Limnological patterns of the filling and stabilization phases in the Manso multiple-use reservoir (MT)

Padrões limnológicos durante as fases de enchimento e estabilização no reservatório de uso múltiplo de Manso (MT)

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Abstract: This study aims to verify the limnological variation patterns produced mainly by decomposition processes during the filling and stabilization phases in a tropical reservoir. A total of 24 surveys (Dec./1999 to Apr./2003) were conducted, and the following variables were included: dissolved oxygen (DO), electrical conductivity (EC), turbidity, Kjeldahl organic nitrogen, ammonia, nitrate, and total phosphorus (P). Turbidity was affected by the hydraulic factor, especially in the fluvio-lacustrine transition zone. EC was affected by decomposition processes in the section of the Casca river. DO contents decreased and ammonia contents increased in all the collection sites during the first months of the filling period mainly due to the decomposition of labile organic matter. DO was lower in the main body of the reservoir and hypolimnion, with increased anoxia in the majority of the bottom samples. Ammonia concentration in the reservoir increased in the first months, remaining higher than in the rivers during the following years and showing higher concentrations in the bottom than in the surface. Nitrate concentration in the main body of the reservoir showed oscillations similar to those described for ammonia, reaching peaks during the dry period due to thermal inversions. P content was higher in the reservoir than in the rivers, with the exception of some peaks during the rainy months. The concentrations of P in the reservoir were relatively high and characterized by the eutrophic status for all the samples, mainly in the metalimnion and hypolimnion, with tendency to decrease in the epilimnion. The patterns observed suggest: i) DO consumption and high EC in the first months with the decomposition of labile matter; ii) increased concentration of nutrients in the following years due to slow decomposition of refractory matter; and iii) similar patterns among reservoirs that flood savanna zones through long-term residence.

Keywords: tropical reservoir, decomposition, fluvio-lacustrine transition, nutrients, oxygen.

Resumo: Este estudo tem por objetivo verificar os padrões de variação limnológica, promovidos principalmente pelos processos de decomposição, nas fases de enchimento e estabilização de um reservatório tropical. Foram realizadas 24 campanhas (dez./1999 a abr./2003), incluindo as seguintes variáveis: oxigênio dissolvido (OD), condutividade elétrica, turbidez, nitrogênio Kjeldhal (NKT), amônia, nitrato e fósforo (P). A turbidez teve influência do fator hidráulico, especialmente nos locais de transição flúvio-lacustre. A condutividade sofreu influência dos processos de decomposição ocorridos no braço do rio Casca. Os teores de OD diminuíram e os de amônia aumentaram em todas as estações de coleta nos primeiros meses de enchimento, devido, principalmente, à decomposição da matéria orgânica lábil. As concentrações de OD foram, em média, menores nas estações de coleta no corpo central do reservatório e no hipolímnio, com anoxia na maioria das amostragens de fundo em relação à superfície. As concentrações de amônia aumentaram na fase de estabilização, permanecendo sempre mais altas do que a dos rios nos anos seguintes e com maiores concentrações no fundo em relação à superfície. No corpo central do reservatório o nitrato teve oscilações similares à amônia, com picos na estiagem devido ao evento de inversão térmica. O teor de P foi maior no reservatório do que nos rios, exceto pela ocorrência de alguns picos nos meses chuvosos. As concentrações de P foram relativamente altas e de estado eutrófico no reservatório, principalmente no meso e hipolímnio durante todas as amostragens. Os padrões observados sugerem: i) consumo de OD nos primeiros meses com a decomposição de material lábil; ii) aumento na concentração de nutrientes nos anos seguintes devido à lenta decomposição de material vegetal refratário e iii) ocorrência de padrões similares em reservatórios com longo tempo de residência que inundem áreas com vegetação de cerrado.

Palavras-chave: reservatório hidrelétrico, decomposição, transição flúvio-lacustre, nutrientes, oxigênio.

1. Introduction

The hydroelectricity represents more than 80% of the total electrical energy produced in Brazil (ANEEL, 1997), and its greater production takes place in the south and southeast regions, where the demand for energy is higher. In these regions, the hydraulic potential of the rivers has been almost completely exploited, mainly due to dam constructions for reservoir formation. In the State of Mato Grosso, on the other hand, there are few hydroelectric centrals, considering its large energy generation potential. Among them, there is the Manso multiple-use reservoir, which is the object of this study. The construction of such reservoir was a landmark in Mato Grosso, and it has surpassed all the other hydroelectric plants in this region. In effect, its flooded area comes to 427 km^2, its time of water residence is 429 days on average, and its filling period is 14 months.

During the reservoir filling phase, when the vegetation is submerged, there is intense release of mineral and organic elements derived from the decomposition process. The degradation rate of these elements depends on physical and chemical conditions, such as the heterotrophic activity of the organisms and the quality as well as quantity of the submerged vegetation (Bianchini-Jr. and Cunha-Santino, 2005).

The average time for the formation of a reservoir has been shown to vary from 4 to over 10 years. The Amazonian reservoirs, for example, are emphasized as taking more than 10 years to achieve stabilization – a result of low decomposition rates of the submerged forest. To describe the fast alterations and the deterioration of the water quality in the first years of the reservoir formation, Straskraba and Tundisi (2000) used the term aging as a synonym of stabilization, also denominated as succession by Odum (1998). Those authors argued that the problems in the stabilization phase are related to the increased concentration of organic dissolved matter, nutrients and phytoplanktonic production, as well as to the decreased rates of dissolved oxygen, pointing out that the variation patterns of these variables in a reservoir located in the Czech Republic allowed them to identify three phases: filling, stabilization and stable.

The existence of a large number of reservoirs in Brazil, some of which still being built, points to the need for further understanding the metabolic processes involved in the first phases of their formation. Such knowledge would in turn contribute to determine the future pattern of a reservoir functioning (Tundisi, 2005). Although many limnological studies have been performed in these aquatic ecosystems, research concerned with their filling and stabilization phases in loco are scarce. Among these few studies, there are the ones performed by Magrin (1993) e Magrin and Matsumura-Tundisi (1997) in the Samuel UHE, Moreno (1996) in the Balbina UHE, De Filipo et al. (1999) in the Serra da Mesa UHE, and Pagioro et al. (2005) in the Iraí reservoir. In contrast, according to Bitar et al. (2002), techniques for performing decomposition assays have been frequently used in mathematical simulation studies in order to provide valuable knowledge about alterations in the quality of the water as well as in the other limnological characteristics of the future reservoir.

As regards the limnological knowledge about the Manso reservoir, only two studies have been published thus far. To verify the role of the "Green Tunnel" (a hydraulic device that ensures the outflow) in the maintenance of water quality in the Manso River, Soares et al. (2001) analyzed the conditions of the Manso reservoir during the filling phase in a place near the dam. Lopes (2003) studied the collection station situated near the dam, in order to analyze, for twelve months of filling, the vertical profile of the water column in relation to physical and chemical variables. In this context, the current study aims to demonstrate the existence of limnological patterns in the filling and stabilization phases of the Manso reservoir as well as to identify the main controlling forces of these patterns. In this sense, this study may be one of the first contributions towards the knowledge about artificial lakes in the state of Mato Grosso, Brazil.

2. Material and Methods

2.1. Study area

The Manso multiple-use reservoir is located in the State of Mato Grosso, approximately between the coordinates UTM 631.450-685.380X and 8.334.228-8362.150Y. It belongs to the Paraguay Hydrographic Region (PNRH, 2006), in the basin of Cuiabá river. It is formed by two rivers, Manso and Casca, which converged upon next to the current embankment, thus allowing the formation of a bifurcated lake, whose hydrogeochemical conditions are distinctive in each one of the arms. Neto et al. (1993) remarked that the Casca river waters are chemically poorer, more acid, and with lower concentration of electrolytes when compared with the arm of the Manso river (Figure 1).

The climate in the Cuiabá river basin is semi-humid tropical, and its seasonality is marked by two well-distinctive periods: dry (from May to October) and rainy (from November to April) periods. The average annual temperature is 28.6 °C, and the average precipitation is between 1,300 and 1,700 mm $year^{-1}$. (HABTEC-FURNAS, 2001).

This reservoir shows the following characteristics: i) normal operation level: quota 287.0 m; ii) flooded area: 427 km^2; iii) total volume: 7.4 billion m^3; iv) average depth: 19 m; v) residence time: ca. 429 days; and vi) established potency: 210 MW (Soares et al., 2001). These characteristics allow to classify the reservoir as medium in relation to the flooded area and volume, as well as to categorize it into

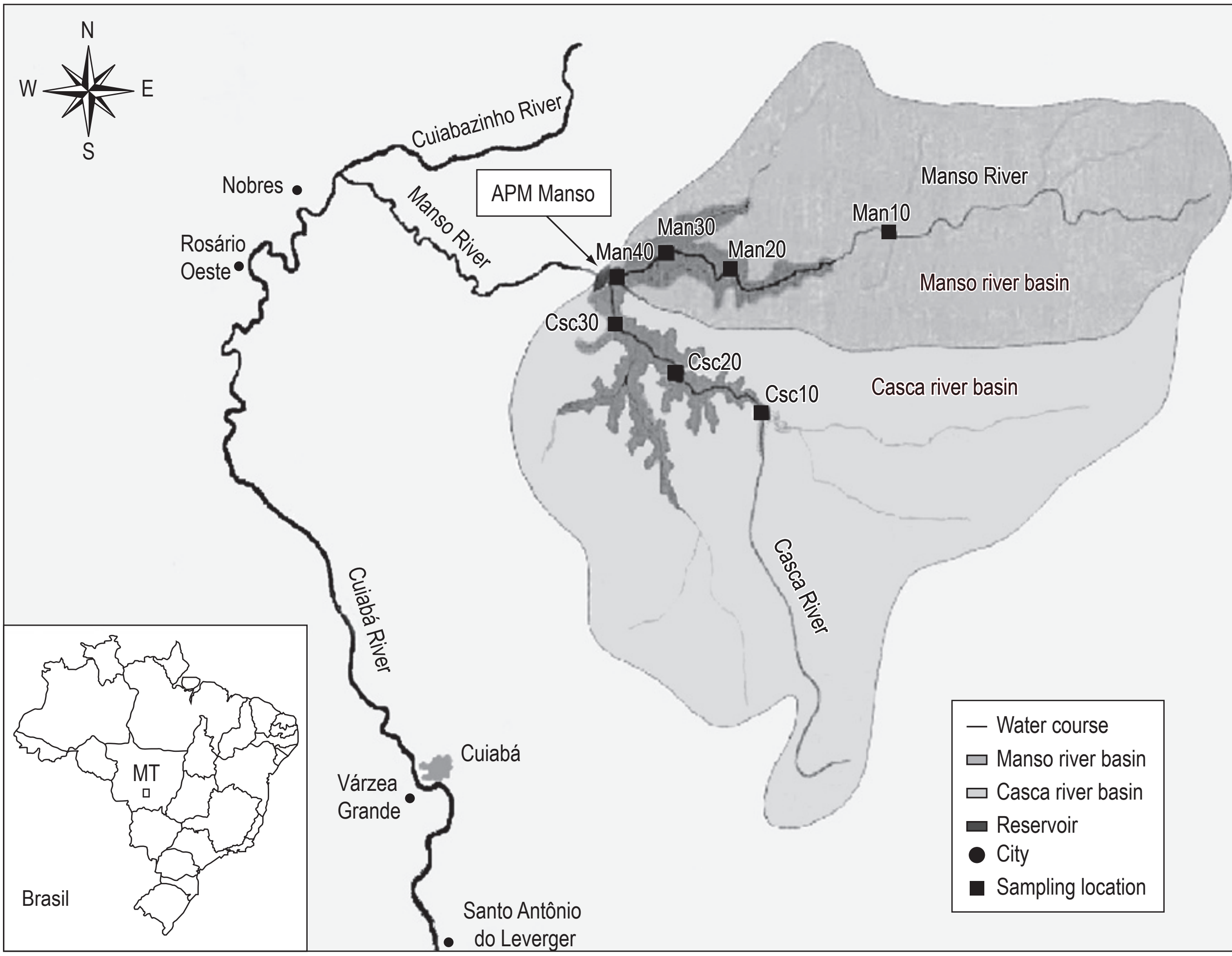

Figure 1. Manso Reservoir map and its drainage area with the limnological sample stations (change from HABTEC-FURNAS, 2001).

the C class due to its long retention time (RT > one year), according to the Straškraba (1999) classification.

The filling phase occurred between Dec./99 and Dec./00, and the first turbine started to work in February, 2001. According to what was described in HABTEC-FURNAS (2001), the quota of the reservoir started to increase in a slight way from Dec./00, when compared to the previous months, and almost 90% of the reservoir was formed in Dec./00, when the last monitoring survey of this phase was conducted.

The flooded area consisted predominantly of *cerrado* vegetation, especially the open tree savanna, and it was intersected by gallery forests. The soil was mainly occupied by extensive cattle breeding and subsistence agriculture.

2.2. Limnological inventory

Eleven surveys were conducted during the filling of the reservoir. The samples were collected between the months of Dec./99 and Apr./00 – within the first 150 days after the damming of the river –, and between May/00 and Feb./01 – from the 151st day to the 410th day. Afterwards, 13 other surveys were conducted until Apr./03, totaling 1,250 days since Dec./99. The collections were performed in seven sampling stations: two of them were in lotic environments in the Casca and Manso rivers, that is, the station upstream (Csc10 e Man10); two in the fluvio-lacustrine transition zone; and three in main body of the reservoir (Csc30, Man30 e Man40) (Figure 1). In the river, the collections were only performed in the surface and transition and reservoir stations at different depths (Table 1).

The dissolved oxygen (DO) concentrations and the electrical conductivity were determined in the field by using multiple probe (YSI). The analytical procedures for determining total turbidity, organic nitrogen (Kjeldhal total nitrogen-KTN), ammonia, nitrate and phosphorus were performed according to the methods described in AWWA/APHA (1995).

For the analysis of the temporal variation of the variables adopted in the post-damming period, the initial time was defined as the approximate day when the flooding started in the Man40 station. As regards the variables in which the vertical profile was contemplated, the results reflect the

Table 1. Description of the limnological samplings performed in the collection stations of the Manso Reservoir in the filling and stabilization phases.

Collection stations	Coordinates (UMT)	Type of environment	Filling month/year	Collection depth	Sampled period
Man10	685380-8362150	Riverine zone	-	Surface	Dec./99-Apr./03
Csc10	662386-8334228		-		
Man20	657100-8356880	Transitional zone	Apr./00	Surface	Dec./99-Apr./03
Csc20	655889-8338627		Mar./00	Botton	Feb./01-Apr./03
Man30	640000-8358800	Lacustrine zone	Jan./00	Surface	Dec./99-Dec./00
Csc30	632732-8348074		Jan./00	Middle and botton	Feb./00-Apr./03
Man40	631459-8355339	Lacustrine zone	Dec./99	Surface and botton surface, middle and botton four depths five depths	Dec./99-Jan./00 Feb./00-Dec./00 Feb./01-Oct./01 Dez./01-Apr./03

averages of all the stations from the surface to the bottom. The standard deviation was calculated for those variables and that were measured in the stations with more than two depths, surface (S) and bottom (B) (Man30, Man40 and Csc30). In samples contemplating no vertical profile, the temporal variation only refers to the measurement of the variables in the surface. The results obtained in Man10 and Csc10 were used as background comparison with the environments of their respective influence reservoir (Man20/Man30 and Csc20/Csc30, respectively). The results from Man40 were compared with those from Man10, since the former was the one with the highest flow, therefore exerting greater influence upon the limnological conditions of this site. For the results below the detection limit of the analytical method, the limit value was adopted for the purpose of figure construction, with 0.02 mg L^{-1} for KTN, nitrate and phosphorus, and 0.01 mg L^{-1} for ammonia. The organic nitrogen (KTN-ammonia) was also considered for analysis. The variance analysis (ANOVA) was applied to verify temporal (rainy and dry periods) and spatial variances (longitudinal and vertical) that were significant for the sampled sites ($p < 0.005$) as well as to analyze the differences between the filling (Dec./00-Dec./00) and stabilization phases (Feb./01-Apr./03) of the reservoir.

3. Results and Discussion

The trees and the bushes forming the flooded land vegetation in a reservoir contain a large quantity of material resistant to decomposition. Although the structural composition of the submerged vegetation can remain practically unchanged for several years, the leaves and petioles of the vegetation contain a great amount of easily biodegradable (labile) compounds, thus being the first ones to decompose after damming the river (Bitar et al., 2002). As a consequence, a number of substances are released, altering the limnological conditions in the first days or months of the reservoir filling and stabilization processes. Furthermore, the damming of a river leads to a decrease in current velocity, which in turn interferes with some limnological variables of the water. The degree of interference basically depends on the reservoir residence time and the force of the river upon the environment. However, since the decomposition and hydraulic processes act at the same time, it is difficult to separately measure their degree of interference.

In the Manso reservoir, the hydraulic factor was clearly the preponderant force to interfere with turbidity (Figure 2). The decreased current velocity in the lake contributed to the increase in the rates of sedimentation of water column particles, thus leading to a decrease in turbidity in comparison with the rivers. The turbidity is a typically seasonal variable in the rivers of this basin, since it increases with the addition to the river bed of materials originated from the drainage area in the rainy periods (Figueiredo, 1996; FEMA/MMA, 1997). This seasonality was evident in the Manso and Casca rivers throughout the study period as well as in the Csc20 and Man20 stations, where the reduction was slighter in relation to the limnetic zone of the reservoir, specifically in the filling phase, when the oscillations temporally followed the two rivers. In the main body of the reservoir, the turbidity remained substantially below the ones registered in the rivers, especially in the operation phase, when the values were on average below 10 NTU. On the other hand, in all the reservoir stations, including the transition ones (Man20 and Csc20), the values of turbidity in the stabilization phase were significantly lower than those in the filling phase.

In the filling phase, an increment in electrical conductivity was observed in the Csc30 station (Figure 3). Since the Casca river lacks electrolytes (Neto et al., 1993), it is unequivocal that this alteration was a consequence of the decomposition process in the reservoir. The decomposition determined the variation patterns in the conductivity, making them higher in the reservoir than in the river during the filling phase, a difference that remained in the stabilization phase. In Csc20, the conductivity was similar to the river in the filling phase and remarkably higher in the following phase. This result may be due to the fact that this transition zone was flooded later than the limnetic zone, and that the influence of the river in the stabilization phase was lower in relation to the filling one.

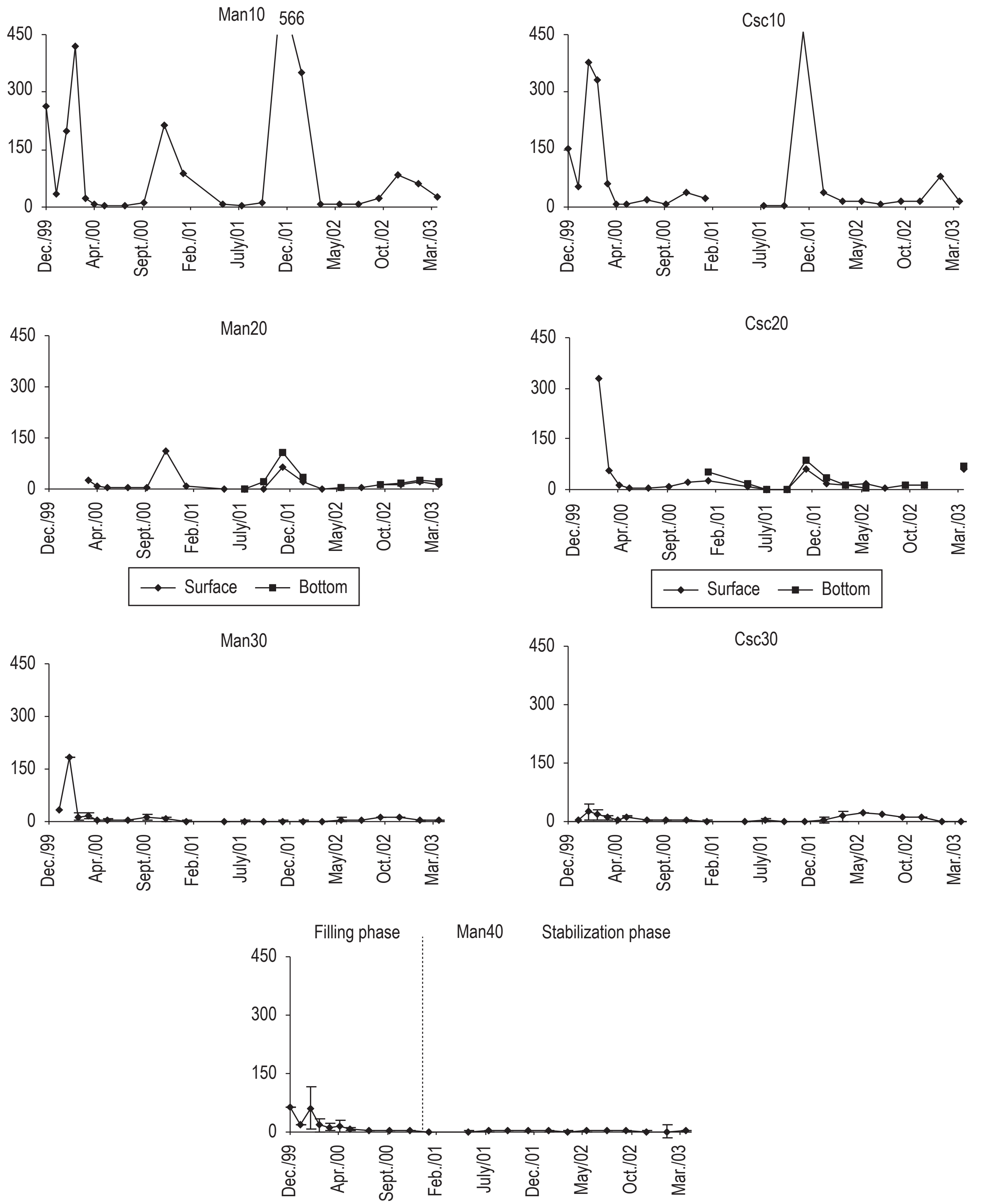

Figure 2. Turbidity average variation (NTU) in the Manso (Man10) and Casca rivers (Csc10) and in the Manso Reservoir in the filling (Dec./99-Dec./00) and stabilization phases (Feb./01-Apr./03).

The increments in the values of electrical conductivity in the first stages of the organic matter degradation are related to the CO_2 formation and the release of mineral compounds resulting from the leaching process, mainly of the leaves (Cunha-Santino and Bianchini-Jr., 2002). This increment may also have occurred in the Manso river arm, but it may have not been detected in the sample scale adopted and/or it may have been underestimated on

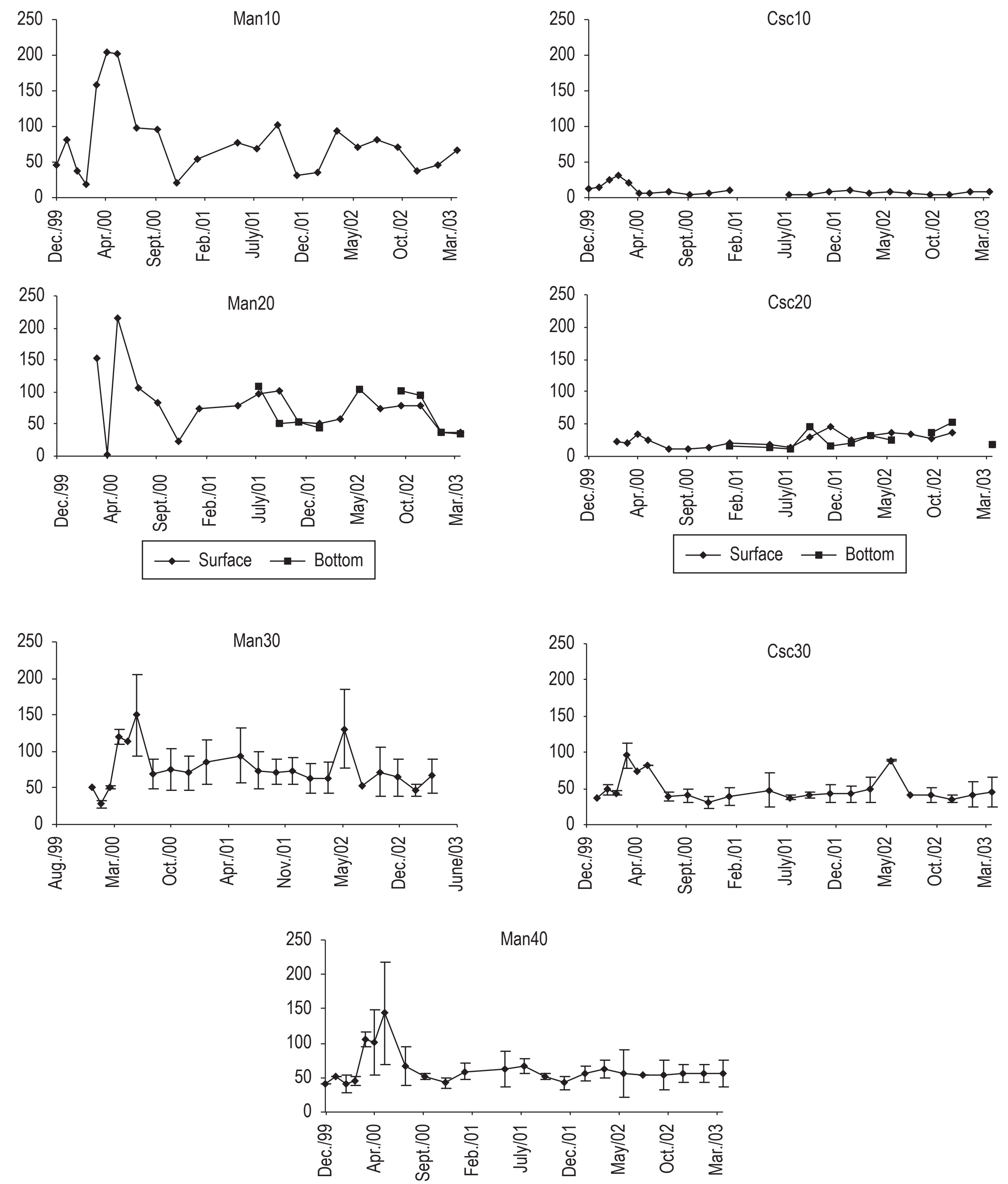

Figure 3. Conductivity average variation ($\mu S.cm^{-1}$) in the Manso (Man10) and Casca rivers (Csc10) and in the Manso Reservoir in the filling (Dec./99-Dec./00) and stabilization phases (Feb./01-Apr./03).

account of the high conductivity in the Manso river. In the following years, the conductivity remained on average similar to the river in Man20, 30 and 40, but in this latter station, the values were practically stable after the filling phase (Feb./01, Figure 3). Thornton et al. (1996) described a similar conductivity variation pattern in the Kariba Lake, Zimbabwe, as the one observed in Man40. In summary, when compared to the river, the conductivity of the Kariba Lake substantially increased in the filling phase, slightly decreased in the following phase, and remained almost the same in the transition and stabilization phases. However, these values were demonstrated to be always higher than those observed in the main river prior to damming.

In the collection stations Man30-40 and Csc30, the average DO concentrations decreased in the water column in the first days of filling (Figure 4). In Man40, the surface values were low from January to Mar./00 (<5.0 mg.L^{-1}). Low surface values were also observed in Man30 in both March and May/00, and in Csc30 from February to May/00. In the filling and operation phases, all collection stations showed

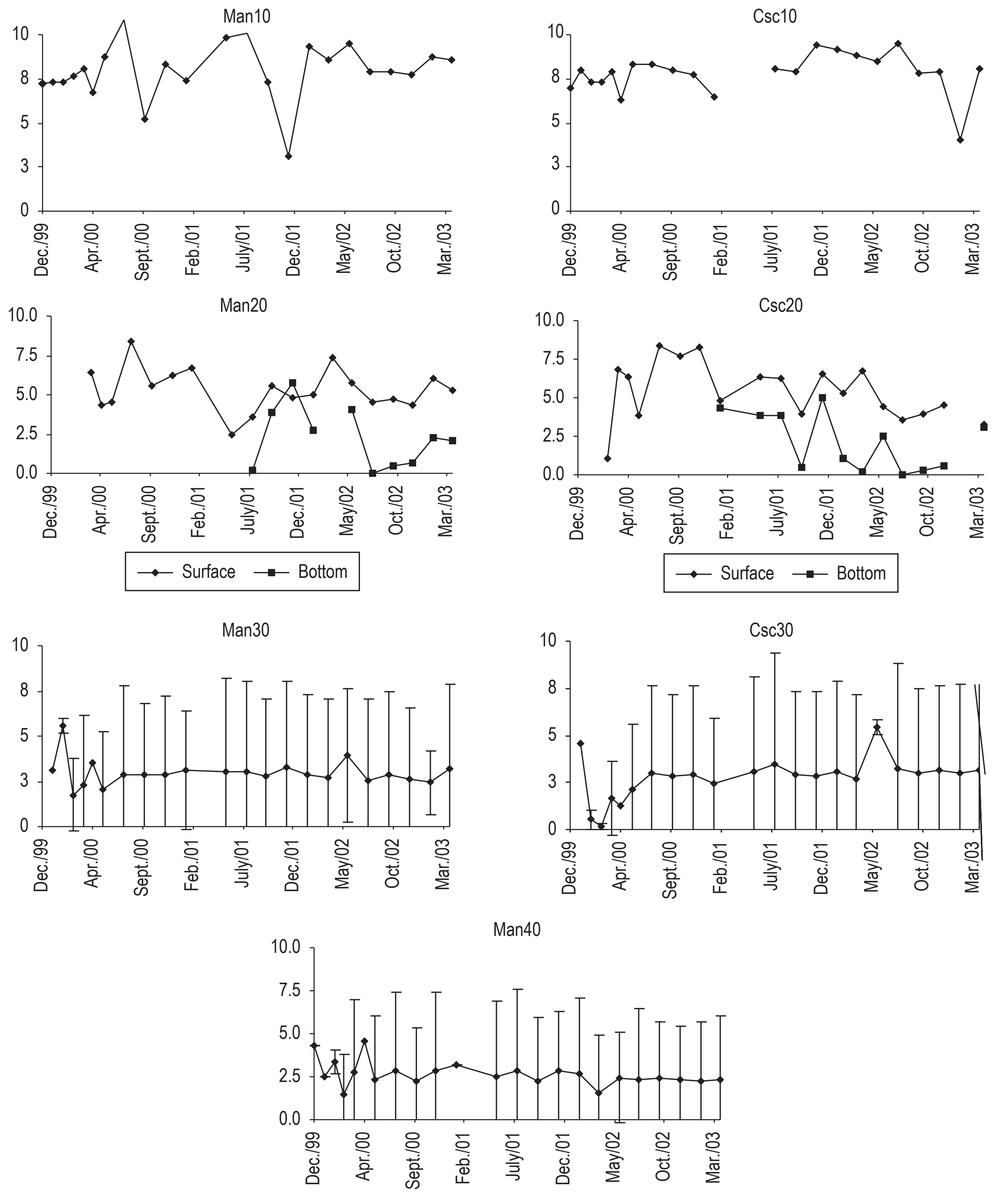

Figure 4. Dissolved oxygen average variation (mg.L^{-1}) in the Manso (Man10) and Casca rivers (Csc10) and in the Manso Reservoir in the filling (Dec./99-Dec./00) and stabilization phases (Feb./01-Apr./03).

increased anoxic in the bottom and decreased anoxic in the middle of the water column; however both values were significantly lower than those for the surface concentration. In Csc20 and Man20, the reduction in DO concentration during the filling phase was slight, but noticeable (Figure 4). In the following samples, especially in Man40, the DO remained, on average, lower than in the rivers, with values below 1.0 mg L^{-1} until total anoxia in the hypolimnion, which is a usual condition in several deep reservoirs with long water residence time or in shallow eutrophic lakes (Pagioro et al., 2005; Henry, 1999). In the epilimnion, on the other hand, DO concentrations remained above 5.0 mg.L^{-1}. The increased DO concentration in the rivers is promoted not only by the current velocity, but also by the incipient process of decomposition in this environment in relation to the Manso Reservoir during the period studied. In contrast, the DO contents in the epilimnion of Man40 were significantly higher in the operation phase than in the filling one.

The first stage of DO consumption is mainly related to the oxidation of the easily degradable carbon compounds (Antonio et al., 1999; Bitar et al., 2005). Due to the low cycling rates for humic substances and structural plant compounds (refractory material), the decomposition will only be concluded in a larger time scale, that is, after several years or decades (Bitar et al., 2002). The lignin is one of the major polyphenols forming humic substances (Campos-Jr, 1998; Bianchini-Jr., 1982; Wetzel, 1983), and it can be found in great quantities in *cerrado* plants. In this context, Moreno (1996) observed that superficial DO concentrations in a site near the Balbina Dam, in Amazon region (Brazil), remained below 5.0 mg.L^{-1} for approximately two years after the beginning of the filling process. The flooding of dense areas of Tropical Rain Forest was demonstrated to be responsible for the addition of organic detritus to the reservoir. These materials are composed of leaves and leaf litter that previously covered the soil and are rich in soluble carbohydrates, which in turn have high demand for DO.

The flooded *cerrado* vegetation in the Manso Reservoir is significantly less dense and more difficult to be degraded than the Amazonian Rain Forest, since the former contains a greater amount of refractory materials in leaves, branches and leaf litter. This may have contributed to the lack of prolonged deficit in epilimnion DO during the filling and stabilization phases of this reservoir. Soares et al. (2001) and Lopes (2003) observed that, from the ninth month after damming, DO concentrations in Man40 remained above 5.0 mg.L^{-1} in the first 9m. In the Serra da Mesa reservoir, which also flooded an area of *cerrado*, the DO concentration in the station near the embankment was above 5.0 mg.L^{-1} from the seventh month after filling in the first 9 m (De Filipo et al., 1999).

On average, oscillations in ammonia were more clearly observed in Man30-40 and Csc30 in the stabilizationn phase than in the filling phase, due to the release of this compound from the hypolimnion, specially related to refractory materials (Figure 5). In this layer, the concentrations of ammonia remained below 0.2 mg.L^{-1}, as evidenced by the significant differences among surface, middle, and bottom depths. Such differences were also observed for the nitrate and KTN (Figures 6 and 7), with gradual increase in the water column, from the bottom to the surface. Ammonia is originated mainly from nitrate (Esteves, 1998) and the decomposition of organic matter.

In lotic environments, only the N-organic concentration was shown to be expressive. This fact may have affected the transition stations (Man20 e Csc20), especially in relation to the ammonia peaks, which were different from the ones observed in the main body of the reservoir. The inflow of the river into the transition zone possibly led to the addition of the organic form to the reservoir bottom, as evidenced by the KTN variation (Figure 6), later occasioning the ammonia formation. Serra da Mesa reservoir (GO, Brazil) was similarly described to be affected by the hydraulic influence in this ecotone (De Filipo et al., 1999).

In Man30-40 and Csc30, the variation of nitrate concentration was similar to the ammonia, with significantly low concentrations until Jun/01, when the first peak was observed In Oct/02 and April/03, the nitrate contents reached 0.5 mg.L^{-1}, and the ammonia concentrations were always higher in the stabilization phase when compared to the filling one.

In Man30-40, nitrate peaks occurred simultaneously with the ammonia ones in both Jun./01 and Oct./02 (Figures 5 and 7). In Jun./00, the nitrate peak was only observed in Cs30, which was coincident with the thermal inversions in the region as well as with the non stratification of the water column and consequent mixture between epilimnion and hypolimnion (Lopes, 2001), which conveys nutrients to the former and oxygen to the latter. This certainly led to the ressuspension of ammonia with the nitrate formation in contact with the DO. Considering the deficit of DO in the main body of the reservoir in the months previous to Jun/01, the possible aeration of the water column was insufficient to increase the nitrate percentages, except in Csc30. In the months after Jun/01, when other nitrate peaks occurred (Figure 7), frequent thermal inversions were also observed, being induced either by the abrupt fall in air temperature or by greater differences between diurnal and nocturnal air temperature, with colder nights when compared to other periods of the year. In HABTEC-FURNAS (2001), the non stratification of DO profile was demonstrated to be more evident in the dry-cold period (April-October).

In the Manso reservoir, the phosphorus concentrations were generally higher than those in the rivers (Figure 8), except for some peaks observed in the lotic environments, which always occurred in the rainy period, that is, when

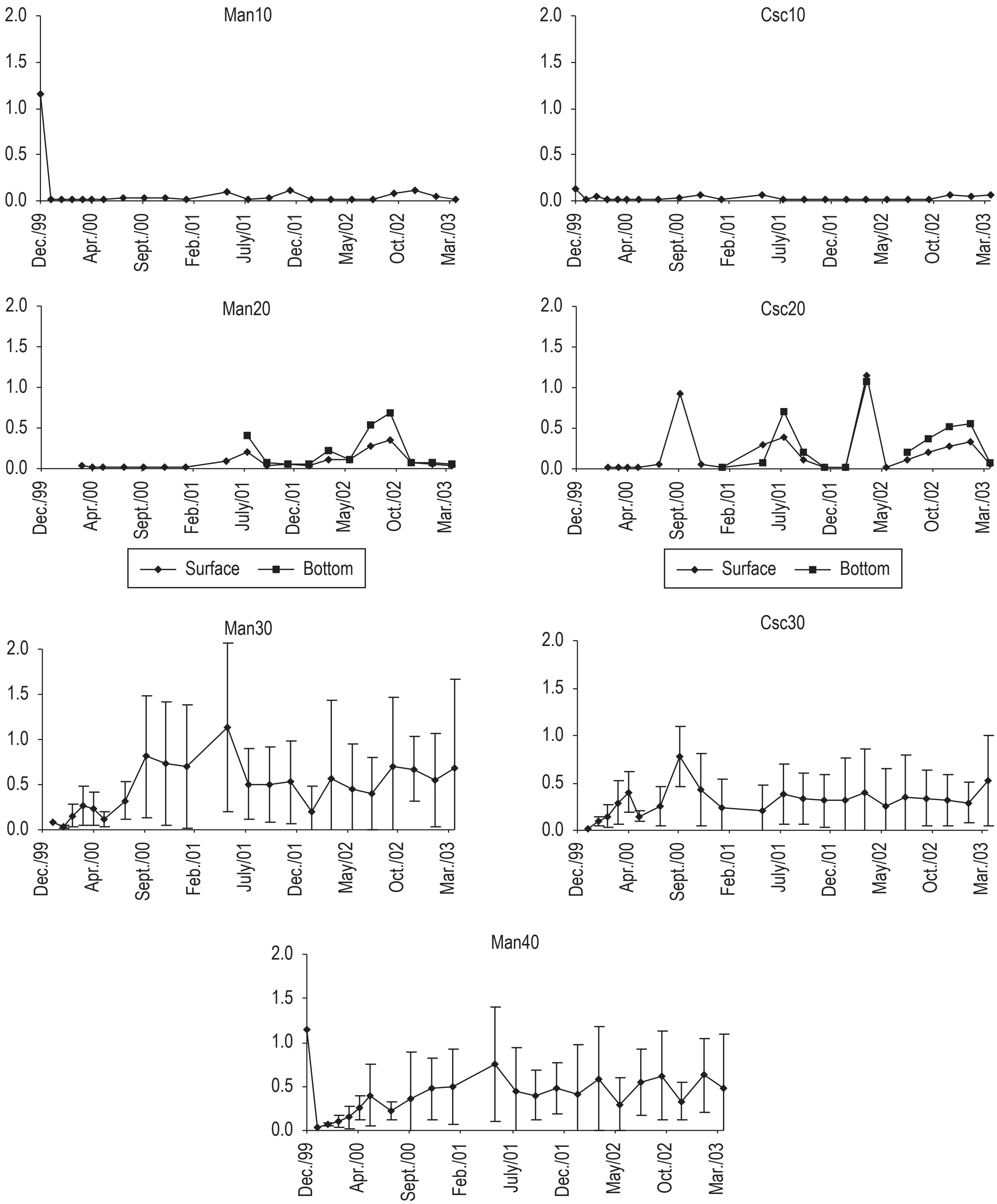

Figure 5. Ammonia average variation (mg.L^{-1}) in the Manso (Man10) and Casca rivers (Csc10) and in the Manso Reservoir in the filling (Dec./99-Dec./00) and stabilization phases (Feb./01-Apr./03).

the rain waters made the differences between these environments insignificant. The increased of phosphorus in the rivers are related to the erosion of their basins (PCBAP, 1997), which is a result of the soil type and the intense soil occupation by grain monocultures, stockbreeding and abandoned sites for gold digging in areas of permanent preservation. These factors are known to promote the addition of nutrients to the rivers through the superficial drainage in the rainy period.

In reservoirs, in addition to the influence of oxygen and temperature, the amount of flooded plant biomass at the formation of these environments is essential to determine

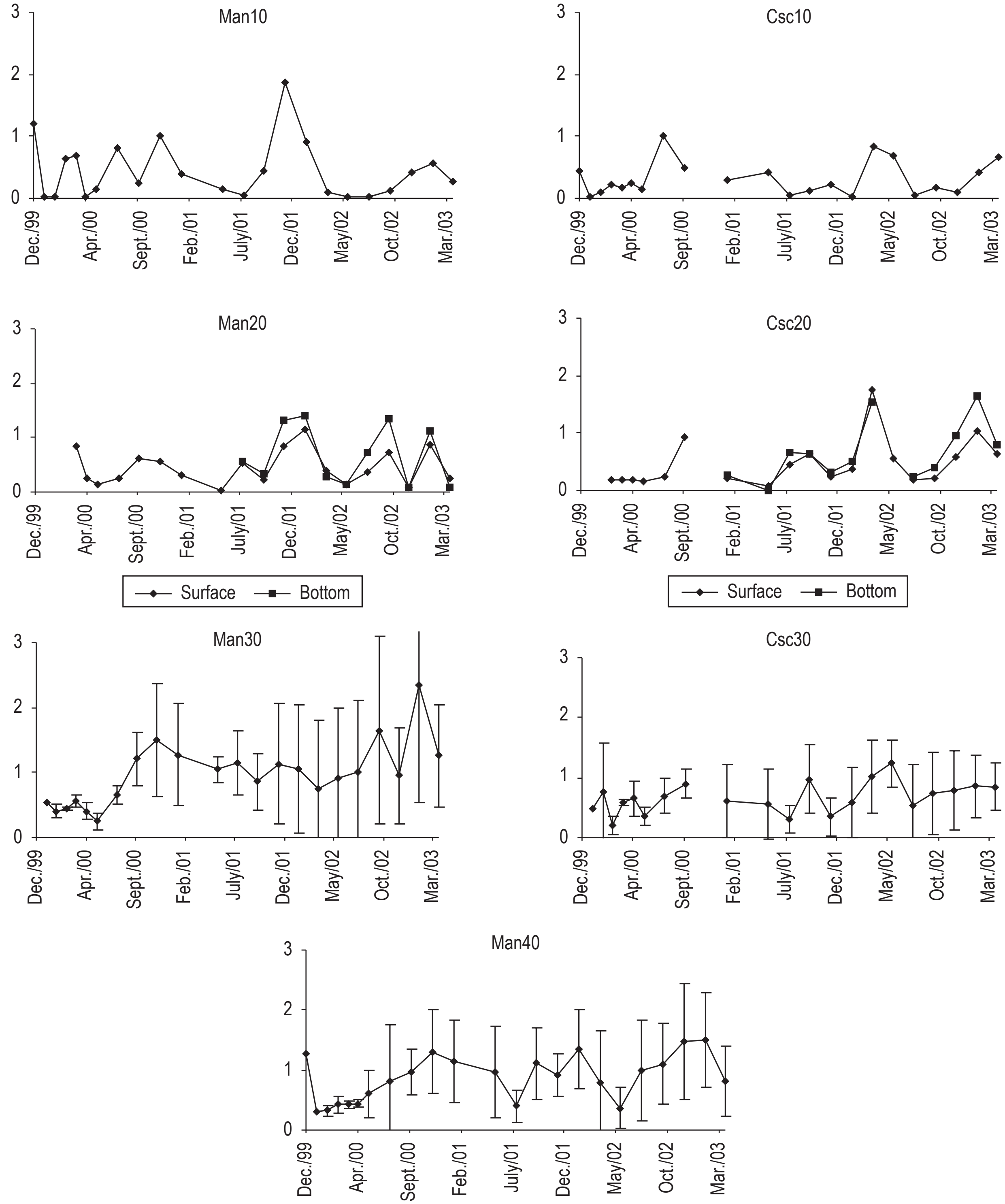

Figure 6. Kjeldhal total nitrogen average variation (mg.L^{-1}) in the Manso (Man10) and Casca rivers (Csc10) and in the Manso Reservoir in the filling (Dec./99-Dec./00) and stabilization phases (Feb./01-Apr./03).

phosphorus concentration and distribution in the water column (Esteves, 1998). These factors may have influenced the mean phosphorus variations mainly in Man30, Man40 and Csc30, and the results in the metalimnion and hypolimnion were always higher than the epilimnion ones, oscillating between 0.10 and 0.35 mg.L^{-1}. The difference in phosphate concentrations was insignificant when comparing the filling and operation phases.

Similarly to other well-documented reservoirs, the Manso Reservoir is probably a site of phosphorus retention. According to Straškraba (1999), there is a dependence relationship between residence time (RT) and phosphorus

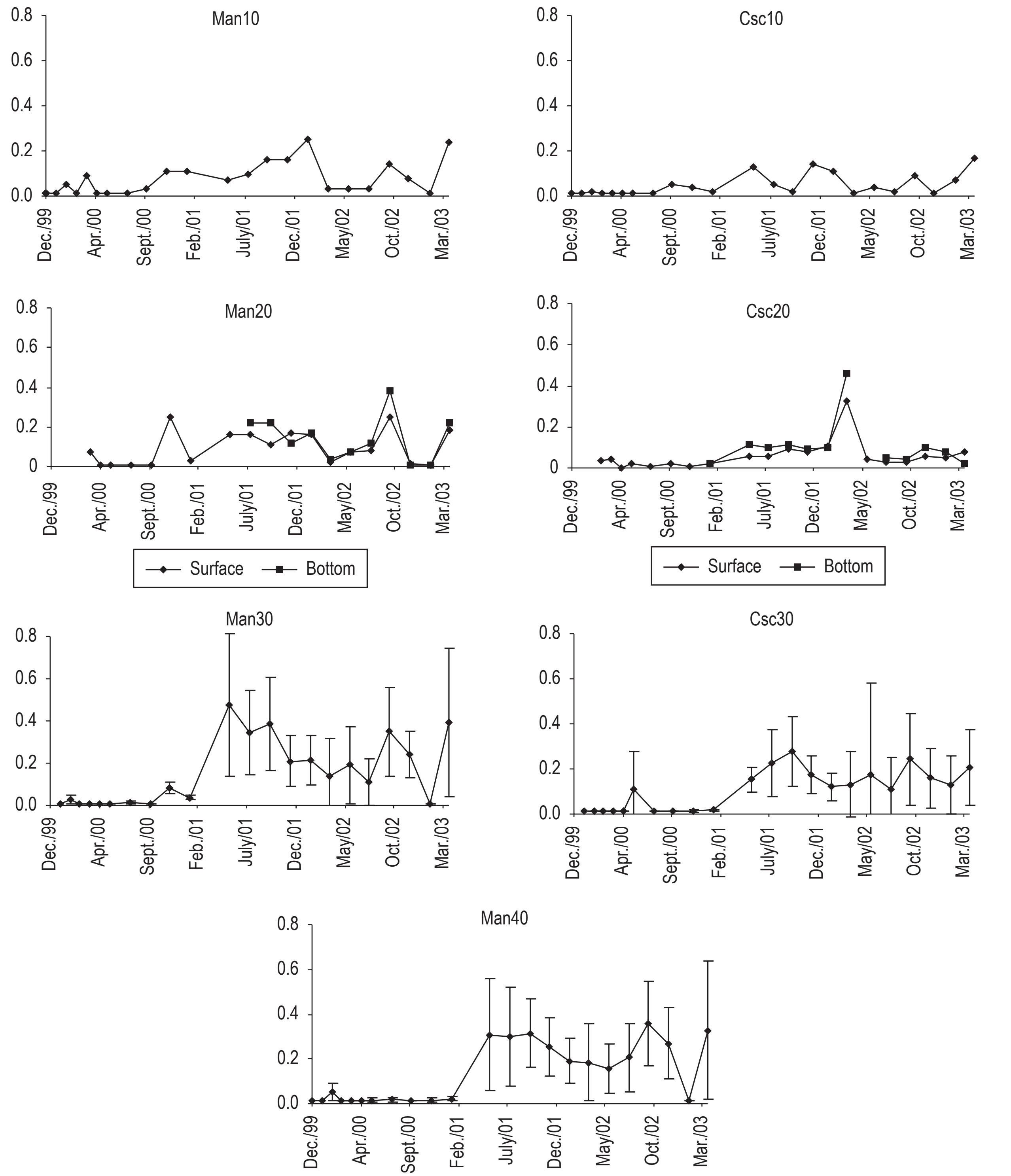

Figure 7. Nitrate average variation (mg.L^{-1}) in the Manso (Man10) and Casca rivers (Csc10) and in the Manso Reservoir in the filling (Dec./99-Dec./00) and stabilization phases (Feb./01-Apr./03).

retention (PR), in which phosphorus tends to increase with increase of the RP. In the Manso reservoir, this addition can be originated from both the hypolimnion and the Manso and Casca rivers.

In summary, limnological patterns were observed in the filling phase of the main body of the Manso reservoir, and they were shown to be related to both the decreased DO concentration and the increased electrical conductivity (Casca arm) on account of the intense decomposition processes of the labile organic matter (oxidation of carbon compounds), which lasted approximately one year after the damming of the river. In the following phase, both DO

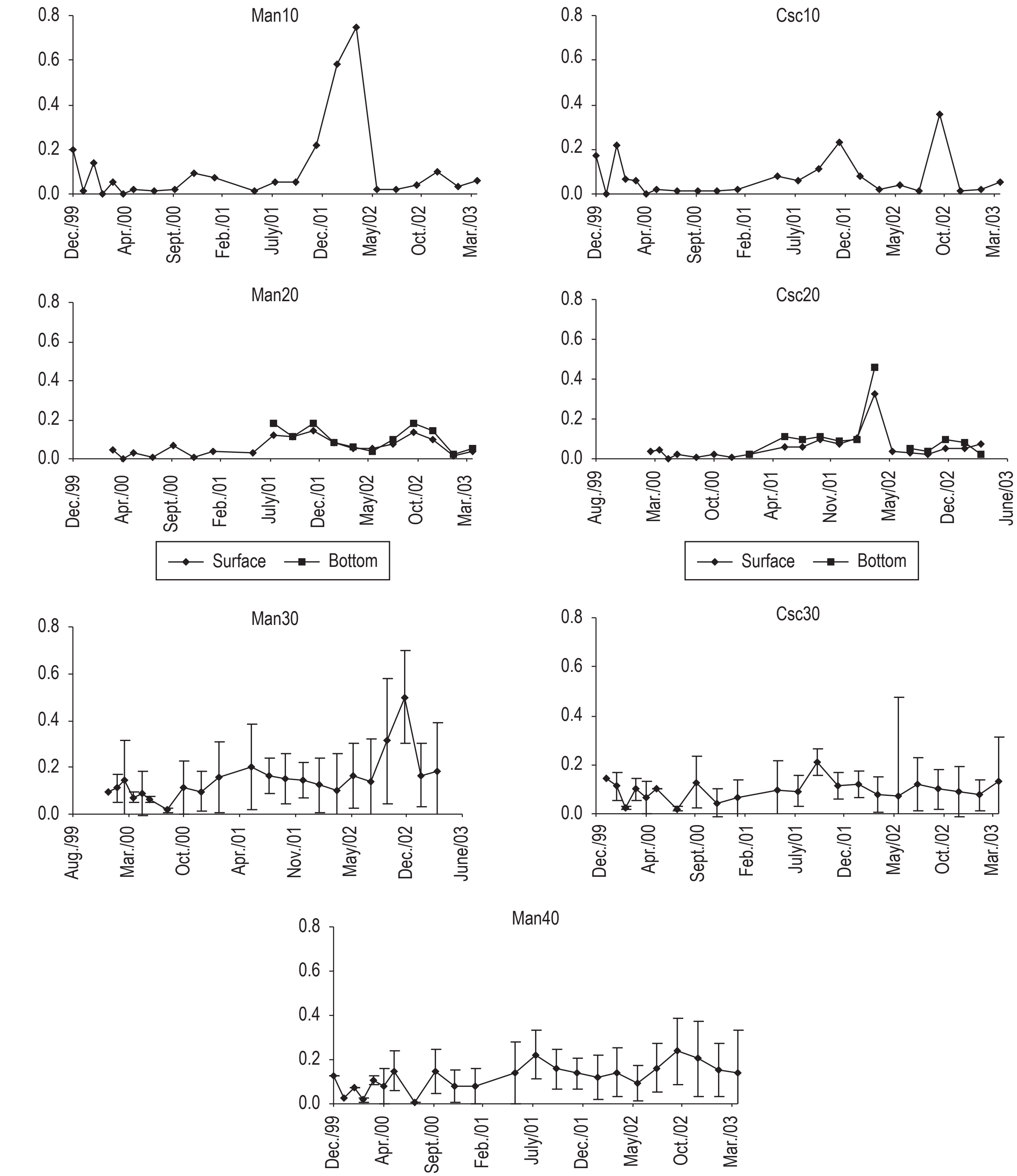

Figure 8. Phophorus average variation (mg.L^{-1}) in the Manso (Man10) and Casca rivers (Csc10) and in the Manso Reservoir in the filling (Dec./99-Dec./00) and stabilization phases (Feb./01-Abr./03).

and conductivity tended to stabilize. The concentrations of DO were lower in the reservoir than in the rivers and hypolimnion, which was often anoxic when compared to the epilimnion. Conductivity in the Casca river arm was higher in relation to the river. This indicates that the first months of the Manso formation were central in establishing further limnological patterns, since vertical and longitudinal variations of DO as well as longitudinal variations of electrical conductivity could be determined despite being so slight. On the other hand, the nutrients were the main indicators of the decomposition processes in the operation phase. Decomposition was still intense in the hypolimnion, considering that refractory material should be in slow mineralization until April/2003, with predominance of anaerobic decomposition processes induced by the long water residence time.

The consequences of organic matter degradation in reservoirs are mainly related to DO consumption and eutrophication (Bianchini-Jr., 1999). In Manso reservoir, the DO consumption was evidenced in the first months of filling, while the process of nutrient enrichment in the water column was evidenced in the following phase, thus allowing the identification of two different stages: 1) dominance of aerobic decomposition processes, with rapid carbon mineralization resulting in the increase of ions in the water column (Casca arm) as well as of DO consumption for 100-150 days after filling; 2) predominance of slow anaerobic decomposition processes in the meta-hypolimnion, in which substrate is compounded of hardly decomposable organic matter, sub products of the previous phase (humic substances) or undecomposed green matter, thus making ammonia, nitrate and phosphorus available for the surface through thermal inversion.

Laboratory experiments verified that DO discontinuities indicated two different stages in the process of decomposition: the first one was a result of the oxidation of carbon compounds; and the second one was induced by nitrification and mineralization processes of the refractory structures (Bianchini-Jr., 1999).

Water residence time and the decomposition processes of the submerged vegetation, which were mainly related to the nature (*cerrado* vegetation) and the amount of flooded biomass, are highlighted to be the main controlling factors of the limnological variation patterns observed in the Manso reservoir in the filling and stabilization phases, except for turbidity. This observation suggests that large and middle-sized reservoirs flooding *cerrado* areas may have similar limnological patterns.

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References

Agência Nacional de Energia Elétrica – ANEEL. *Atlas hidrológico do Brasil.* Brasília: ANEEL, 1997. 50p.

American Public Health Association; America Water Works Association; Water Environment Federation. *Standard methods for the examination of water and wastewater.* Washington: APHA; AWWA; WPCF, 1995.

ANTONIO, RM., BITAR, AL. and BIANCHINI-Jr., I. Consumo de oxigênio na mineralização de folhas, galhos, cascas e serapilheira. *Acta Limnol. Brasil.* 1999, vol. 11, no. 2, p. 65-78.

BIANCHINI-Jr., I. *Contribuição ao estudo da decomposição de plantas aquáticas.* São Carlos: Universidade Federal de São Carlos - UFSCar, 1992. 178p. Dissertação de Mestrado.

BIANCHINI-Jr., I. Decomposição da vegetação e o consumo de oxigênio nos reservatórios: implicações ecológicas. In Henry, R. (Ed.). *Ecologia de reservatórios:* estrutura, função e aspectos sociais. Botucatu: FAPESP; FUNDIBIO, 1999. p. 627-650.

BIANCHINI-Jr., I. and CUNHA-SANTINO, MB. The decomposition of drowned biomass during filling of reservoirs. In Santos, MA. and Rosa, LP. (Eds.). *Global warming and hydroelectric reservoirs.* Rio de Janeiro: COPPE; UFRJ; ELETROBRÁS, 2005. p. 55-66.

BITAR, AL., ANTÔNIO, RM. and BIANCHINI-Jr., I. Degradação anaeróbia de folhas e galhos, cascas e serapilheira. *Acta Limnol. Brasil.* 2002, vol. 2, no. 14, p. 17-26.

CAMPOS Jr., JJF. *Contribuição ao estudo da decomposição de macrófitas aquáticas da lagoa do Infernão:* processo anaeróbio. São Carlos: Universidade Federal de São Carlos - UFSCar, 1998. 130p. Dissertação de Mestrado.

CUNHA-SANTINO, MB. and BIANCHINI-Jr., I. Estequiometria da decomposição aeróbia de galhos, cascas, serapilheira e folhas. In *Recursos Hidroenergéticos:* usos, impactos e planejamento integrado. São Carlos: Rima, 2002. p. 43-56. Programa de Pós-Graduação em Ciências da Eng. Ambiental. Série Ciências da Engenharia Ambiental.

De FILIPPO, R., GOMES, EL., LENS-CÉZAR, J., SOARES, CBP. and MENEZES, CFS. As alterações na qualidade da água durante o enchimento do reservatório de UHE Serra da Mesa-GO. In Henry, R. (Ed.). *Ecologia de reservatórios:* estrutura, função e aspectos sociais. Botucatu: FAPESP; FUNDIBIO, 1999. p. 321-346.

ESTEVES, FA. *Fundamentos de limnologia*. Rio de Janeiro: Interciência; FINEP, 1998. 602p.

FIGUEIREDO, DM. A *influência dos fatores climáticos e geológicos e da ação antrópica sobre as principais variáveis físicas e químicas do rio Cuiabá, Estado de Mato Grosso.* Cuiabá: Universidade Federal de Mato Grosso - UFMT, 1996. Dissertação de Mestrado.

Fundação Estadual de Meio Ambiente; Ministério do Meio Ambiente. *Qualidade da água dos principais rios da Bacia do Alto Paraguai:* 1996-97. Cuiabá: FEMA; MMA, 1997. 118p.

HABTEC - Engenharia Ambiental; Furnas Centrais Elétricas S.A.; APM Manso. *Monitoramento limnológico e da qualidade da água:* relatório final de avaliação da fase de enchimento do reservatório. Rio de Janeiro: HABTEC-Furnas, 2001. 120p.

HENRY, R. Heat budgets, thermal structure and dissolved oxygen in Brazilian reservoirs. In Tundisi, JG. and Straškraba, M. (Eds.). *Theoretical reservoir ecology and its applications.* São Carlos: Braz. Acad. Sci.; IIE; Backhuys Publ., 1999. p. 125-152.

LOPES, IR. *Avaliação limnológica do primeiro ano de enchimento do reservatório de Manso (MT):* perfil da estação de coleta próxima à barragem. Cuiabá: Universidade Federal do Mato Grosso - UFMT, 2003. Monografia.

MAGRIN, AGE. *Aspectos limnológicos, composição e distribuição da comunidade fitoplanctônica em um reservatório da Amazônia Brasileira (Reservatório da UHE Samuel, Estado de Rondônia), durante sua fase de enchimento.* São Carlos: Universidade Federal de São Carlos - UFSCar, 1993. Dissertação de Mestrado.

MAGRIN, AGE. and MATSUMURA-TUNDISI, T. Phytoplankton assemblages in Samuel reservoir (Rondônia State, Brazil) during the filling phase. *Verh. Internat. Verein. Limnol.* 1997, vol. 26, p. 529-534.

MORENO, IH. *Estrutura da comunidade planctônica do reservatório da UHE Balbina (Floresta tropical úmida-Amazonas) e sua relação com as condições limnológicas apresentadas na fase de enchimento e pós-enchimento (1987-1990).* São Carlos: Universidade Federal de São Carlos - UFSCar, 1996. 237p. Tese de Doutorado.

NETO, MSS., ALVES, R., FIGUEIREDO, AC. and HINO, K. Caracterização hidrogeoquímica da Bacia do Rio Manso-Cuiabá, Mato Grosso. *Acta Limnol. Brasil.* 1993, vol. 6, no. 1, p. 230-244.

ODUM, EP. *Ecologia*. Rio de Janeiro: Guanabara, 1988. 434p.

PAGIORO, TA., ROBERTO, MC., THOMAZ, SM., PIERINI, SA. and TAKA, M. Zonação longitudinal das variáveis limnológicas. In Rodrigues, L., Thomaz, SM., Agostinho, AA. and Gomes, LC. (Orgs.). *Biocenoses em reservatórios:* padrões espaciais e temporais. São Carlos: Rima, 2005. p. 39-46.

Ministério do Meio Ambiente. *Hidrossedimentologia do Alto Paraguai.* Brasília: MMA, 1997. 394p. Plano de Conservação da Bacia do Alto Paraguai-Pcbap.

Ministério do Meio Ambiente. *Síntese Executiva.* Brasília: MMA; SRH, 2006. 135p. Plano Nacional de Recursos Hídricos - PNRH 2006.

SOARES, CBP., De FILIPPO, R. and FIGUEIREDO, DM. Vazão sanitária durante a fase de enchimento: avaliação dos efeitos sobre a qualidade da água a jusante do APM-Manso (MT). In *Anais do XVI Seminário Nacional de Produção e Transmissão de Energia Elétrica*, Outubro 21-26, 2001. Campinas: Universidade Estadual de Campinas - UNICAMP, 2001. p. 25-28.

STRAŠKRABA, M. and TUNDISI, JG. *Diretrizes para o gerenciamento de lagos*: gerenciamento da qualidade da água de represas. São Carlos: CNPq; ILEC; IIE, 2000. 258p.

STRAŠKRABA, M. Retention time as a key variable of reservoir limnology. In Tundisi, JG. and Straškraba, M. (Eds.). *Theoretical reservoir ecology and its applications.* São Carlos: Braz.Acad.Sci.; IIE; Backhuys Publ., 1999. p. 385-410.

THORNTON, J., STEEL, A. and RAST, W. Reservoirs. In Chapman, D. (Ed.). *Water quality assessments:* a guide to use of biota, sediments and water in environmental monitoring. London: UNESCO; WHO; UNEP, 1996. p. 105-145.

TUNDISI, JG. Gerenciamento integrado de bacias hidrográficas-estudos de caso e perspectivas. In Nogueira, MG., Henry, R. and Jorcin, A. (Eds.). *Ecologia de reservatórios:* impactos potenciais, ações de manejo e sistemas em cascata. São Carlos: Rima, 2005. p. 1-22.

WETZEL, RG. *Limnology.* Washington: Saunders College Publ., 1983. 762p.

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