values of chlorophyll-**a** (at surface of the water column) are presented in table 2. Observed values varied between undetectable levels at stations 1, 4, 5 and 6 to 15.4 $\mu g \cdot l^{-1}$ at station 2. The highest values were observed during the dry phase and the lowest values during the filling and flood phases. The mean value was 5.3 $\mu g \cdot l^{-1}$ (s = 5.0; n = 13).

In figure 4 the results of water transparency and total suspended solids are presented. These two variables showed opposite patterns which evidenced their interrelationship. Water transparency was much reduced at stations 3, 4, 5 and 6 during the drawdown, dry and filling phases, while increases in concentration of suspended solids were observed. Measured transparency values varied between 0.15 m and 1.9 m (x = 1.0; s = 0.5; n = 20), while values for suspended solids varied between 1.70 and 33.25

$mg \cdot l^{-1}$ ($x = 13.90$; $s = 9.71$; $n = 20$). Transparency did not show a definite pattern of temporal variation. In those areas where tailings were absent or present in small quantities, the highest transparency values occurred during the filling phase. The temporal changes of the values for suspended solids were more well-defined, since the highest values occurred during the dry phase and diminished with rise in water level.

Total zooplankton density (Fig. 5) varied between 32,120 and 952,800 ind. m^{-2}. The lowest density values were observed during the flood phase and the highest values during the filling phase. In regard to spatial distribution, a tendency toward a decrease in density at the stations where tailings were present could be verified. This pattern is evident when the results obtained during the drawdown, dry and principally the filling phases are considered.

The rotifers were dominant in the dry and flood phases; the densities of this group varied between 2,558 (station 6) and 427,880 ind. m^{-2} (station 1). The copepods showed densities between 5,413 (station 2) and 617,280 ind. m^{-2} (station 1). This group was numerically dominant during the drawdown and filling phases. The cladocerans contributed less to the total observed values at all phases of the year. Densities of cladocerans varied between 1,488 (station 2) and 158,420 ind. m^{-2} (station 4).

The general pattern of reduction of total zooplankton density during the drawdown, dry, and filling phases at those stations with tailings present reflected the behavior of the three different groups, since the same tendency is seen when the densities of rotifers, copepods and cladocerans are considered separately (Fig. 5).

During the flood phase a different pattern was observed, as only station 1 showed a higher density, while the remaining stations showed similar values without any evidence of changes of densities in the area with tailings present.

Among the rotifer species, during the drawdown phase, *Brachionus gessneri* contributed most to the total number of individuals at stations 2, 3, 5 and 6, and *Collotheca* sp. 1 at stations 1 and 4. During the dry phase *Keratella americana* became dominant at station 4 and at the other stations the pattern of the drawdown phase was maintained. During the filling phase, dominance of *Collotheca* sp. 2 at stations 1, 2, 3 and 4 and of *B. gessneri* at stations 5 and 6 was recorded. During the flood phase, *B. gessneri* was dominant at stations 1, 2, 5 and 6 while *Conochilus dossuarius* was dominant at stations 3 and 4 (see species list in BOZELLI 1992).

Ceriodaphnia cornuta was recorded as the dominant species of cladoceran at stations 1, 2, 3, 4 and 5 and *Bosmina hagmanni* at station 6 during the drawdown phase. During the dry phase, *Bosminopsis deitersi* was dominant at stations 1 and 2, while *Diaphanosoma birgei* dominated at stations 3 and 4. During the filling and flood phases *B. deitersi* had the highest density at all the stations.

Among the copepods, the dominance of *Oithona amazonica* was practically total at the different stations and seasons. Exceptions were the dominance of *Rhacodiaptomus retroflexus* at station 3 during drawdown and of *Notodiaptomus* coniferoides at station 4 during the dry phase. The nauplii and copepodids of calanoid and cyclopoids were recorded at all seasons and stations at densities varying from 4,509 to 502,902 ind. m^{-2} (nauplii) and from 684 to 112,058 ind. m^{-2} (copepodids).

In table 3 the multiple linear regression parameters between total zooplankton density and five of the environmental variables studied are presented. The zooplankton density was significantly positively correlated with transparency and water temperature and the model which could be established to explain the density by means of these two variables explained 60 % of the variation of the data. The introduction of additional variables into the model did not improve significantly the fit, since these had non-significant partial correlation coefficients.

Discussion

The reduced climatic variations, typical of tropical regions, and the research of some authors such as BURGIS (1969, 1971, 1978) and BURGIS & WALKER (1972) led to the consensus that zooplankton populations remain relatively stable over time. According to TWOMBLY (1983), however, a growing number of investigations have demonstrated seasonal variations in the abundance of populations of tropical zooplankton. In many situations where the climatic elements diminish in importance, other factors maximize their influence on these systems. Thus, for the Amazon region, the extreme fluctuation of the water level of the rivers which exerts a strong influence over the surrounding landscape, whether by hydrodynamic action or by transport of materials, must be considered. The consensus among researchers who study the zooplanktonic community of these environments is that the density of these organisms is related to this event and consequently its quantification must consider a sufficient time span to include these changes. The sampling carried out during this study had a frequency stablished considering these fluctuations and the general results indicated that the lowest densities of total zooplankton occurred during the flood phase. This result has been found in several investigations of the zooplankton community in aquatic habitats subject to strong water level fluctuation (BONETTO & FERRATO 1966; BRANDORFF 1977; HARDY 1978; HARDY et al. 1984; MEDINA & VASQUEZ 1988). PAGGI & PAGGI (1974) considered water level variation as a complex variable that signifies not only changes in the volume of the basin but also in the current velocity, having a positive or negative effect on zooplankton community density. BRANDORFF & ANDRADE (1978), HARDY (1978) and BOZELLI & ESTEVES (1991) mentioned dilution as one factors responsible for the low density observed during the flood period. HAMILTON et al. (1990) pointed out that zooplankton densities on the Orinoco River floodplain are affected not only by the residence time of the water in the systems, but also by the passage of water between lakes, which exposes the populations to losses among the aquatic macrophytes. Although Batata Lake does not have an exuberant community of aquatic macrophytes, during the flood phases, especially that of 1989 which reached unprecedented levels, the water overflows the shoreline dikes that separate the river from the lake, inundates extensive parts of the forest and interlinks several subsystems. These systems that are eventually subject to inundation may play a role similar to that attributed by HAMILTON et al. (1990) to the macrophytes. TWOMBLY & LEWIS (1987) called attention to variations in depth as a possible delinking action from increases in density. Moreover according to the same authors, some populations may be capable of taking advantage of subtle changes in ambient conditions, because of physiological adaptations to the floodplain environment. TWOMBLY & LEWIS (1987) also referred to the improvement of nutritional conditions in the water during the filling and flood process, a fact already described by BRANDORFF (1977) and CARVALHO (1983).

The results obtained in this study indicated that factors such as pH, dissolved oxygen and chlorophyll-a did not show significant correlation with total zooplankton density. Therefore these cannot contribute to an explanation of the spatial and temporal variations observed in the zooplankton. On the other hand, multiple correlation analysis showed the existence of a significant correlation of the zooplankton density with transparency and water temperature. This last correlation is difficult to interpret, because the results probably were influenced by differences in the time of day that samples were taken at different stations and also for the same station at different times of year. This ought to be taken into account, since the environment undoubtedly shows diurnal variation in the thermal pattern, which was impossible to investigate in the present study. On the other hand, the correlation with water transparency is shown to be important, since together with suspended matter it has been shown to be a factor which can indicate the action of tailings in the water column. PAGGI & PAGGI (1974) found a significant correlation between turbidity, estimated from SECCHI disc visibility, and fluctuations in the density of the zooplankton community. They considered that inorganic matter can act indirectly by means of its effect on the phytoplankton community or by mechanical influences on feeding and movement. Another possibility is decreasing the energy value of ingested particles. MOGHRABY (1977) attributed the disappearance of zooplankton in the Blue Nile to the increase in the concentration of suspended matter acting in the same manner as explained above. CARVALHO (1983) on the other hand, did not find a decrease in the zooplankton standing-crop with increased concentration of suspended matter. ARRUDA et al. (1983) discussed the importance of suspended sediments in the ecology of cladocerans in reservoirs. These authors found that high turbidity values led to an increase in the rates of rejection of food, decreasing the efficiency of assimilation. HART (1987) demonstrated a positive relationship between the abundance of zooplankton and water transparency, and that Daphnidae were virtually absent in years when high levels of inorganic turbidity prevailed. The results obtained by HARDY (1989) both in the field and in the laboratory demonstrated how the presence of the suspended matter may influence the dominance of the species and their different responses. It is possible that lumping all species together one risks of masking the differences and obtaining only a weak overall relationship between species abundance and sediment load. However a specific analysis would be extremely extensive. More than 100 species were identified and the numeric dominance changed many times along the year. So, there are many important species.

It appears that the change in the phytoplankton community, which was reeduced in concentration in the area with tailings present, must be a determinant factor. Considering that the concentration of mineral particles can be drastically altered with changes in factors such as turbulence and reduced water depth, those species that show even small and subtile differences in their efficiency of utilization of food resources can perhaps succeed better in their strategies to populate the environment (BOZELLI, unpubl.).

Considering the marked decreases in zooplankton density and water transparency in the area where tailings are present, at the same time that the quantity of suspended matter increased, it can be concluded that there is a potential for the tailings to impact upon the zooplankton community. However, it is difficult to define which mechanisms might be effectively occurring in the interaction of the zooplankton with clay particles in the water. The material discarded into the water is composed of 96 % of particles smaller than 50 µm. ARRUDA et al. (1983), working with *Daphnia*, found a substantial decrease of ingestion rates of food in the presence of sediment particles of 10 µm mean size. HARDY (1989) detected the influence of suspended matter on zooplanktonic organisms working experimentally with sediment particles between 0.7 and 2.0 µm. It appears evident that the zooplankton species present in Batata Lake, especially cladocerans, are able to capture inorganic particles of the magnitude of those of the clay materials in the tailings and, because of their non-selective feeding, may be even forced to collect them. There is no possibility that such particles can pass through the filtration structures of certain organisms without being ingested. The granulometry of this material is shown to be in a range which permits it to be considered as a potentially interfering factor in the ingestion rates of the food of zooplankton, which is dependent on the quantity in suspension. The animals could reject the entire food bollus, but they do not do it. Even so, the tailings continue to be a interfering factor.

The results of this investigation demonstrate that the presence of this finely particulate inorganic material in the water of Batata Lake altered the density of the zooplankton community. However this phenomenon was not constant, since during the flood phase, the area with tailings did not differ from the non-impacted area of the lake. Preliminarily became evident the necessity to investigate aspects of the life cycle of these organisms which might be even more sensitive to environmental changes than are the density values. In this sense, it will be necessary to ascertain recruitment and mortality rates, aspects of the organization of the trophic webs, intra-specific adaptations and ecophysiological aspects of the zooplanktonic organisms that were not detected by sporadic field investigations.

Resumo

Esta pesquisa aborda os padrões de variações da densidade da comunidade zooplanctônica no Lago Batata (PA). Durante um ano foram realizadas 4 coletas em períodos marcantes do ciclo hidrológico da região. Juntamente com a densidade da comunidade zooplanctônica foi determinado temperatura, transparência, pH, concentração de sólidos em suspensão, clorofila-a e oxigênio dissolvido na água. Os objetivos principais do trabalho foram a observação das flutuações espaço temporais da densidade da comunidade zooplanctônica, relacionando-as com as variáveis ambientais citadas e a identificação da possível influência sobre estes organismos do material argiloso finamente particulado, proveniente do processo de lavagem de bauxita, que foi lançado no lago durante 10 anos. As flutuações temporais e a redução de densidade observada na área do lago que foi alterada, são discutidas considerando fatores como a flutuação do nível d'água e alterações da quantidade de material inorgânico em suspensão, considerando as consequências diretas deste sobre o zooplâncton ou sua ação através de mecanismos interativos com outras variáveis ambientais como a produção primária fitoplanctônica.

Acknowledgments

The author expresses his thanks to the Mineração Rio do Norte S.A. for financial support and to the Max-Planck-Institut für Limnologie for facilities granted during development of the manuscript; to Dr. Francisco Esteves and colleagues of the Laboratório de Limnologia, Universidade Federal do Rio de Janeiro for the comments on the manuscript and for their cooperation in fieldwork; to Janet W. Reid for the English translation; to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the MSc. grant, and to the ÖSW (Ökumenisches Studienwerk - Bochum) for the PhD. grant in Germany.

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Table 1: Values of pH (surface of water column) at the different stations (# indicates samples not taken; * indicates presence of tailings).

	STATIONS					
	1	2	3	4*	5*	6*
Drawdown	6.8	6.2	6.4	6.3	6.9	5.2
Dry	5.4	5.5	5.4	5.2	#	#
Filling	5.8	6.0	6.0	6.2	5.9	5.8
Flood	5.4	5.5	5.5	5.5	#	#

Table 2: Concentrations of chlorophyll-a in mg l^{-1} (mean values of water column) at the different stations (# indicates samples not taken; - indicates values not detected; * indicates presence of tailings).

	STATIONS					
	1	2	3	4*	5*	6*
Drawdown	5.8	2.3	3.3	3.1	-	-
Dry	7.9	15.4	14.8	8.4	#	#
Filling	-	1.8	1.1	-	-	-
Flood	0.6	1.8	2.2	-	#	#

Table 3: Multiple regression parameters relating the effect of different ambient variables (xn) to the total zooplankton density (y) in the entire study area at the four hydrological phases.

Regression model: $y = -1{,}366{,}000 + 284{,}200x_1 + 106{,}500x_2$

R = multiple correlation coefficient; CR = regression coefficient;

t = values for partial correlation test; df = degrees of freedom for t test; * indicates significant at respective P-value.

		PARAMETERS			
Variables	**R**	**CR**	**t**	**P**	**df**
Secchi (x_1)	0.3689	284200	2.63*	0.0220	17
Temperature (x_2)	0.6000	106500	3.12*	0.0089	17
Chlorophyll-a	0.6418	-26493	-1.55	0.1478	17
Oxygen	0.6430	2783	-0.65	0.5271	17
pH	0.6940	-234800	-1.41	0.1828	17

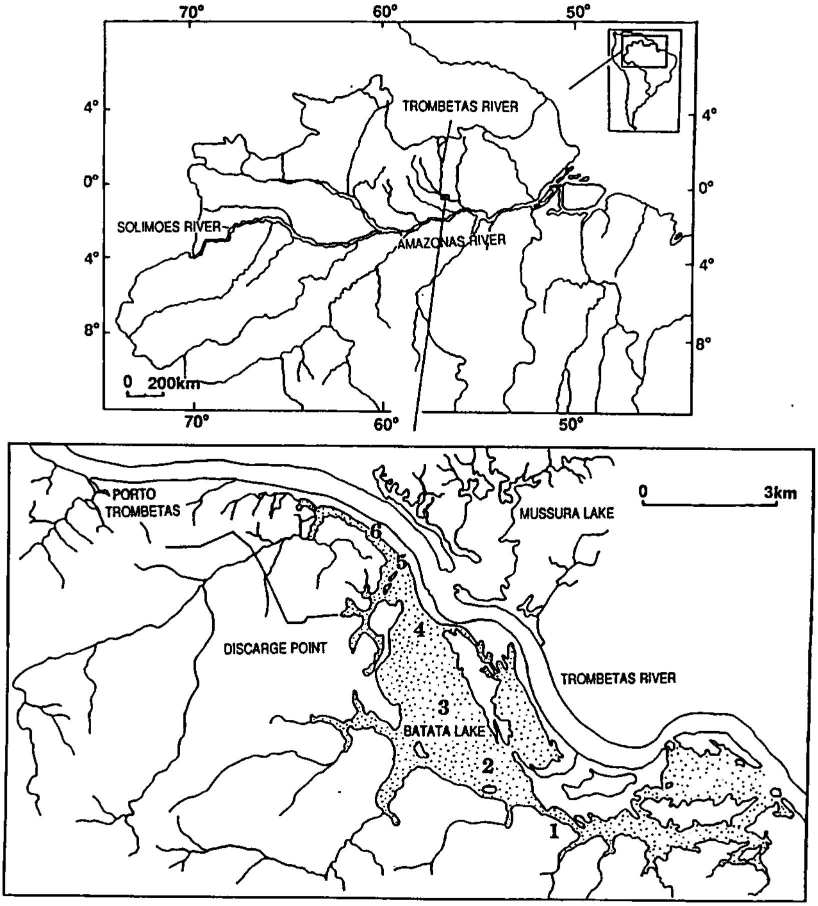


Fig. 1:
Map showing location of study-area and collection stations.

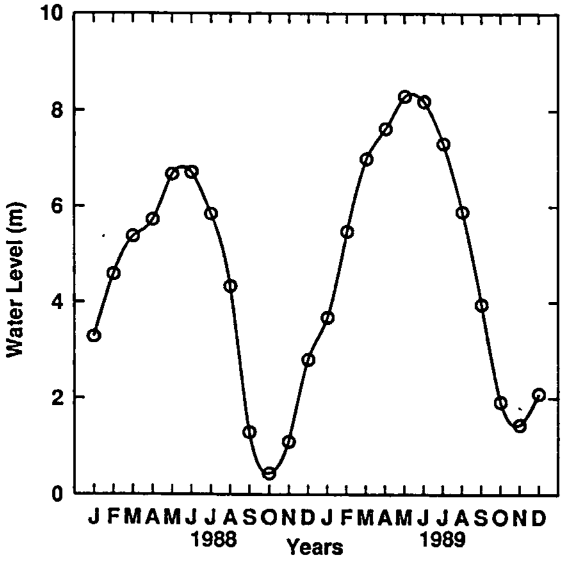
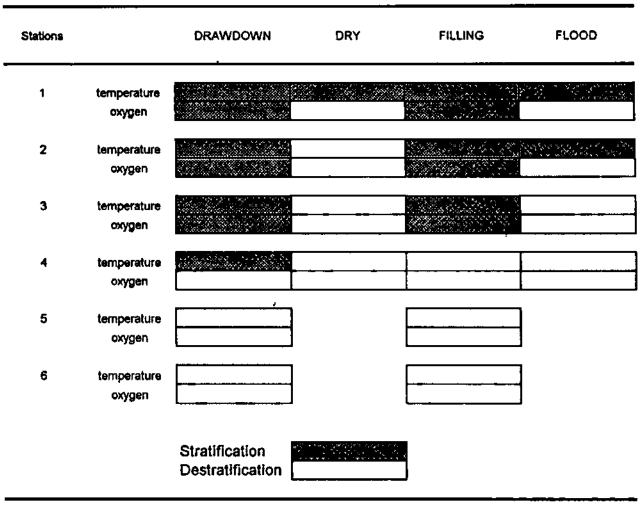


Fig. 2:
Water level of the Trombetas River during 1988 and 1989 in reference to elevation of 40 m above sea level.



Stations		DRAWDOWN	DRY	FILLING	FLOOD
1	temperature	▨	▨	▨	▨
	oxygen	▨	☐	▨	☐
2	temperature	▨	☐	▨	▨
	oxygen	▨	☐	▨	☐
3	temperature	▨	☐	▨	☐
	oxygen	▨	☐	▨	☐
4	temperature	▨	☐	☐	☐
	oxygen	☐	☐	☐	☐
5	temperature	☐		☐	
	oxygen	☐		☐	
6	temperature	☐		☐	
	oxygen	☐		☐	

Stratification ▨
Destratification ☐

Fig. 3:
Schematic representation of temperature profiles and dissolved oxygen in the water column. Samples were not taken at flood phase.

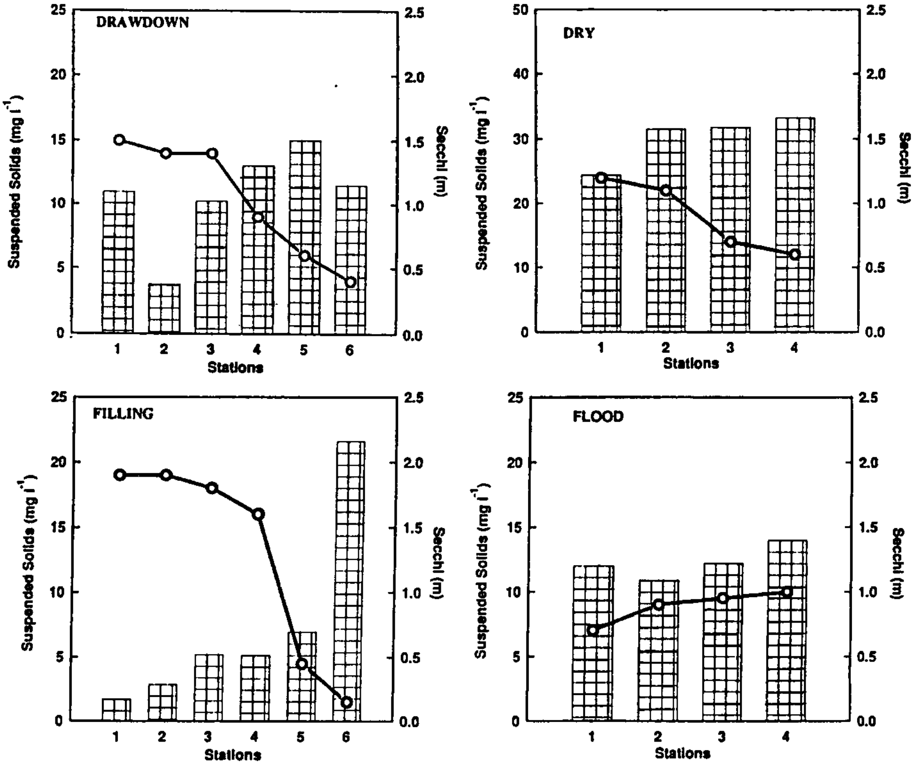


Fig. 4:
Suspended solids (bars) and water transparency (lines) at the drawdown, dry, filling and flood phases. Note the different scales.

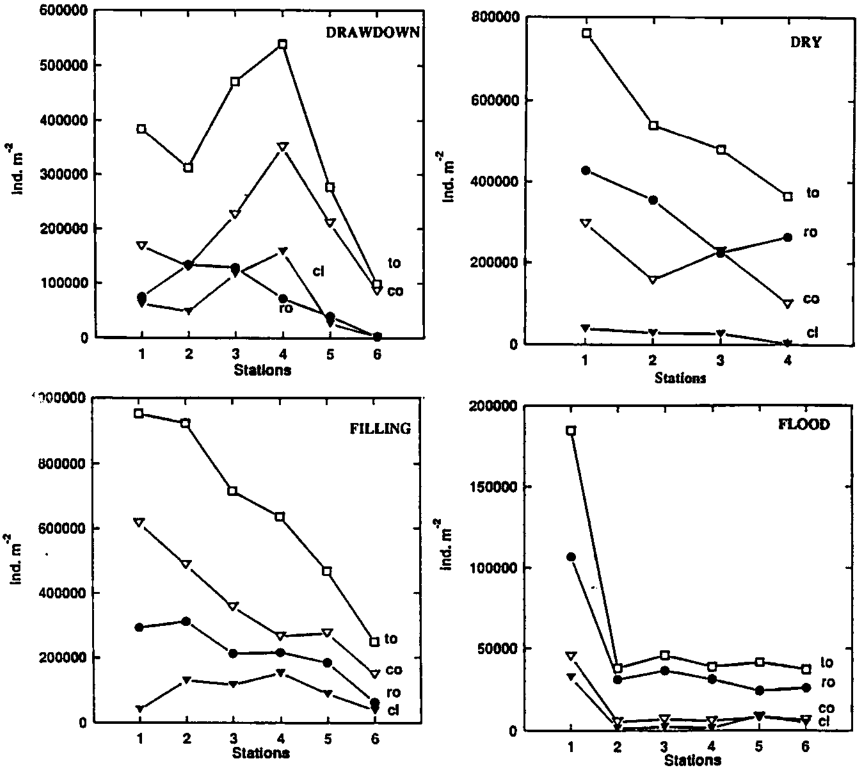


Fig. 5:
Total zooplankton density (to), rotifers (ro), copepods (co) (nauplii and copepodids are included) and cladocerans (cl) at the drawdown, dry, filling and flood phases. Note the different scales.