# Spatial distribution and secondary production of Copepoda in a tropical reservoir: Barra Bonita, SP, Brazil

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(With 7 figures)

## Abstract

The present paper aims to describe the spatial distribution of zooplankton copepods, their biomass and instantaneous secondary production, in Barra Bonita, a large eutrophic, polymitic reservoir (22° 29' S and 48° 34' W) on the Tietê River, of the Paraná basin. Sampling was carried out during two seasons: dry winter and rainy summer. Species composition, age structure and numerical density of each copepod species population were analyzed at 25 sampling stations. Secondary production was calculated for Copepoda, the dominant group in zooplankton communities, taking Calanoida and Cyclopoida separately. Copepoda represented the largest portion of the total zooplankton biomass, the dominant species being *Notodiaptomus iheringi* among the Calanoida and *Mesocyclops ogunnus* and *Thermocyclops decipiens* among the Cyclopoida. The production of Copepoda was higher during the rainy summer (23.61 $mgDW.m^{-3}.d^{-1}$ in January 1995) than during the dry winter season (14 $mgDW.m^{-3}.d^{-1}$ in August 1995), following the general pattern of abundance for the whole zooplankton community. Among the copepods, Cyclopoida production was higher than that of Calanoida, a pattern commonly observed for tropical lakes and reservoirs. Barra Bonita copepods are very productive, but there was a great degree of spatial heterogeneity, related to the physical and chemical conditions, particularly the level of nutrients and also to phytoplankton biomass.

*Keywords:* reservoir ecology, Copepoda production, tropical reservoir, zooplankton distribution.

## Distribuição espacial e produção secundária de Copepoda em um reservatório tropical em Barra Bonita, SP, Brasil

## Resumo

O presente estudo visou avaliar a distribuição espacial e quantificar a biomassa e a produção secundária de copépodos em Barra Bonita, um reservatório eutrófico e polimítico (22° 29' S e 48° 34' W) no rio Tietê, bacia do rio Paraná. As amostragens foram realizadas em duas estações do ano: inverno seco e verão chuvoso. A composição de espécies, a estrutura etária e a densidade numérica de cada população foram analisadas em 25 estações de amostragem. A produção secundária foi calculada para Copepoda, o grupo dominante na comunidade zooplanctônica, considerando Calanoida e Cyclopoida separadamente. Copepoda representou a maior porção da biomassa do zooplâncton total, sendo *Notodiaptomus iheringi* a espécie dominante entre os Calanoida e *Mesocyclops ogunnus* e *Thermocyclops decipiens* entre os Cyclopoida. A produção de Copepoda foi maior no verão chuvoso (23,61 $mgPSm^{-3}.d^{-1}$ em janeiro de 1995), comparada àquela registrada no período de inverno e seca (14 $mgPSm^{-3}.d^{-1}$ em agosto de 1995), seguindo o padrão geral da abundância de toda a comunidade zooplanctônica. Entre os copépodos, a produção de Cyclopoida foi mais alta que a de Calanoida, um padrão normalmente observado para lagos e reservatórios tropicais. Os Copépodos do reservatório de Barra Bonita foram muito produtivos, mas houve uma grande heterogeneidade espacial, relacionada a condições físicas e químicas, particularmente nutrientes e a biomassa fitoplanctônica na porção superior do reservatório.

*Palavras-chave:* ecologia de reservatórios, produção de Copepoda, reservatórios tropicais, distribuição do zooplâncton.

## 1. Introduction

The secondary production of a system corresponds to the production of organic matter by the heterotrophic organisms, that can be quantified by measuring the increase in biomass resulting from the assimilation of food per unit of time (Edmondson and Winberg, 1971). Secondary production also represents the main via for the flux of materials and energy through the food chains and the process by which populations maintain themselves.

In tropical regions research on secondary production of plankton is still incipient comparing to the amount of information that has been produced in temperate regions. For freshwater copepods most tropical studies refer to the production of dominant species only. In Brazil, these studies began with Rocha and Matsumura-Tundisi (1984), which determined the biomass and production of *Argyrodiaptomus furcatus*, the most abundant copepod in the oligotrophic Broa Reservoir. Recently, Melão and Rocha (2004) quantified the production of dominant cyclopoid species in Lagoa Dourada, a small oligotrophic reservoir in Southeast Brazil, during both summer and winter of 1995. Also, Rietzler et al. (2004) provided data on Copepoda production in a study of the hypereutrophic Salto Grande reservoir.

A large amount of limnological studies have already been carried out in Barra Bonita Reservoir (Tundisi and Matsumura-Tundisi, 1986; Tundisi, 1981, 1983; Matsumura-Tundisi et al., 1981; and Tundisi et al., 1988), and therefore information on secondary production will be relevant. In the current study, the species composition, numerical abundance and biomass of the zooplankton community were inventoried on two dates representing contrasting climatic conditions, namely dry and rainy seasons, with the aim of establishing patterns of spatial distribution of zooplankton, and of measuring the instantaneous rates of production for the main species of Copepoda, the most representative component of the plankton in Barra Bonita Reservoir.

### *1.1. Study area*

Barra Bonita Reservoir was constructed on the Tietê River with the aim of generating electricity, but is now used also for other purposes, including transport, irrigation, aquaculture, recreation and potable water supply. It is the first in a cascade of six reservoirs built in the middle and low portions of the river (22° 29' S and 48° 34 W), being at an altitude of 430 m. The reservoir has a surface area of 32,484 ha, a volume of $3.6 \times 10^9$ m$^3$, a maximum depth of 29 m (Tundisi, 1990). Among the six reservoirs it is the most productive and commercially exploited (CESP, 1998).

The climate is a transition between tropical and subtropical, with well-defined rainy and dry seasons. The predominant vegetation cover in the area is a monoculture of sugar cane. Organic and industrial wastes flow into the reservoir from the Tietê and Piracicaba rivers, as well as large amounts of agricultural fertilizers and pesticides from the surrounding agricultural fields. As a consequence, Barra Bonita reservoir is highly eutrophic and polluted.

## 2. Materials and Methods

Sampling was carried out at 25 fixed stations distributed as follows: 2 stations in the affluent Tietê River arm, 2 stations in the Piracicaba River arm, and 21 in the central body of the reservoir (Figure 1). Among the latter, 7 were located in the centre, 7 near the left band, and 7 near the

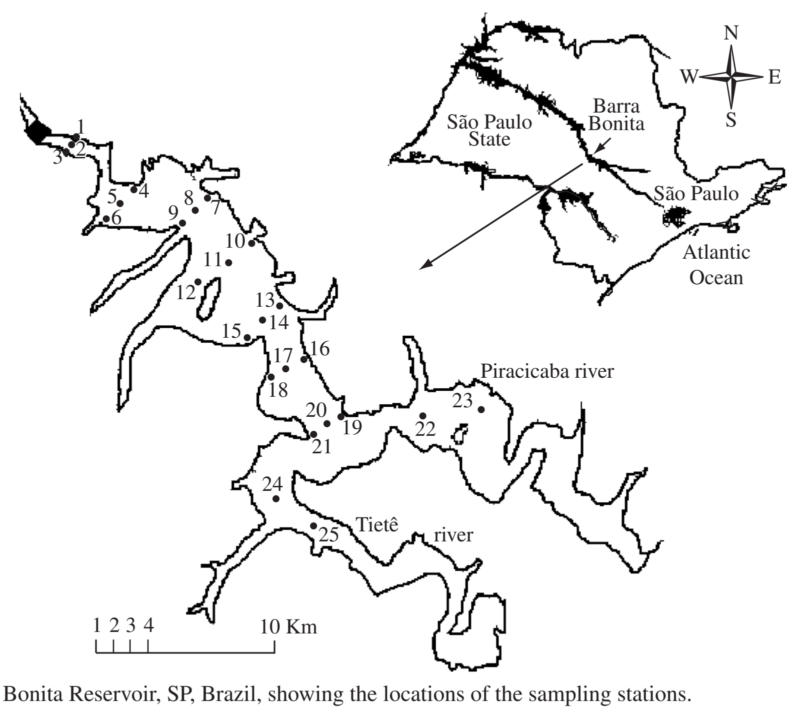


**Figure 1.** Barra Bonita Reservoir, SP, Brazil, showing the locations of the sampling stations.

right. Sampling was carried out during January 27th-28th and August 20th-21st, 1995. These dates were chosen to represent the rainy and dry seasons, respectively.

At each sampling station, zooplankton was sampled by filtering 200 L of water with a suction pump (Sthill P-835), taken from the entire the water column. The water was filtered in a zooplankton net 68 µm mesh and the concentrated material was preserved in 4% formaldehyde with added sucrose. Qualitative and quantitative analyses were carried out with a stereomicroscope, at magnification 100x, and a compound microscope, with camera lucida, at magnifications up to 600x. The main references employed were Edmondson (1959), Rocha and Matsumura-Tundisi (1976), Matsumura-Tundisi (1986), Reid (1985), Dussart and Defaye (1995) and Matsumura-Tundisi and Silva (2002). For Copepod enumeration, the nauplius, copepodid and adult stages of Calanoida and Cyclopoida were counted separately. Adults were identified at species level. Counts were carried out in acrylic chambers, under stereomicroscope, at a magnification of 50x.

Dry weights of individual copepod species were those supplied by Rietzler (unpublished data), as presented in Table 1. Development times adopted were those determined by Rietzler (1995) for cyclopoids, and by Espíndola (1994) for calanoids (Table 2). The biomass increment method of Winberg et al. (1965) was used to calculate secondary production, considering different developmental stages (nauplii, copepodids and adults) and mean values for development times and biomass for each stage.

## 3. Results

The values obtained for physical and chemical variables measured in Barra Bonita reservoir are presented in Table 3 for both sampling periods. Concentrations of nitrate were higher in August, varying from 706.7 to 1714.6 $\mu g.L^{-1}$ In January concentrations varied from 412.7 to 705.8 $\mu g.L^{-1}$ In relation to the spatial distribution of nutrients the highest nitrate concentrations occurred in August in the middle and lower portion of the reservoir whereas the highest values of total phosphorus (115 $\mu g.L^{-1}$) occurred in January in the upper portion of the reservoir (stations 23 to 25). Dissolved oxygen concentrations varied between 2.1 and 8.0 $mg.L^{-1}$, with lowest values in the upper portion of the reservoir in the Tietê arm. A similar pattern was observed for conductivity, and values varied between 102.6 and 280.8 $\mu S.cm^{-1}$, the highest values also occurring in the Tietê arm of the reservoir. The pH varied widely from 6.5 to 8.3, but data include diurnal cycle variation, since sampling lasted a whole day in order to cover all 25 stations.

Mean water residence time of Barra Bonita Reservoir in the period was 54.1 days in January and 119.4 days in August.

Species of calanoid copepods occurring in Barra Bonita Reservoir were *Notodiaptomus iheringi* and *Notodiaptomus* sp., among cyclopoids there were *Mesocyclops meridianus*, *Mesocyclops ogunnus*, *Mesocyclops longisetus*, *Metacyclops mendocinus*, *Thermocyclops decipiens* and *Thermocyclops minutus*. The species *Mesocyclops longisetus*, *Mesocyclops meridianus* and *Metacyclops mendocinus* occurred in very low densities, and were found only at a few sampling stations. Despite earlier records of *M. kieferi* and of *M. brasilianus* in this reservoir, recent work on Cyclopoida taxonomy have evidenced that those species actually corresponded respectively to *M. ogunnus* and *M. meridianus* (Matsumura-Tundisi and Silva, 2002; Silva, 2003).

Concerning population densities, it can be observed that spatial distribution is heterogeneous, with highest abundances occurring at stations in the Tietê River arm (24 and 25) in both sampling periods (Figures 2 and 3). At most stations sampled the highest abundance was found during the dry season. High abundances were also found at station 21 (dry season) and station 19 (rainy sea-

**Table 1.** Mean dry weight values (µgDW) for the main stages of Copepoda Cyclopoida and Calanoida from Barra Bonita reservoir. Means were computed for the dominant species (source, Rietzler, unpublished results).

| | Egg | Nauplii | Cop. I | Cop. Iv | Cop. Vi |
|---|---|---|---|---|---|
| Cyclopoid | 0.013 | 0.044 | 0.424 | 2.790 | 4.615 |
| Calanoid | 0.109 | 0.570 | 0.770 | 3.400 | 7.760 |

**Table 2.** Duration of embryonic and post-embryonic development time for Copepod (days). Mean for the dominant species from Espíndola (1994) and Rietzler (1995).

| | Cyclopoid | | Calanoid | |
|---|---|---|---|---|
| | 23 °C | 28 °C | 23 °C | 28 °C |
| Egg | 1.27 | 0.98 | 1.58 | 1.11 |
| Nauplii | 7.20 | 3.77 | 4.34 | 2.38 |
| Cop. I-iv | 3.07 | 1.96 | 6.71 | 3.86 |
| Cop. Iv-vi | 2.04 | 1.30 | 3.86 | 1.60 |

**Table 3.** Physical and chemical variables in the Barra Bonita Reservoir (SP, Brazil), January 27th - 28th, 1995 (J) and August 20th - 21st, 1995 (A). TDP = Total Dissolved Phosphate, DO = Dissolved Oxygen.

| Stations | Nitrate ($\mu g.L^{-1}$) | | TDP ($\mu g.L^{-1}$) | | Temp. (°C) | | D.O. ($mg.L^{-1}$) | | Cond. ($\mu S.cm^{-1}$) | | pH | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | A | J | A | J | A | J | A | J | A | J | A |
| 1 | 702.4 | 164.2 | 40.2 | 8.3 | 27.9 | 20.2 | 7.7 | 6.8 | 165.3 | 191.7 | 8.2 | 7.0 |
| 2 | 662.7 | - | 46.4 | - | 27.3 | 20.1 | 3.4 | 6.9 | 169.0 | 192.4 | 7.1 | 6.9 |
| 3 | 684.4 | 1624.9 | 47.6 | 8.1 | 27.5 | 20.5 | 4.9 | 7.8 | 162.9 | 190.8 | 7.4 | 7.1 |
| 4 | 705.5 | 1588.7 | 46.4 | 8.6 | 27.5 | 20.2 | 4.8 | 6.7 | 167.8 | 193.4 | 7.1 | 7.0 |
| 5 | 683.8 | 1662.6 | 46.1 | 8.8 | 27.2 | 20.3 | 3.3 | 6.8 | 155.7 | 193.4 | 6.6 | 7.0 |
| 6 | 704.2 | 1705.1 | 45.7 | 8.3 | 27.3 | 20.3 | 4.3 | 6.8 | 163.8 | 193.4 | 7.3 | 6.9 |
| 7 | 702.7 | 1556.4 | 56.0 | 7.4 | 27.5 | 20.0 | 4.1 | 5.8 | 161.6 | 195.0 | 7.1 | 6.9 |
| 8 | 678.2 | 1569.8 | 54.9 | 8.8 | 28.2 | 20.2 | 7.3 | 5.6 | 154.6 | 198.5 | 8.2 | 6.9 |
| 9 | 681.0 | 1571.3 | 44.3 | 9.3 | 28.0 | 20.6 | 8.0 | 6.9 | 156.9 | 194.8 | 8.3 | 7.0 |
| 10 | 692.6 | 1714.6 | 48.2 | 8.2 | 27.8 | 19.9 | 5.1 | 5.2 | 149.4 | 197.4 | 7.1 | 6.8 |
| 11 | 689.3 | 1645.3 | 53.4 | 8.5 | 27.8 | 19.9 | 5.2 | 5.1 | 141.3 | 198.5 | 7.2 | 6.8 |
| 12 | 692.6 | 1686.2 | 47.5 | 11.0 | 27.8 | 20.5 | 5.2 | 6.8 | 159.2 | 192.4 | 7.7 | 7.0 |
| 13 | 696.0 | 1720.9 | 51.4 | 9.9 | 28.2 | 19.6 | 6.1 | 4.7 | 143.8 | 198.6 | 7.2 | 6.8 |
| 14 | 668.1 | 1570.6 | 56.0 | 8.8 | 27.8 | 19.6 | 4.5 | 4.5 | 150.9 | 198.9 | 7.6 | 6.7 |
| 15 | 691.1 | 1580.0 | 51.2 | 8.6 | 27.8 | 20.2 | 4.6 | 6.7 | 152.3 | 198.0 | 7.3 | 7.0 |
| 16 | 589.3 | 1604.4 | 50.7 | 7.9 | 28.2 | 19.5 | 5.6 | 4.2 | 126.7 | 198.1 | 7.4 | 6.8 |
| 17 | 612.7 | 1664.2 | 64.5 | 8.1 | 28.1 | 19.4 | 5.5 | 4.0 | 142.2 | 198.5 | 7.1 | 6.6 |
| 18 | 643.9 | 1415.5 | 54.0 | 9.1 | 28.1 | 20.3 | 4.9 | 6.8 | 146.8 | 200.5 | 7.7 | 7.2 |
| 19 | 644.7 | 1458.0 | 57.7 | 9.5 | 28.4 | 20.2 | 5.9 | 4.1 | 149.8 | 192.7 | 7.2 | 6.8 |
| 20 | 555.8 | 1237.6 | 54.9 | 10.1 | 27.9 | 20.0 | 4.8 | 4.5 | 142.5 | 200.8 | 7.4 | 6.8 |
| 21 | 516.6 | 1179.4 | 67.8 | 11.9 | 27.9 | 20.1 | 4.4 | 4.7 | 141.7 | 211.1 | 7.7 | 6.9 |
| 22 | 602.9 | 1210.1 | 59.1 | 10.8 | 27.6 | 19.7 | 5.9 | 7.3 | 111.9 | 187.1 | 7.2 | 6.7 |
| 23 | 412.7 | 706.7 | 57.3 | 16.7 | 28.3 | 20.0 | 6.7 | 6.1 | 102.6 | 153.3 | 7.4 | 6.9 |
| 24 | 682.6 | 802.2 | 105.6 | 32.3 | 28.2 | 19.6 | 2.1 | 2.3 | 169.2 | 271.1 | 6.5 | 6.8 |
| 25 | 705.8 | 734.7 | 115.9 | 42.4 | 28.4 | 19.8 | 2.7 | 3.4 | 158.3 | 280.8 | 6.5 | 6.9 |

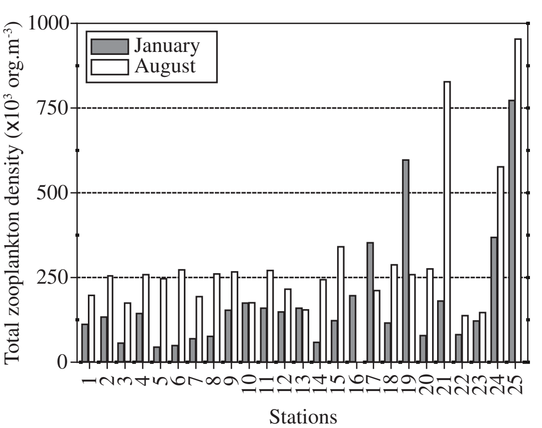


**Figure 2.** Total zooplankton density ($x10^3$ $org.m^{-3}$) in the Barra Bonita Reservoir (SP, Brazil), collected on January 27th-28th, 1995 and August 20th-21st, 1995.

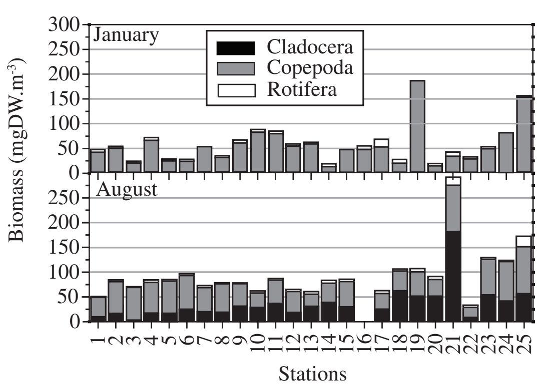


**Figure 3.** Biomass Values to Cladocera, Copepoda and Rotifera ($mgDW.m^{-3}$) in the Barra Bonita Reservoir (SP, Brazil), collected on January 27th-28th, 1995 and August 20th-2st, 1995.

son) in the upper part of the reservoir, at the confluence of rivers Tietê and Piracicaba.

Cyclopoids were more numerous than calanoids, with the greatest proportion being nauplii. Among Calanoida, the species *Notodiaptomus iheringi* was dominant, whereas among Cyclopoida the species *Mesocylops ogunnus* was the most numerous, followed by *Thermocyclops decipiens* (Figures 4 and 5 and Tables 4 and 5).

The greatest instantaneous production was obtained in the survey performed during the rainy period, being highest at stations 19, 24 and 25 (Figures 6 and 7). Cyclopoid production was greater than that of calanoids, in both periods. The highest values found for Calanoida production was 23.67 $mgDW.m^{-3}.d^{-1}$ at station 19, during the rainy period. With regard to the different stages, the greatest contribution to Calanoida production in January was made by copepodid' IV (mean value of 4.01 $mgDw.m^{-3}.d^{-1}$), whereas in general the greatest contribution was that of nauplii (mean value of 9.22 $mgDW.m^{-3}.d^{-1}$). For the survey performed in the dry period, the copepodids (I to IV) contributed most to Cyclopoida production, with a mean value of 6.57 $mgDW.m^{-3}.d^{-1}$, as well as to that of Calanoida, with a mean value of 1.04 $mgDW.m^{-3}.d^{-1}$, for the whole reservoir.

Overall, copepods were found to have total instantaneous production of 23.61 $mgDW.m^{-3}.d^{-1}$ in January 1995 (rainy period) and 14.0 $mgDW.m^{-3}.d^{-1}$ in August 1995 (dry period).

## 4. Discussion

Barra Bonita Reservoir is eutrophic with a polymitic circulation pattern (De Filippo, 1987, Tundisi et al, 1988 and Aranha, 1990). The species recorded in the present study were those already recorded in this reservoir (Fonseca, 1990; Espíndola, 1994; Tundisi and Matsumura-Tundisi, 1994 and Rietzler, 1995), although some species previously recorded by other authors were not found in the present study, due to the restricted sampling.

Copepods are the most abundant zooplankton group in Barra Bonita Reservoir, according to the current results, corroborating previous observations. This might be a consequence of the long residence times of Barra Bonita Reservoir favoring species with relatively long development times such as the copepods. The species *Mesocyclops ogunnus* (Matsumura-Tundisi and Silva, 2002) and *Thermocyclops decipiens* were the same species previously found as dominant in Barra Bonita Reservoir by Rietzler (1995) during a study carried out between January 1992 and December 1993. On the other hand, Fonseca (1990) did not record two of the species which were abundant in the present study as *Mesocyclops ogunnus* and *Thermocyclops minutus* in samples collected daily in the period 10th to 24th March 1988, thus suggesting that some species might not always be present. *Metacylops mendocinus* and *Thermocyclops decipiens* occur preferentially in highly productive environments (Sendacz et al., 1985).

Espíndola (1994) found four species of *Notodiaptomus*, namely *Notodiaptomus iheringi, Notodiaptomus cearensis*, *Notodiaptomus conifer* and *Notodiaptomus* nsp., during a two-year study of population dynamics of Copepoda Calanoida in Barra Bonita Reservoir. Looking back at samples collected in that

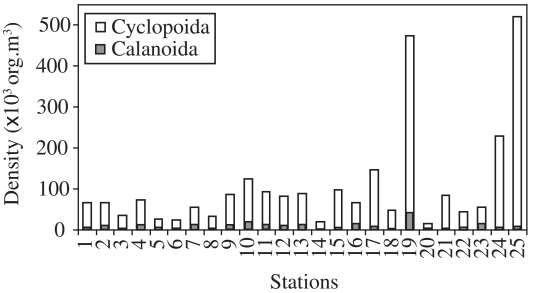


**Figure 4.** Numerical density of Copepoda groups on January, 27th-28th, 1995 (rainy period) at Barra Bonita reservoir, SP, Brazil.

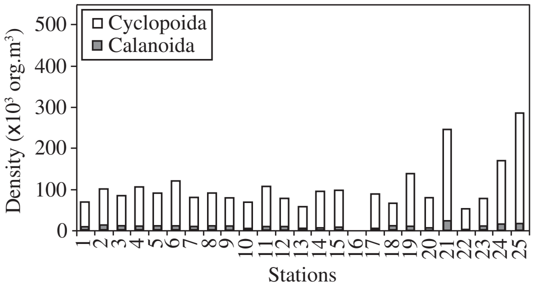


**Figure 5.** Numerical density of Copepoda groups in August, 20th-21st, 1995 (dry period) at Barra Bonita reservoir, SP, Brazil.

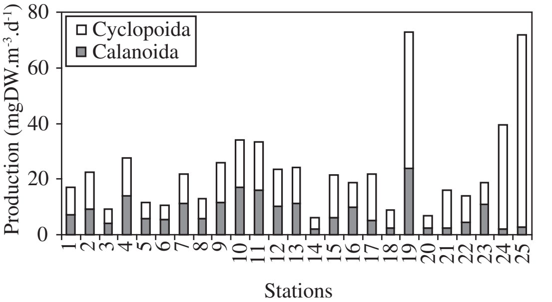


**Figure 6.** Production of Cyclopoida and Calanoida copepods on January, 27th-28th, 1995 (rainy period) at Barra Bonita reservoir, SP, Brazil.

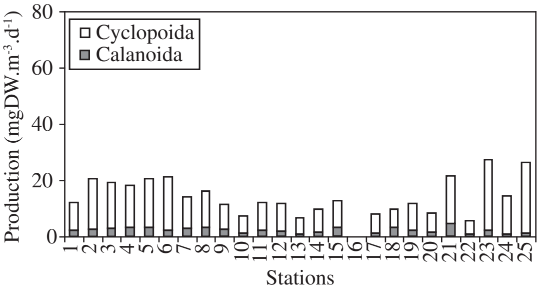


**Figure 7.** Production of Cyclopoida and Calanoida copepods on, August, 20th-21st, 1995 (dry period) at Barra Bonita reservoir, SP, Brazil.

**Table 4.** Numerical density of Copepoda groups (org.m$^{-3}$) on January, 27$^{th}$-28$^{th}$, 1995 (rainy period) at Barra Bonita Reservoir. Cop. = Copepodid.

| Species/Stations | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | P11 | P12 | P13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CYCLOPOIDA** | | | | | | | | | | | | | |
| *Mesocyclops kieferi* | 144 | 84 | 79 | 127 | | 83 | 425 | 244 | 187 | 224 | 604 | 87 | 592 |
| *M. meridianus* | - | - | - | - | - | - | 23 | - | - | - | - | - | - |
| *M. longisetus* | - | - | - | - | - | - | 17 | - | - | - | - | - | - |
| Cop. 1 *Mesocyclops* | 288 | 3196 | 165 | 2508 | 1280 | 854 | 2552 | 1613 | 1520 | 2016 | 2493 | 1907 | 1184 |
| Cop. 2 *Mesocyclops* | 180 | 752 | 579 | 456 | 480 | 110 | 696 | 440 | 400 | 504 | 189 | 953 | 789 |
| Cop. 3 *Mesocyclops* | 108 | 627 | - | 76 | 320 | - | 232 | 83 | 80 | - | 189 | 173 | 296 |
| Cop. 4 *Mesocyclops* | 36 | - | 33 | - | - | - | - | - | - | 504 | 38 | - | 296 |
| *M. mendocinus* | - | 21 | - | - | - | - | - | - | - | - | - | - | - |
| Cop. 3 *M. men.* | 36 | 188 | 83 | - | - | - | - | - | - | - | - | - | - |
| *Thermocyclops decipiens* | 180 | 188 | 94 | 127 | 107 | 386 | 398 | 73 | 320 | 840 | 604 | 693 | 102 |
| *T. minutus* | 21 | - | 83 | 25 | 53 | - | 33 | 24 | 53 | 168 | 38 | 87 | - |
| Cop. 1 *Thermocyclops* | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Cop. 2 *Thermocyclops* | - | - | - | - | - | - | - | - | 80 | - | 340 | 87 | - |
| Cop. 3 *Thermocyclops* | - | 188 | 28 | 76 | 320 | 83 | - | - | 160 | 336 | - | 173 | - |
| Cop. 4 *Thermocyclops* | 21 | - | - | - | - | - | - | - | 80 | - | - | - | - |
| Nauplii | - | 49444 | 30008 | 53580 | 16640 | 17939 | 37584 | 23760 | 69120 | 97524 | 73440 | 65000 | 69856 |
| Eggs | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **CALANOIDA** | | | | | | | | | | | | | |
| *N. iheringhi* | 2160 | 1692 | 772 | 3040 | 1920 | 1378 | 1740 | 23760 | 3120 | 3080 | 4458 | 2427 | 1875 |
| *Notodiaptomus* sp. | 72 | 42 | 24 | 152 | - | 28 | 93 | 44 | 133 | 84 | 76 | 29 | 197 |
| Cop. 1 *Notodiaptomus* | - | 1128 | 1240 | 2888 | 1280 | 827 | 4292 | 2713 | 480 | 6636 | 4987 | 3900 | 1184 |
| Cop. 2 *Notodiaptomus* | - | 1128 | 909 | 2736 | 800 | 882 | 2436 | 1540 | 1440 | 3108 | 529 | 867 | 4144 |
| Cop. 3 *Notodiaptomus* | 720 | 2632 | 496 | 1368 | 1120 | 441 | 696 | 440 | 400 | 3276 | 302 | 87 | 1480 |
| Cop. 4 *Notodiaptomus* | 432 | 1253 | 138 | 380 | 480 | 83 | 1044 | 660 | 720 | 1344 | 604 | 1040 | 592 |
| Nauplii | - | 2444 | 992 | 2052 | 1920 | 661 | 3248 | 2053 | 6720 | 2940 | 2380 | 3120 | 4144 |
| Eggs | 576 | 188 | - | 76 | - | 28 | 232 | - | - | 252 | - | 173 | 296 |

**Table 4.** Continued...

| Species/Stations | P14 | P15 | P16 | P17 | P18 | P19 | P20 | P21 | P22 | P23 | P24 | P25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CYCLOPOIDA** | | | | | | | | | | | | |
| *Mesocyclops kieferi* | 85 | 352 | 444 | 848 | 71 | 4080 | 387 | 1568 | 352 | 320 | 736 | 1980 |
| *M. meridianus* | - | - | - | - | - | - | - | - | - | - | - | - |
| *M. longisetus* | 57 | - | - | - | - | - | - | - | - | - | 184 | 73 |
| Cop. 1 *Mesocyclops* | 228 | 1848 | 1067 | 664 | 568 | 6120 | 1226 | 3136 | 3432 | 1200 | 5459 | 5720 |
| Cop. 2 *Mesocyclops* | 427 | 264 | 467 | 627 | - | 3876 | 423 | 653 | 880 | 400 | 4109 | 1540 |
| Cop. 3 *Mesocyclops* | - | 352 | 333 | 184 | - | 4692 | 364 | 196 | 176 | 160 | 859 | 807 |
| Cop. 4 *Mesocyclops* | - | - | - | 184 | 36 | 748 | 114 | 131 | 88 | 160 | 368 | 880 |
| *M. mendocinus* | - | - | - | - | - | - | 46 | - | - | 80 | - | 440 |
| Cop. 3 *M. men.* | - | - | - | - | - | - | - | - | - | - | 184 | - |
| *Thermocyclops decipiens* | 28 | 1584 | 178 | 1180 | 142 | 2720 | 387 | 719 | 352 | 80 | 859 | 4253 |
| *T. minutus* | - | - | - | 443 | 11 | 204 | 182 | 131 | 117 | 240 | 184 | 733 |
| Cop. 1 *Thermocyclops* | - | - | - | - | - | - | 296 | - | - | - | 61 | - |
| Cop. 2 *Thermocyclops* | 512 | - | - | 74 | - | - | - | 131 | 264 | - | 245 | 147 |
| Cop. 3 *Thermocyclops* | 256 | 1085 | 133 | 184 | 284 | 612 | 150 | 261 | 117 | 160 | 1349 | 1100 |
| Cop. 4 *Thermocyclops* | - | 88 | - | 37 | - | - | - | 196 | - | - | 429 | 220 |
| Nauplii | 15104 | 88176 | 49800 | 135456 | 43310 | 428196 | 9091 | 76244 | 32208 | 36960 | 209944 | 495880 |
| Eggs | 256 | 1056 | - | - | - | - | 592 | - | - | - | - | 147 |
| **CALANOIDA** | | | | | | | | | | | | |
| *N. iheringhi* | 455 | 1320 | 1489 | 885 | 284 | 2788 | 501 | 327 | 557 | 2053 | 184 | 244 |
| *Notodiaptomus* sp. | 28 | - | - | - | 142 | 272 | - | 65 | - | - | - | - |
| Cop. 1 *Notodiaptomus* | 427 | 2288 | 6800 | 2545 | 426 | 11016 | 677 | 915 | 2200 | 5280 | 736 | 293 |
| Cop. 2 *Notodiaptomus* | 427 | 792 | 1000 | 1107 | 142 | 7140 | 296 | 261 | 1408 | 2560 | 184 | 73 |
| Cop. 3 *Notodiaptomus* | 171 | 352 | 667 | 480 | - | 3060 | 296 | 392 | 235 | 720 | 184 | - |
| Cop. 4 *Notodiaptomus* | 171 | 176 | 822 | 332 | 284 | 1496 | 433 | 392 | 352 | 1520 | 184 | 73 |
| Nauplii | 427 | 792 | 4000 | 3320 | 1278 | 15708 | 1776 | 2156 | 2728 | 3600 | 5520 | 5060 |
| Eggs | 256 | 528 | - | - | - | 42 | 23 | 27 | 88 | - | - | - |

**Table 5.** Numerical density of Copepoda groups (org.m$^{-3}$) on August, 20$^{th}$-21$^{st}$, 1995 (dry period) at Barra Bonita reservoir. Cop.= Copepodids.

| Species/Stations | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | P11 | P12 | P13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CYCLOPOIDA** | | | | | | | | | | | | | |
| *Mesocyclops kieferi* | 625 | 2628 | 2141 | 1031 | 1225 | 726 | 997 | 1133 | 1140 | 368 | 384 | 248 | 208 |
| *M. meridianus* | - | - | - | - | - | - | - | - | 456 | - | - | - | - |
| *M. longisetus* | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Cop. 1 *Mesocyclops* | 2960 | 6424 | 6716 | 5568 | 8736 | 8520 | 4224 | 4800 | 1938 | 1104 | 1600 | 2893 | 1456 |
| Cop. 2 *Mesocyclops* | 1776 | 5548 | 3796 | 2629 | 1179 | 3408 | 1995 | 2267 | 1482 | 1227 | 1216 | 1405 | 1040 |
| Cop. 3 *Mesocyclops* | 888 | 2336 | 2336 | 1547 | 1317 | 3124 | 1173 | 1333 | 684 | 307 | 128 | 620 | - |
| Cop. 4 *Mesocyclops* | 592 | 292 | 876 | 309 | 69 | 189 | 235 | 267 | 570 | 20 | 384 | - | 23 |
| *M. mendocinus* | - | - | 65 | 52 | 23 | 284 | 176 | 200 | - | - | - | - | - |
| Cop. 3 *M. mendocinus* | - | - | - | - | - | 284 | - | - | - | 61 | - | - | - |
| *T. decipiens* | 1447 | 209 | 1071 | 1108 | 3282 | 663 | 411 | 467 | 1026 | 631 | 960 | 496 | 1525 |
| *T. minutus* | 0 | 876 | 195 | 206 | 624 | 95 | 117 | 133 | 570 | 102 | 192 | 83 | 416 |
| Cop. 1 *Term* | 592 | 83 | - | - | 624 | 568 | - | - | 342 | - | - | 41 | - |
| Cop. 2 *Term* | 592 | 42 | - | 387 | 416 | 568 | 293 | 333 | 570 | 552 | 768 | 744 | 485 |
| Cop. 3 *Term* | 395 | 125 | 1168 | 1856 | 2565 | 568 | 1408 | 1600 | 114 | 123 | 1216 | 1240 | 763 |
| Cop. 4 *Term* | 1184 | 125 | 487 | - | 69 | - | - | - | 798 | - | - | 331 | - |
| Nauplii | 47952 | 50516 | 52560 | 78648 | 62608 | 92584 | 59664 | 67800 | 62586 | 61088 | 91008 | 61256 | 49296 |
| Eggs | - | - | 876 | 696 | 277 | 568 | 528 | 600 | - | 123 | 1152 | - | - |
| **CALANOIDA** | | | | | | | | | | | | | |
| *N. iheringhi* | 395 | 417 | 1265 | 1284 | 1595 | 978 | 1115 | 1267 | 798 | 204 | 768 | 951 | 347 |
| *Notodiaptomus*. nsp | 33 | - | 97 | 206 | 763 | 221 | 117 | 133 | - | 20 | 128 | 83 | - |
| Cop. 1 *Notodiaptomus* | 2664 | 3504 | 584 | 2629 | 485 | 1420 | 1995 | 2267 | 2280 | 1901 | 2240 | 1364 | 1040 |
| Cop. 2 *Notodiaptomus* | 1480 | - | 681 | 928 | 555 | 95 | 704 | 800 | 1140 | 491 | 384 | 248 | 277 |
| Cop. 3 *Notodiaptomus* | 296 | 584 | 487 | 464 | 139 | 189 | 352 | 400 | - | 184 | 192 | 124 | 139 |
| Cop. 4 *Notodiaptomus* | 296 | - | - | 232 | 139 | - | 176 | 200 | 114 | 184 | - | 124 | 139 |
| Nauplii | 3848 | 7592 | 7300 | 6496 | 6656 | 7668 | 4928 | 5600 | 6612 | 2392 | 5184 | 5208 | 2288 |
| Eggs | - | - | 1233 | 62 | - | - | 59 | 67 | - | 184 | - | 124 | - |

**Table 5.** Continued...

| Species/Stations | P14 | P15 | P16 | P17 | P18 | P19 | P20 | P21 | P22 | P23 | P24 | P25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CYCLOPOIDA** | | | | | | | | | | | | |
| *Mesocyclops kieferi* | 360 | 588 | | 367 | 550 | 1543 | 587 | 1027 | 204 | 347 | | 2144 |
| *M. meridianus* | - | - | - | - | - | - | - | - | - | - | - | - |
| *M. longisetus* | - | - | - | - | - | - | - | - | - | - | - | - |
| Cop. 1 *Mesocyclops* | 1260 | 1241 | - | 733 | 1430 | 661 | 1100 | 1587 | 861 | 1560 | 5200 | 6700 |
| Cop. 2 *Mesocyclops* | 180 | 719 | - | 953 | 385 | 1157 | 147 | 653 | 408 | 693 | - | 4020 |
| Cop. 3 *Mesocyclops* | 180 | 457 | - | 147 | 330 | 992 | 147 | 280 | 68 | 289 | 260 | 268 |
| Cop. 4 *Mesocyclops* | - | 131 | - | - | 715 | - | - | 653 | 68 | 260 | - | - |
| *M. mendocinus* | - | 44 | - | 73 | 110 | 28 | 220 | 1493 | - | - | - | - |
| Cop. 3 *M. mendocinus* | - | - | - | - | - | - | 220 | 1960 | 204 | - | - | - |
| *T. decipiens* | 720 | 588 | - | 220 | 1155 | 4051 | 440 | 747 | 680 | 2947 | 260 | 1608 |
| *T. minutus* | 300 | 653 | - | 1100 | 147 | 3885 | 1540 | 2800 | 997 | 1127 | 1040 | 12596 |
| Cop. 1 *Term* | - | - | - | - | - | - | - | 560 | 68 | - | 780 | - |
| Cop. 2 *Term* | 60 | 719 | - | 147 | - | 165 | 440 | 933 | - | 520 | - | 1608 |
| Cop. 3 *Term* | 1800 | 1764 | - | 660 | 495 | 83 | 807 | 933 | 204 | 144 | 1040 | 2948 |
| Cop. 4 *Term* | 360 | 65 | - | - | 220 | 55 | 147 | 280 | v49 | 347 | 260 | 0 |
| Nauplii | 85140 | 80948 | - | 82060 | 49610 | 126976 | 71940 | 215880 | 49572 | 36920 | 148200 | 251116 |
| Eggs | - | 196 | - | 587 | 440 | 992 | 220 | 280 | 204 | 1820 | - | 268 |
| **CALANOIDA** | | | | | | | | | | | | |
| *N. iheringhi* | 600 | 1568 | - | 318 | 1045 | 496 | 660 | 1213 | 476 | 780 | - | - |
| *Notodiaptomus.* nsp. | - | 196 | - | 29 | 220 | - | 220 | - | - | - | - | - |
| Cop. 1 *Notodiaptomus* | 1260 | 1699 | - | 807 | 1540 | 2232 | 1100 | 5320 | 1020 | 1560 | 260 | 268 |
| Cop. 2 *Notodiaptomus* | 360 | 196 | - | 1100 | 880 | 1075 | 293 | 560 | 181 | 867 | 260 | 536 |
| Cop. 3 *Notodiaptomus* | 240 | 261 | - | 0 | 935 | 744 | - | 840 | 136 | 260 | - | - |
| Cop. 4 *Notodiaptomus* | 180 | 392 | - | 147 | 495 | 28 | - | - | 45 | 462 | 260 | - |
| Nauplii | 4140 | 5292 | - | 1833 | 5940 | 3968 | 3300 | 14560 | 635 | 6500 | 13780 | 17688 |
| Eggs | 180 | - | - | 147 | - | - | - | 1120 | - | 260 | - | 536 |

reservoir in past years and deposited at the Plankton Collection of the Federal University of São Carlos, the author recorded *Scolodiaptomus corderoi* in 1982 and 1984 and *Argyrodiaptomus furcatus* in 1986, 1988, 1992 and 1993, although in low densities. A new species of *Notodiaptomus* has appeared in Barra Bonita Reservoir since July 1992, starting in low numbers and progressively increasing throughout the year 1993 (Espíndola, 1994). This species was also recorded in the present study but in low densities, for both sampling periods. A characteristic of Calanoida copepods observed in these and also recorded in the previous work of Espíndola (1994) was the occurrence of nauplii in lower abundances than those of copepodids and adults, suggesting high mortality rates for this stage.

The dominant species among Calanoida was *Notodiaptomus iheringi*. This species seems well adapted to mesotrophic and eutrophic conditions, tolerating a high level of turbidity. Rietzler et al. (2002) observed that this species replaced *Argyrodiaptomus furcatus* in Broa (Lobo) Reservoir in 1988 as a result of the impact of turbid washing from riverbed sand-extraction discharged into the upper portion of the reservoir. Sendacz and Kubo (1982) also found *N. iheringi* to be dominant in Funil Reservoir, RJ, which has high levels of nutrients and chlorophyll *a*.

In Barra Bonita Reservoir, Calanoida contributed approximately one third to one fourth of the total Copepoda production. This pattern reflects the fact that in eutrophic systems, the food-chain changes from directly herbivorous to mainly detritic, due to changes in phytoplankton quality (switching dominance from Chlorophyceae to Cyanophyceae) which favour cyclopoids in detriment to calanoids (Tundisi et al., 1988).

A distinctive characteristic of reservoirs is the existence of horizontal gradients (Tundisi et al., 1986 and Tundisi et al., 1988) in chemical composition, material transport and community abundances, frequently along the main axis of the reservoir and also at the entrances of tributaries. Usually three distinct regions are observed: the river, the transition zone and the reservoir. In terms of copepod distribution, two regions could be discerned in Barra Bonita Reservoir: the upper portion formed by the inflowing Tietê and Piracicaba rivers, and the body of the reservoir. Usually the spatial heterogeneity of plankton communities can be related to environmental heterogeneity in physical and chemical features of the water column. Brondi (1994) recorded the highest abundance of algae in the dammed portions of the Tietê and Piracicaba rivers in Barra Bonita Reservoir, and suggested that this was related to the higher availability of phosphorus in that part of the reservoir.

In the present study, the spatial distribution of copepods in general matched this pattern, with greater density, biomass and production in the upper part of the reservoir, although the central part was also quite productive. No great variation was found between the samples taken on the left and right banks and the centre. Lowest copepod densities were found near the dam. In January, when greatest outflow and shortest retention time occurred, copepod densities were lowest, indicating washout via the overspill.

Normally the magnitude of secondary production is related to the trophic state of the system; eutrophic systems having higher secondary productivity than oligotrophic ones. In Lake Rhenosterkop (South Africa), secondary production was recorded to vary from 8 to 14.8 $gC.m^{-3}.y^{-1}$, being greater than in the oligotrophic Lake Le Roux (Hart et al., 1983 in Robarts et al., 1992), showing that eutrophic systems are more productive. Similarly, comparing the reservoirs of Barra Bonita, which is eutrophic, with the oligotrophic Lagoa Dourada Reservoir, both in Brazil, the production recorded in the present study was greater than that found in the latter. In Lagoa Dourada Reservoir the copepod production varied from 0.043 to 0.364 $mgDW.m^{-3}.d^{-1}$ in a Copepoda assemblage formed by cyclopoids alone (Melão and Rocha, 2004), whereas in the present study, mean production values were 8.08 $mgDW.m^{-3}.d^{-1}$ for Calanoida and 15.52 $mgDW.m^{-3}.d^{-1}$ for Cyclopoida. Of additional interest is the fact that Copepoda was the major group with regard to biomass in Barra Bonita Reservoir, whereas in Lagoa Dourada Reservoir, Cladocera was the most important. These values are nevertheless much lower than those found by Rietzler et al. (2004) in Salto Grande Reservoir. In this hypereutrophic system, mean values for Copepoda production were 46.2 $mgDWm^{-3}.d^{-1}$ in the summer and 53.55 $mgDW.m^{-3}.d^{-1}$ in the winter. Overall, with regard to Copepoda productivity, Barra Bonita Reservoir can be considered moderately productive, compared to other tropical reservoirs of distinct trophic state.

## 5. Conclusion

There is spatial variation in regarding Copepoda species density within Barra Bonita Reservoir. Two contrasting regions can be identified: one in the upper riverine portions of the Tietê and Piracicaba rivers and the other in the central body of the reservoir.

There were temporal differences regarding Copepoda species density in the period studied, the highest abundance of Copepoda being found during the dry winter period, a fact already observed by previous studies in the same reservoir.

Density and production of Cyclopoida are higher than those of Calanoida, in both dry and rainy seasons. *Mesocyclops ogunnus* and *Thermocyclops decipiens* were the most important species.

Copepoda secondary production at Barra Bonita Reservoir is similar to those found in other eutrophic water bodies such as Lake Okaro (Japan) and Lake George (Africa) and much higher than that recorded in the oligo-mesotrophic Lake Sybaya (South Africa). It is however much lower than that of hypereutrophic Salto Grande Reservoir (SP, Brazil).

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