Ecotoxicological analysis of the water and sediment from middle and low Tietê River cascade reservoirs (State of São Paulo, Brazil).

RODGHER[1], S., ESPÍNDOLA[1], E.L.G., ROCHA[2], O., FRACÁCIO[3], R., PEREIRA[1], R.H.G. & RODRIGUES[1], M.H.S.

[1] University of São Paulo, Engineering School of São Carlos, Water Resources Center and Applied Ecology. Av. Trabalhador São Carlense, nº 400, C.P 292. Cep 13.560-970 – São Carlos/SP, Brazil. surodgher@uol.com.br; elgaeta@sc.usp.br

[2,3] Dept of Hydrobiology and Ecology and Evolutionary Biology. Federal University of São Carlos. Via Washington Luiz, km 235 – C.P 676. Cep 13565-905 – São Carlos/SP, Brazil. odoro@power.ufscar; rfrac@terra.com.br

ABSTRACT: Ecotoxicological analysis of the water and sediment from the middle and low Tietê River cascade reservoirs (State of São Paulo, Brazil). This study tried to evaluate the environmental quality of the reservoirs from the middle and low Tietê River (SP) through ecotoxicological analyses. Water and sediment samples were obtained in four different periods (October/99, February, May and July/00), in 15 sampling stations. The samples were used for bioassays of acute toxicity with Daphnia similis and chronic with Ceriodaphnia dubia, as well as for determination of metals (cadmium, cobalt, chromium, copper and zinc) concentration in water and sediment. The results demonstrated that in the rainy period a larger number of water and sediment samples caused chronic toxicity effect in Ceriodaphnia dubia. The bioassays only indicated acute toxicity for Daphnia similis in stations downstream of Barra Bonita Reservoir. However, the results of chronic toxicity, showed a decreasing tendency in toxicity (from Barra Bonita to Três Irmãos Reservoirs), in most sampling periods. This fact can be related to the presence of metals in the Tietê system, as well as to the different sensibility among the species, and also to the intrinsic characteristics of each kind of experiment. An increase in the concentration of bioavailable metals was observed in the sediment of the reservoir along the years.
Key-words: ecotoxicology, water, sediment, reservoir, zooplankton.

RESUMO: Análise ecotoxicológica da água e do sedimento dos reservatórios em cascata do médio e baixo rio Tietê (Estado de São Paulo, Brasil). Neste trabalho procurou-se avaliar a qualidade ambiental dos reservatórios do Médio e Baixo rio Tietê (SP) por meio de análises ecotoxicológicas. Foram realizadas coletas de água e sedimento em quatro períodos distintos (outubro/99, fevereiro, maio e julho/00), em 15 estações de amostragens. As amostras foram utilizadas para a realização de bioensaios de toxicidade aguda com Daphnia similis e crônica com Ceriodaphnia dubia, bem como para a determinação dos metais cádmio, cobalto, cromo, cobre e zinco na água (concentração total) e no sedimento (biodisponíveis). No período chuvoso, um maior número de amostras de água e sedimento causaram toxicidade crônica em Ceriodaphnia dubia. Os bioensaios revelaram toxicidade aguda para Daphnia similis somente nos reservatórios localizados à jusante da barragem de Barra Bonita. Os resultados de toxicidade crônica, porém, configuraram um padrão diferente, verificando-se toxicidade em ordem decrescente (de Barra Bonita a Três Irmãos), na maioria dos períodos de amostragens. Tal fato pode estar relacionado à presença de metais no sistema Tietê, bem como a diferença de sensibilidade entre os organismos-teste e outras características intrínsecas ao tipo de experimento realizado. Um aumento da concentração de metais biodisponíveis no sedimento dos reservatórios ao longo dos anos foi registrado.
Palavras-chaves: ecotoxicologia, água, sedimento, reservatórios, zooplâncton.

Introduction

Rivers are used for dilution of industrial and domestic residues and, of course, the reservoirs built along them are also exposed to a decrease in water quality. According to Tundisi et al. (1999), the interaction of a reservoir or a cascade of reservoirs (with several dams built along a river) with its watershed is not only a consequence of the initial conditions during its construction. It also reflects the evolutionary process that depends on the use of water and the activities developed in the adjacent area. Thus, in addition to the intrinsic mechanisms of the reservoirs operation (retention time, circulation, stratification pattern), environmental patterns also appear as a response to the ecological, social and economical conditions (Tundisi, 2000).

In Brazil, according to Kohlhepp (1999), the construction of large reservoirs reflects the effort of the country to increase its electrical power production, and from 1962 to 1996 the capacity of the electric plant grew about ten times. Most hydroelectric plants are concentrated in Paraná watershed, in the northeast area of the San Francisco River and in the Amazon area. Among these enterprises, the cascade of reservoirs in the middle and low Tietê River stands out as part of the Paraná River watershed. The system is formed by Barra Bonita, Bariri, Ibitinga, Promissão, Nova Avanhandava and Três Irmãos reservoirs. The first reservoirs were built in the decade of 60 and the last one in 1991 (Três Irmãos dam).

These complex artificial ecosystems have an ecological, economical and social significance due to its position amidst important agricultural and industrial regions (Tundisi et al., 1991). The main activities developed in the superior part of the cascade (from Barra Bonita to Promissão) are related to production of paper, cellulose, alcohol and sugar as well as activities related to textile, metallurgic and chemistry industries. There is the predominance of agriculture activities such as coffee, corn cultures and horticulture in the inferior part of the basin (Nova Avanhandava and Três Irmãos reservoirs). Besides the electric generation, the water of the reservoirs is also destined to public and industrial supply, irrigation and recreation, along with the reception of domestic and industrial effluents (Cetesb, 1998). According to the Environmental National Council (CONAMA) Resolution 20/1986, which establishes water quality standards for the National Territory on the basis of its preponderant uses, the water from the middle and low Tietê reservoirs are classified as Class 2 (water destined to domestic supply, primary contact recreation, irrigation and protection of aquatic communities).

According to Espíndola et al. (1999), limnological studies in the cascade of the Tietê River have been developed since 1979, approaching physical, chemical and biological aspects from water and sediment, as well as its relationship with the use and occupation of the drainage area. Significant changes in the water quality as a consequence of the accelerated process of contamination and eutrophication of the system were observed along the years due to the impacts derived from the expansion of industrial and agricultural activities.

Another aspect to be considered in the environmental evaluation of the system is the position of reservoirs in the cascade, which gives it a peculiar particularity. Studies developed in Spanish reservoirs by Armengol (1977) and Margalef (1983) and in the Czech Republic by Straskraba (1994), showed that a downstream improvement in the water quality is expected, as part of the nutrients and pollutants is retained in the beginning of the system. This pattern has not been verified in the Tietê system (Barbosa et al., 1999) implicating in the necessity of wider analysis of the reservoirs.

New approaches have been implemented to the monitoring programs considering the extension of the environmental impacts from pollutants introduced into the aquatic ecosystems (Espíndola et al., 2002). Quantification of chemical concentrations is not enough to evaluate the impact of toxic substances in aquatic ecosystems. The interaction processes of these substances with the biota are not well understood or they are difficult to be quantified. In this way, the toxicity tests are considered as important tools to recognize the effects of pollutants in the aquatic biota using live organisms (Zagatto, 1999). According to Cairns et al. (1998), the ecotoxicological studies evaluate the environmental conditions and predict tendencies along the time. They can be used to determine the effects of toxic agents and to guide the selection of remediation practices to maximize the ecological benefits.

In order to get a better analysis of the impacts caused by the multiple uses of the system, the current study intends to evaluate the quality of water and sediment of the cascade dams of Tietê River through toxicity bioassays with microcrustacean and metal analyses in both compartments.

Material and methods

In this study 15 (fifteen) sampling stations were evaluated, as shown in Fig. 1, including stations in the Tietê River (station 1) and Piracicaba River (station 2) and in the Upstream and Downstream of the dams of Barra Bonita (stations 3 and 4, respectively), Bariri (stations 6 and 7, respectively), Ibitinga (stations 9 and 10, respectively), Promissão (stations 10 and 11, respectively), Nova Avanhandava (stations 12 and 13, respectively) and Três Irmãos (stations 14 and 15, respectively). Samples were also collected in Bauru River (station 5), a very impacted tributary and consequently a significant source of degradation for the water of Bariri reservoir.

The samples were collected in four different periods, October/99, February (rainy period), May and July (dry period) of 2000. Water was collected with a suction bomb, in a single vertically integrated sample from each station. The water samples were transferred to gallons, previously washed and dried, and stored at the temperature of 4°C until the analyses. Sediment samples were collected with an Eckman dredge, and immediately, conditioned in plastic containers and maintained in styrofoam with ice until their subsequent use in laboratory.

The maintenance of the test organisms used in the toxicity bioassays was done in agreement with Cetesb Norm (1991a). The water used for culturing of test organisms and in the acute and chronic toxicity tests was artificially reconstituted. Test organisms were fed daily with 10^5 cells/L of green alga Selenastrum capricornutum Printz and suspension of yeast and ration for fish (VitôrmonioÒ).

The bioassays of acute toxicity were conducted with water samples collected in the different sampling stations, and the newborn of Daphnia similis (younger than 24 hours) were exposed to water without dilution and, after 48 hours, the immobile organisms were counted. The bioassays of acute toxicity were considered valid when the immobility of the organisms in the control treatment did not surpass 10% (Cetesb, 1991a).

For the bioassays of chronic toxicity carried out with water samples, 1 newborn of Ceriodaphnia dubia (younger than 24 hours) was exposed, in 10 test vessels, in 15mL of water without dilution for each sampling station. The bioassay lasted from seven to ten days, the necessary period to the production of the third offspring, being registered the number of newborns produced along the experiment (Cetesb, 1991b).

The toxicity bioassays with sediment samples were done following the recommendations of Burton & Macpherson (1995), using the dilution ratio of 1:4 sediment/water. The duration and the evaluated parameters in the bioassays of acute and chronic toxicity using the sediment were similar to the ones described for water samples.

The total concentration of cadmium, cobalt, chromium, copper, zinc in the water was determined following Apha-Awwa-Wpcf (1995) using atomic absorption spectrophotometer. In order to determinate potentially bioavailable metals (cadmium, cobalt, chromium, copper, zinc) in the sediment, the samples were dried at the temperature of 40°C and the extraction followed Tessier & Campbell (1987).

The following criteria was adopted for the results evaluation obtained in the bioassays of acute toxicity with Daphnia similis: a) non toxic sample - when the immobility ranged between 0 and 10% of the test organisms; b) toxicity trace - for the immobility between 10 and 40% of the test organisms and c) toxic - when the immobility was equal or above to the 40% of the organisms (Barbosa, 2000). The results obtained in the bioassays of chronic toxicity for Ceriodaphnia dubia were submitted to a normality analysis. In case of a normal distribution it was performed the test of Tukey (parametric test), and the Kruskall-Wallis test (non parametric test), was applied in order to verify the occurrence of significant differences for each sample in relation to control.

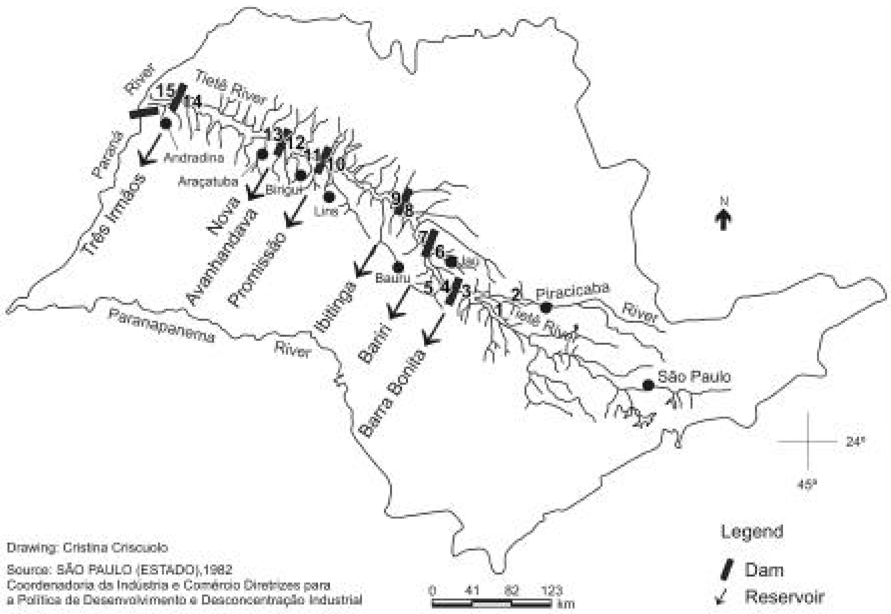

Figure 1: Location of sampling stations in the reservoirs of the midle and low River Tietê.

Pearson correlation analyses were performed to detect relationship between metal concentration in the water and sediment and the results observed in acute and chronic toxicity bioassays.

Results

The toxicity bioassays revealed acute toxicity for Daphnia similis, when exposed to Bariri Upstream's water samples (immobility of 50%, in October/99) and Bariri Downstream (immobility of 60% and 100%, in October/99 and February/00, respectively), of Ibitinga Upstream (immobility of 60%, in October/99), Promissão Upstream (immobility of 90%, 60% and 100%, in October/99, May/00 and July/00, respectively), Promissão Downstream (immobility of 70% and 93%, in October/99 and July/00, respectively), Nova Avanhandava Upstream (immobility of 100%, 90%, 100% and 80%, in October/99, February/00, May/00 and July/00, respectively), Nova Avanhandava Downstream (immobility of 100%, 60% and 73%, in October/99, May/00 and July/00, respectively), Três Irmãos Upstream (immobility of 60%, in October/99) and Downstream (immobility of 45%, in October/99) (Tab. I).

Most of the water samples collected in October/99 caused acute toxicity or toxicity traces for Daphnia similis, while only two samples (Bariri Downstream and Nova Avanhandava Upstream) collected in the rainy period, caused acute toxicity to the test organisms. Water from Nova Avanhandava Upstream caused toxic effect in the test organism in the four study periods.

The bioassays of acute toxicity with sediment samples revealed acute toxicity for Daphnia similis when exposed to the samples from Ibitinga Downstream (immobility of 60%, in February/00), Promissão Upstream (immobility of 50%, in February/00), Nova Avanhandava Upstream (immobility of 73%, in October/99) and Três Irmãos Upstream (immobility of 100%, in May/00). Toxicity traces for the test organisms were registered in all of the sediment samples of October/99 and in the minority of the samples collected in February, May and July/00.

The results obtained from the bioassays of chronic toxicity with water and sediment samples using Ceriodaphnia dubia are presented in Tab. II. The bioassays of chronic

Table I: Immobility percentage of newborns of Daphnia similis and toxicity classification in bioassays of acute toxicity with water and sediment samples from middle and low Tietê reservoirs.

Sampling stations	October/99		February/00		May/00		July/00	
	Water %	Sediment %	Water %	Sediment %	Water %	Sediment %	Water %	Sediment %
Laboratorial control	6 (TA)	3 (TA)	5 (TA)	2 (TA)	0 (TA)	3 (TA)	5 (TA)	3 (TA)
Tietê River	6,7 (NT)	23 (IT)	0 (NT)	0 (NT)	25 (IT)	0 (NT)	30 (IT)	0 (NT)
Piracicaba River	33 (IT)	30 (IT)	0 (NT)	3 (NT)	0 (NT)	0 (NT)	0 (NT)	10 (NT)
Barra Bonita Upstream	20 (IT)	37 (IT)	0 (NT)	7 (NT)	0 (NT)	0 (NT)	10 (NT)	5 (NT)
Barra Bonita Downstream	20 (IT)	3 (NT)	0 (NT)	20 (IT)	0 (NT)	3 (NT)	0 (NT)	5 (NT)
Bauru River	20 (IT)	17 (IT)	5 (NT)	10 (NT)	30 (IT)	10 (NT)	0 (NT)	0 (NT)
Bariri Upstream	**50 (T)**	30 (IT)	0 (NT)	7 (NT)	0 (NT)	0 (NT)	0 (NT)	0 (NT)
Bariri Downstream	**60 (T)**	20 (IT)	**100 (T)**	3 (NT)	0 (NT)	10 (NT)	0 (NT)	0 (NT)
Ibitinga Upstream	**60 (T)**	13 (IT)	0 (NT)	0 (NT)	33 (IT)	5 (NT)	13 (IT)	0 (NT)
Ibitinga Downstream	20 (IT)	0 (NT)	20 (IT)	**60 (T)**	0 (NT)	0 (NT)	6 (NT)	0 (NT)
Promissão Upstream	**90 (T)**	13 (IT)	0 (NT)	**50 (T)**	**60 (T)**	3 (NT)	**100 (T)**	20 (IT)
Promissão Downstream	**70 (T)**	17 (IT)	10 (NT)	10 (NT)	27 (IT)	20 (IT)	**93 (T)**	10 (NT)
Nova Avanhandava Upstream	**100 (T)**	**73 (T)**	**90 (T)**	25 (IT)	**100 (T)**	0 (NT)	**80 (T)**	0 (NT)
Nova Avanhandava Downstream	**100 (T)**	13 (IT)	5 (NT)	0 (NT)	**60 (T)**	0 (NT)	**73 (T)**	10 (NT)
Três Irmãos Upstream	**60 (T)**	7 (NT)	0 (NT)	30 (IT)	13 (IT)	**100 (T)**	0 (NT)	10 (NT)
Três Irmãos Downstream	**45 (T)**	17 (IT)	0 (NT)	20 (IT)	27 (IT)	0 (NT)	0 (NT)	15 (IT)

TA (test accepted) = immobility < 10%, NT (non toxic) = immobility < 10 %; IT (toxicity trace) = 10% ‹ immobility < 40%, T (toxic) = immobility ³ 40%

Table II: Numbers of newborns produced by Ceriodaphnia dubia in bioassay of chronic toxicity, when exposed to the water and sediment samples from the middle and low Tietê reservoirs in the study period and the results of Kruskall-Wallis' test for the reproduction data.

Sampling stations	October/99		February/00		May/00		July/00	
	Water %	Sediment %	Water %	Sediment %	Water %	Sediment %	Water %	Sediment %
Laboratorial control	147	177	147	169	145	146	146	154
Tietê River	97	0*	33*	11*	50*	72	0*	21*
Piracicaba River	38	51	25*	76	72	134	111	52
Barra Bonita Upstream	56	91	10*	12*	98	64	0*	23*
Barra Bonita Downstream	67	23*	12*	50*	103	115	43	113
Bauru River	100	0*	25*	11*	148	91	23	50
Bariri Upstream	82	0*	36*	28*	108	92	0*	112
Bariri Downstream	51	0*	10*	45*	85	98	39	67
Ibitinga Upstream	45	14*	32*	20*	131	106	142	35
Ibitinga Downstream	15*	0*	119	139	111	72	145	96
Promissão Upstream	28*	0*	36*	126	116	91	0*	101
Promissão Downstream	77	14*	53	120	124	79	61	125
Nova Avanhandava Upstream	101	24	92	105	72	128	67	113
Nova Avanhandava Downstream	125	136	122	77	60	147	111	123
Três Irmãos Upstream	110	159	146	81	54	117	141	127
Três Irmãos Downstream	97	72	142	85	52	65	143	149

* significant difference in relation to the controls ($p<0.05$)

toxicity were done with water and sediment samples from all the sampling stations, including those for the acute toxicity of Daphnia similis.

Despite that the water from some sampling stations (Upstream and Downstream of Bariri reservoir, Promissão Upstream, Promissão Downstream, Nova Avanhandava Downstream, Três Irmãos Upstream and Três Irmãos Downstream) have caused a toxic effect for Daphnia similis, the same one did not cause chronic effect in Ceriodaphnia dubia. The water samples without acute effect for Daphnia similis but with a significant chronic effect for Ceriodaphnia dubia were originated from Tietê River (in February/00, May/00 and July/00), Piracicaba River (in February/00), Barra Bonita Upstream (in February/00 and July/00), Barra Bonita Downstream (February/00), Bauru River (February/00), Bariri Upstream (in February/00 and July/00), Ibitinga Downstream (in October/99) and Promissão Upstream (in February/00). Only water samples from Bariri Downstream (February/00) and Promissão Upstream (October/99, February/00 and July/00) caused both acute and chronic effects in the test organisms.

In the rainy period, a larger number of water samples (Tietê, Piracicaba and Bauru Rivers, Upstream and Downstream of the reservoirs of Barra Bonita and Bariri, Upstream of reservoirs of Ibitinga and Promissão) caused chronic toxicity effect in Ceriodaphnia dubia. In May/00, only one water sample (Tietê River) caused chronic effect.

In the bioassays of chronic toxicity with sediment samples, some samples (Ibitinga Downstream and Promissão Upstream in February/00, Nova Avanhandava Upstream in October/99 and Três Irmãos Upstream in May/00) have caused a toxic effect for Daphnia similis, but chronic effect was observed in the Ceriodaphnia dubia test. The sediment samples without acute effect for Daphnia similis, but significant chronic effect for Ceriodaphnia dubia in the reproduction data of the test organisms, were came from Tietê River (in October/99, February/00 and July/00), Barra Bonita Upstream (in February/00 and July/00), Barra Bonita Downstream (in October/99 and February/00), Bauru River (October/99 and February/00), Bariri Upstream (in October/99 and February/00), Bariri Downstream (in October/99 and February/00), Ibitinga Upstream (in October/99 and February/00), Ibitinga Downstream (in October/99), Promissão Upstream (in October/99) and Promissão Downstream (in October/99).

In the months of October/99 and February/00, there was a larger number of sediment samples with chronic effect for Ceriodaphnia dubia, being 9 sediment samples in October/99 (Tietê River, Barra Bonita Downstream, Bauru River, Upstream and Downstream of the dam from Bariri, Ibitinga and Promissão reservoirs) and 7 samples in February/00 (Tietê and Bauru Rivers, Upstream and Downstream of the dam from Barra Bonita and Bariri reservoirs, and Ibitinga Upstream). In July/00, only two samples (Tietê River and Barra Bonita Upstream) and none in May/00 caused chronic effect. In general way, a decreasing gradient of the chronic toxicity was recorded for Ceriodaphnia dubia along the cascade system, conversely to the bioassays of acute toxicity with Daphnia similis.

In relation to the values of total concentrations of metals in the water (Tab. III) the values for cadmium were above of CONAMA Resolution 20/1986 for Class 2 rivers. Higher values were registered in July (0.004mg/L to 0.013mg/L, Ibitinga and Promissão reservoirs and Piracicaba River, respectively) and the lowest values (0.002mg/L to 0.009mg/L, Tietê River and Barra Bonita reservoir, respectively) in February/00. In relation to cobalt, the values were below to the established by the resolution. For chromium, one value detected in February/00 in Piracicaba River (0.056mg/L) was higher than the of the CONAMA Resolution and, in July/00 it was only detected just in Tietê River (0.008mg/L). In February/00, copper was only detected in Tietê River (0.008mg/L) and in July/00 the values varied from 0.001mg/L (dam of Ibitinga) to 0.011 mg/L (Tietê River). In February/00, zinc had the minimum concentration of 0.035mg/L in Tietê River and the maximum of 1.215mg/L in Piracicaba River (above the limit of the by CONAMA Resolution for Class 2 rivers). In July/00, the minimum value was of 0.002mg/L (in the dam of Barra Bonita) and the maximum was 0.043mg/L (Bauru River).

Considering to the analysis of the potentially bioavailable metals in the sediment (Tab. IV), the largest mean values of cadmium were registered in Bauru River and Três Irmãos reservoir (2.36mg/Kg and 2.13mg/Kg, respectively); cobalt in Tietê and Bauru Rivers (38.70mg/Kg and 27.00 mg/Kg, respectively); chromium in Tietê and Piracicaba Rivers

Table III: Values of metals concentration (total) in the water samples of Tietê River and tributaries during in the study period (rainy and dry season) and comparison with the limits established by CONAMA Resolution 20/1986 for Class 2 rivers.

Sampling stations	Total Metals (mg/L)									
	Cadmium		Cobalt		Chromium		Copper		Zinc	
	Feb/00	Jul/00	Feb/00	Jul/00	Feb/00	Jul/00	Feb/00	Jul/00	Feb/00	Jul/00
Tietê River	**0.0028**	**0.0074**	0.0256	0.024	ND	0.0084	0.008	0.0114	0.03574	0.01216
Piracicaba River	ND	**0.0138**	0.002	0.057	**0.056**	ND	ND	0.0054	**1.21526**	0.01524
Barra Bonita Dam	**0.0092**	**0.0054**	0.028	ND	ND	ND	ND	0.0046	0.11974	0.00252
Bauru River	ND	**0.0078**	0.039	ND	ND	ND	ND	ND	0.0961	0.04348
Bariri Dam	**0.0022**	**0.0086**	0.033	ND	ND	ND	ND	0.0032	0.05212	0.0212
Ibitinga Dam	ND	**0.0042**	0.054	0.021	ND	ND	ND	0.0012	0.0428	0.0111
Promissão Dam	ND	**0.0046**	0.022	ND	ND	ND	ND	0.003	0.06942	0.01028
Nova Avanhandava Dam	**0.0052**	**0.0088**	0.028	0.096	ND	ND	ND	0.0078	0.04762	0.00942
Três Irmãos Dam	**0.007**	**0.0084**	0.035	ND	ND	ND	ND	ND	0.07506	0.01218
CONAMA 20/1986	0.001		0.2		0.05		0.02		0.18	

ND = not detected. Values in bold are higher than the maximum limit allowed by CONAMA 20/1986 for Class 2 rivers.

Table IV: Comparison among the mean concentrations of potentially bioavailable metals in the middle and low Tietê dams in 1981 and 1999/2000.

Sampling stations	Potentially Bioavailable Metals (mg/kg)				
	Cadmium	Cobalt	Chromium	Copper	Zinc
Tietê River [b]	2.00	38.70	36.30	36.30	93.31
Piracicaba River [b]	1.45	27.00	32.00	24.30	78.81
Barra Bonita Dam					
1981 [a]	0.77	6.70	9.60	27.50	25.10
1999/2000 [b]	1.78	21.70	20.18	35.03	64.33
Bauru River [b]	2.36	17.56	20.12	55.36	102.33
Bariri Dam					
1981 [a]	0.70	16.10	14.00	60.70	30.80
1999/2000 [b]	1.63	17.48	23.35	54.22	62.01
Ibitinga Dam					
1981 [a]	0.53	8.20	8.40	28.30	21.20
1999/2000 [b]	1.74	11.48	21.02	35.95	28.54
Promissão Dam					
1981 [a]	0.10	1.30	2.00	21.80	2.60
1999/2000 [b]	1.40	9.89	31.10	27.33	18.56
Nova Avanhandava Dam					
1981 [a]	-	-	-	-	-
1999/2000 [b]	2.08	17.45	24.57	20.66	11.62
Três Irmãos Dam					
1981 [a]	-	-	-	-	-
1999/2000 [b]	2.13	4.68	25.75	7.46	3.82

[a] Esteves et al. (1981) e [b] current study (mean values obtained during the study period)

(36.30mg/Kg and 32.00mg/Kg, respectively); copper in Bauru River and Bariri reservoir (55.36mg/Kg and 54.22mg/Kg, respectively) and for zinc in Bauru and Tietê Rivers (102.33mg/Kg and 93.31mg/Kg, respectively).

In relation to the correlation analysis between the metals concentration and bioassays toxicity, only cadmium concentration in the sediment showed a positive correlation ($r>0.4$; $p<0.05$) with the data obtained in the bioassays of chronic toxicity with sediment samples. For the values of the water samples, no correlation was observed between the metal concentrations and the data of in the acute and chronic toxicity bioassays ($r<0.4$ and $p>0.05$).

Discussion

Nowadays, the environmental quality of reservoirs is a central theme for the ecosystems administration due to the increase of the agricultural and industrial activities, the use and the intensive spilling of pesticides and toxic substances into the aquatic ecosystems, which end up contributing to the contamination of the water and sediments of rivers, dams and marginal ponds (Straskraba & Tundisi, 1999).

In this way, several evaluation programs of water quality were implemented, being included methods of chemistry, physics and biological analyses. According to Burton (1999), in the past this evaluation was made through traditional methods such as the determination of the chemicals concentration or, in some cases, the research of biological communities indexes, such as diversity and abundance. However, the evaluation of an environment needs something more complex and the best way could be the use of an approach that integrates physical and chemical data, biological communities and ecotoxicological information about water and sediment. Such an integrated approach is necessary because the ecosystems tend to be very complex and this complexity affects the fate and the effect of the pollutants and their toxicity for the organisms.

In the present study, bioassays of acute toxicity with Daphnia similis and chronic with Ceriodaphnia dubia were performed, in addition to chemical analyses of the water and sediment samples of the middle and low Tietê reservoirs. The aim was to improve the evaluation of the environmental quality of these ecosystems and to supply information that could contribute to the choice of the process of handling measures for the environment recovery. The reservoirs in study are part of a system built in cascade, which represents an peculiar particularity in the evaluation of these systems.

Considering the results of the bioassays of acute toxicity with Daphnia similis, it was not observed an improvement in the quality of water and sediment along the middle and low Tietê reservoirs. Such improvement could be previously expected considering that in the cascade reservoirs, most of the time, an improvement in the environmental quality along the system is predicted. However, the bioassays of chronic toxicity with Ceriodaphnia dubia revealed toxicity in a decreasing order from Barra Bonita to Três Irmãos reservoirs.

Burton & Macpherson (1995) point out that the toxic agents do not affect the same metabolic processes and they can result in different effects. Thus, it is important to choose appropriated parameters of evaluation (survival, reproduction and/or growth), as well as test organisms belonging to different trophic levels. Besides, the toxicity of an environmental sample does not always depend on a single chemical compound. Interaction among different compounds and substances and particular physical and chemical conditions can result in attenuation or, conversely, in synergism, reducing or increasing individual toxic effects (Branco, 1999).

Fonseca (1997), using the species Ceriodaphnia silvestrii (a native species) and Daphnia similis for the evaluation of the water quality in the Piracicaba River watershed, also observed different sensibility between the tested species, when exposed to a water sample with high zinc content. According to the author, no effect was observed for Daphnia similis, while chronic effect was registered for Ceriodaphnia silvestrii. Printes (1996), evaluating the acute toxicity for Daphnia similis and chronic for Ceriodaphnia dubia, using the superficial water from the carboniferous area of the low Jacuí River (RS) verified acute toxicity for Daphnia similis and no chronic toxicity for Ceriodaphnia dubia, when exposed to the water sample. According to the author, the species differ in their susceptibility to the toxic substances, which depends on factors such as metabolism, genetic factors and others linked to the diet. Cowgill (1987) says that in toxicity bioassays with zooplankton, the sensibility of the test organisms can be affected by their own characteristics (nutritional state, life stage and health), which can change the results of toxicity bioassays (Cooney, 1995).

In general, the most common toxic effect measured in aquatic organisms is immobility or lethality. In laboratory studies, chronic effects may be unnoticed in acute toxicity bioassays. A way to study sub lethal toxicity is by using longer exposures and by measuring biological end points, structural and functional. The fact that a chemical does not have adverse effects on aquatic organisms in acute toxicity testes does not necessarily presuppose that it is not toxic for these species (Rand et al., 1995).

Another factor to be considered is that, usually, the acute toxicity of a pollutant on Daphnia similis is determined in the absence of particles in suspension (during the acute test, food is not supplied), while the chronic tests are determined in feeding conditions. It is well known the capacity of the suspended particles to establish connections with chemical compounds through the absorption (Hook & Fisher, 2001). Accessible source of pollutants can be quickly liberated in the acid conditions of the digestive system of those organisms and, as a consequence would cause alterations in their behavior, not revealed in the bioassays of acute toxicity. Such information is important to study metal transport pathways and the toxic effects of metals within food webs (Barata et al., 2002).

Considering the values of metals in the water of the reservoirs, concentrations above the limit of the CONAMA Resolution for Class 2 rivers were registered for cadmium in the dry period. The sensibility for Daphnia pulex for this metal is a LC50 (effective lethal concentration that affects 50% of the population) between 0.007 and 0.3mg/L (Ingersoll & Winner, 1982), and such range of concentrations was found in the present study. For zinc, values above or close of the allowed limit (0.18mg/L) were registered in February/00 and the sensibility established by United States Environmental Protection Agency (Fonseca, 1997) for Daphnia magna, ranges from 0.1 to 0.5mg/L. Close values to the limit could have contributed to the toxicity observed in the test organisms, however no significant correlation was found.

In general, a large number of water and sediment samples collected in the rainy period resulted in acute and chronic toxicity for the organism tests. Such fact is an evidence that larger entrance of pollutants originated from the Tietê and Piracicaba Rivers and from the reservoirs margins (diffuse point sources), promoting the degradation and the toxicity of the system.

The concentrations of potentially bioavailable metals in sediment of the middle and low Tietê reservoirs found in the present study, when compared with data of Esteves et al. (1981), showed an increase along the years. The metals levels found in the sediment are due to the alterations in the environment, due to contamination by domestic and industrial effluents and agricultural inputs.

Largest concentrations of potentially bioavailable metals are in the Tietê, Piracicaba and Bauru Rivers, where anthropogenic effects influence the rivers and the environmental quality of the middle and low Tietê reservoirs. Although high concentrations of potentially bioavailable metals were found in the sediments from Tietê and Piracicaba Rivers and in the first reservoirs of the cascade, acute effects to the test organism were not registered, conversely to the bioassays of chronic toxicity with Ceriodaphnia dubia. Pearson correlation revealed a significant relationship between cadmium concentration in the sediment and in the bioassays of chronic toxicity.

Espíndola et al. (1998), evaluating the environmental quality of Salto Grande reservoir (Americana-SP), found acute toxicity for Daphnia similis using sediment samples from sites that did not present the largest concentrations of metals. The toxicity bioassays would reflect a synergism from all the substances generated in the system, showing that the isolated chemical characteristic can not guarantee the preservation and the maintenance of the aquatic biota, once the system mechanisms and processes are differentiated in the time and space.

Concentrations of cadmium, copper, nickel, lead and other elements are being found in sediments affected by the human activities in higher levels than those detected in the terrestrial area. However, the fraction of the metal that causes ecological risk to the aquatic biota in the sediment is not only indicated by their concentration. Thus, even in concentrations of metals that exceed the known levels, their bioavailability can be minimum and their toxicity reduced (Ankley et al., 1996).

Acknowledgments

The authors would like to thank the Council of Improvement of Higher Education (CAPES) for the granted scholarships, the PROBIO MMA/CNPq Project and technicians of Water Resources Center and Applied Ecology (CRHEA), from the Engineering School of São Carlos (USP) and of the Department of Ecology and Evolutionary Biology from the Federal University of São Carlos (DEBE).

References

APHA- American Public Health Association. 1995. Standard methods for the examination of water and wastewater.19 ed. APHA, New York. 1268p.

Ankley, G.T., Di Toro., D.M., Hansen, D.J. & Berry, W.J. 1996. Assessing the ecological risk of metals in sediments. Environ. Toxicol. Chem., 15:2053-2055.

Armengol, J. 1977. Tipologia dos embalses españoles. In: Anais do Seminario sobre medio ambiental y embalses. Montevideu, Tomo I, p 3-6.

Barata, C., Markich, S.J., Baird, D.J. & Soares, A.V.M. 2002. The relative importance of water and food as cadmium sources to Daphnia magna Straus. Aquat. Toxicol., 61:143-154

Barbosa, F.A.R., Padisák, J., Espíndola, E.G.L., Borics, G. & Rocha, O. 1999. The Cascading Reservoir Continuum Concept (CRCC) and Its Application to the River Tietê – Basin, São Paulo State, Brazil. In: Tundisi, J.G. & Straskraba, M. (eds.) Theoretical reservoir ecology and its applications. Brazilian Academy of Sciences and Backhuys Publishers, Rio de Janeiro. p.425-437.

Barbosa, R.M. 2000. Avaliação do impacto de lodo de estações de tratamento de água à biota aquática através de estudos ecotoxicológicos. São Carlos, USP, 200p (Tese).

Branco, S.M. 1999. A Água, Meio Ambiente e Saúde. In: Rebouças, A.C., Braga, B. & Tundisi, J.G. (orgs.) Águas doces no Brasil: capital ecológico, uso e conservação. Escrituras, São Paulo. 760p.

Burton Jr., G.A. 1999. Realistic assessment of ecotoxicity using traditional and novel approaches. Aquat. Ecosystem Health Manag., 2:1-8.

Burton Jr., G.A.. & Macpherson, C. 1995. Sediment toxicity testing issues and methods. In: Hoffman, D.J., Rattner, G.A., Burton Jr., G.A. & Cairns, J.R.(eds.) Handbook of Ecotoxicology. Lewis Plublishers, Boca Raton. 970p.

Cairns, J.J., Niederlehner, B.R. & Bidwell, J.R. 1998. Ecotoxicology Toxicity Testing. In: Meyers, R.A.(ed.) Encyclopedia of environmental analysis and remediation. John Wiley & Sons Inc, New York. 1560p.

Cetesb-Companhia de Tecnologia de Saneamento Ambiental. 1991a. Água e Teste de Toxicidade Aguda com Daphnia similis Claus, 1876 (Cladocera, Crustacea). Cetesb, São Paulo. 33p. (Norma Técnica, L5.018)

Cetesb-Companhia de Tecnologia de Saneamento Ambiental. 1991b. Água e teste de toxicidade crônica utilizando Ceriodaphnia dubia Richard, 1894 (Cladocera, Crustacea). Cetesb, São Paulo. 24p. (Norma Técnica, L5.022)

Companhia de Tecnologia de Saneamento Ambiental. 1998. Relatório de qualidade das águas interiores do Estado de São Paulo. Cetesb, São Paulo. 244p.

CONAMA- Conselho Nacional do Meio Ambiente . 1986. Legislação Ambiental Brasileira.. Resolução do Conselho Nacional do Meio Ambiente CONAMA 20/1986. IBAMA, Brasília.

Cooney, J.D. 1995. Freshwater test. In: Rand, G.M (ed.) Fundamentals of aquatic toxicology: effects, environmental fate, and risk assessment. Taylor & Francis, Washington. 960p.
Cowgill, U.M. 1987. Critical analysis of factors affecting the sensitivity of zooplankton and the reproducibility of toxicity test results. Water. Res., 21:1453-1462.
Espíndola, E.L.G., Pascoal, C.M.R.B., Tonissi, F.B. & Magalhães, R. 1998. Avaliação ecotoxicológica de sedimento como uma instrumento de controle para a qualidade da água do reservatório de Salto Grande (Americana/SP). Anais do Simpósio de Ecossistemas Brasileiros. Águas de Lindóia, v.4, p.99-111.
Espíndola, E.L.G., Rocha, O., Rietzler, A., Calijuri, M.C., Matsumura –Tundisi, T., Tundisi, J.G. & Barbosa, F.A.R 1999. Limnologia comparada dos reservatórios em cascata do Médio Tietê (SP): uma análise temporal. In: Cadernos de Resumos do VII Congresso Brasileiro de Limnologia. UFSC, Florianópolis, v.1, p.233.
Espíndola, E.L.G., Rodgher, S., Fracácio, R., Da Costa, J.B. & Rocha, O. 2002. A abordagem ecotoxicológica nos reservatórios do Médio e Baixo Tietê, São Paulo, Brasil. In: Matsui, S. (ed.). Diretrizes para o Gerenciamento de Lagos. ILEC/ IIE, São Carlos. 199p.
Esteves, F.A., Ferreira, J.R., Pessenda, L.C.R. & Mortatti, J. 1981. Análises preliminares sobre o teor e a distribuição de metais em sedimentos de represas do Estado de São Paulo. In: Anais do II Seminário Regional de Ecologia. UFSCar, São Carlos, p.323-342.
Fonseca, A.L. 1997. Avaliação da qualidade da água na Bacia do Rio Piracicaba através de testes de toxicidade com invertebrados. São Carlos, USP, 211p (Tese).
Hook, S.E. & Fisher, N.S. 2001. Sublethal effcts of silver in zooplankton: importance of exposure pathways and implications for toxicity testing. Environ. Toxicol. Chem., 20: 568-574.
Ingerssol, C.G. 1995. Sediment test. In: Rand, G.M. (ed.) Fundamentals of aquatic toxicology: effects, environmental fate, and risk assessment. Taylor & Francis, Washington. 970p.
Ingerssol, C.G. & Winner, R.W. 1982. Effect on Daphnia pulex of daily pulse exposure to copper or cadmium. Environ. Toxicol. Chem., 1:321-327.
Kohlepp, G. 1999. Grandes barragens no Brasil: problemas ecológicos e sócio-econômicos. Rev. Estud. Ambient., 1:50–61.
Margalef, R. 1983. Limnologia. Omega S, Barcelona. 1010p.
Printes, L.B 1996. Biomonitoramento de Ambientes Aquáticos da Microrregião Carbonífera do Baixo Jacuí RS, através de Testes de Toxicidade com Cladoceros e Implementação de Cultivos e Definição de Faixa de Sensibilidade de Hyalella azteca (Crustacea: Amphipoda) ao Cloreto de Sódio (NaCl). Rio Grande do Sul, UFRG, 251p (Dissertação).
Rand, G.M., Wells, P.G. & McCarty, L.S 1995. Introduction to Aquatic Toxicology. In: Rand, G.M.(ed.) Fundamentals of aquatic toxicology: effects, environmental fate, and risk assessment. Taylor & Francis, Washington. 970p.
São Paulo (Estado). 1982. Coordenadoria da Indústria e do Comércio. Diretrizes para a Política de Desenvolvimento e Desconcentração Industrial. Governo do Estado de São Paulo. São Paulo. 133p.
Straskraba, M. 1994. Vltava cascade as teaching grounds for reservoir limnology. Water. Sci. Technol., 30:289-297.
Straskraba, M. & Tundisi, J.G. 1999. Reservoir water quality management.International Lake Environment Committee Foundation, Kusatsu. 229p. (Guidelines of Lakes Management, 9).
Tessier, A. & Campbell, P.G.C. 1987. Partitioning of trace metals in sediments: Relationships with bioavailability., Ecological Effects of In Situ Sediment Contaminants. Hydrobiologia, 149:43-51.
Tundisi, J.G. 2000. Gerenciamento de Reservatórios. In: Jorgensen, S.E. & Vollenweider, R.A. (ed.) Princípios para o gerenciamento de lagos. Trad. Dino Vannuci. ILEC/IIE/UNEP, São Carlos. 162p.
Tundisi, J.G., Matsumura-Tundisi , T. & Rocha, O. 1999. Limnologia de Águas Interiores. Impactos, Conservação e Recuperação de Ecossistemas Aquáticos. In: Rebouças, A.C., Braga, B. & Tundisi, J.G. (orgs.) Águas doces no Brasil: capital ecológico, uso e conservação. Escrituras, São Paulo. 760p.

Tundisi, J.G., Matsumura –Tundisi, T., Calijuri, M.C. & Novo, E.M.L 1991. Comparative limnology of five reservoirs in the middle Tietê River, S. Paulo State. Verh. Int. Verein. Limnol., 24:1489–1496.

Zagatto, P.A. 1999. Mini – curso: ecotoxicologia aquática. In: Apostila do VII Congresso Brasileiro de Limnologia. UFSC, Santa Catarina. 30p.

Received: 19 March 2003
Accepted: 05 September 2003