Zoological Studies **43**(2): 179-186 (2004)

Zoological Studies

Temporal Variability and Production of the Planktonic Copepod Community in the Cananéia Lagoon Estuarine System, São Paulo, Brazil

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(Accepted January 6, 2004)

Koichi Ara (2004) Temporal variability and production of the planktonic copepod community in the Cananéia Lagoon estuarine system, São Paulo, Brazil. *Zoological Studies* **43**(2):179-186. Diel and seasonal variations in the abundance, biomass, and production rate of the planktonic copepod community were investigated in the Cananéia Lagoon estuarine system, a mangrove-surrounded estuary located near the southern border of São Paulo State, Brazil. On each sampling date, zooplankton samples were collected using a 150-μm-mesh plankton net at intervals of 4 h over multiple 24-h periods from February 1995 to January 1996. Copepods accounted for 68.1%~97.7% (with an annual mean of 84.8%) of the total zooplankton abundance. The copepod community consisted of 37 species; the dominant species were *Oithona hebes*, *O. oswaldocruzi*, *Acartia lilljeborgi*, *A. tonsa*, *Pseudodiaptomus acutus*, *Parvocalanus crassirostris*, *Euterpina acutifrons* and *Temora turbinata*. Copepod abundance, biomass, and production rates showed remarkable seasonal variations, being highest in January. Annual mean abundance, biomass, and estimated production rate, using the Hirst-Lampitt model, of copepodites and adults were $3.33 \times 10^4 \pm 1.76 \times 10^4$ individuals m^{-3}, 19.757 ± 9.776 mg C m^{-3} and 5.249 ± 3.055 mg C m^{-3} d^{-1} (mean ± SD), respectively. The daily mean P/B ratio was 0.20~0.38 d^{-1}. During the study period, the copepod community consisted mainly of the small-sized component: copepods with a total body length less than 1000 μm accounted for 75.1%~99.9% (with an annual mean of 93.1%) of the total copepod abundance. The median individual weight was 0.46~0.95 μg C (with an annual median of 0.63 μg C), and copepods weighing less than 1 μg C dominated the biomass and production rate, constituting 28.7%~68% (with an annual mean of 52.1%) and 43.3%~79.7% (with an annual mean of 66.1%) of the copepod community biomass and production rate, respectively. http://www.sinica.edu.tw/zool/zoolstud/43.2/179.pdf

Key words: Copepod community, Production, Cananéia Lagoon estuarine system, Brazil.

The Cananéia Lagoon estuarine system, located near the southern border of São Paulo State, Brazil, is a complex mangrove-surrounded estuary system (Fig. 1). This estuarine system has 110 km^2 of water area (with a maximum depth of 25 m in Trapandé Bay and a mean depth of 6.5 m) with a drainage basin that covers 1340 km^2. The estuary is connected with the South Atlantic Ocean by Cananéia Inlet in the south and by Icapara Inlet in the north. Water exchanges in this estuarine system are primarily due to inflow of offshore water by tidal currents and outflow of fresh water from several rivers (e.g., Por et al. 1984, Schaeffer-Novelli et al. 1990).

In aquatic ecosystems, copepods, usually the most important component of the mesozooplankton in terms of both abundance and biomass, serve as an important linkage, by transferring energy and organic materials between primary producers (phytoplankton) and animals of higher trophic levels such as planktivorous fish and carnivorous invertebrates. In addition, these small animals may play another important role supplying dissolved inorganic nutrients (N and P) to phytoplankton, since year-round high primary productivity has often been observed in the Cananéia

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Lagoon estuarine system where the water is poor in dissolved inorganic nutrients (Tundisi et al. 1973 1978, Braga 1995) but rich in particulate organic matter which originates from mangrove litter. This indicates that particulate organic matter is not retained for long within this estuarine system, but is transported out of the system by tidal currents, without either undergoing thorough bacterial decomposition or uptake by phytoplankton.

Studies on the planktonic copepods in the Cananéia Lagoon estuarine system have dealt with aspects of the population and/or community structure, spatial distribution and seasonal variations in abundance (Teixeira et al. 1965 1969, Matsumura-Tundisi 1972, Tundisi et al. 1973, 1978, Fonseca and Almeida Prado 1979, Almeida Prado-Por et al 1989). Recently, diel and seasonal variations in abundance, biomass, and estimated production rates in this estuarine system have been reported for some dominant copepod species such as *Acartia lilljeborgi* (Ara 2001a), *Euterpina acutifrons* (Ara 2001d) and *Temora turbinata* (Ara 2002). However, estimations of copepod biomass and production rates in the Cananéia Lagoon estuarine system are yet incipient, as well as they are in all other lagoonal, estuarine, and neritic waters along the coast of Brazil (Ara 1998). This study presents a quantitative survey of the diel and seasonal variations in abundance, biomass, estimated production rates, and size-based community structure of the planktonic copepods in the Cananéia Lagoon estuarine system.

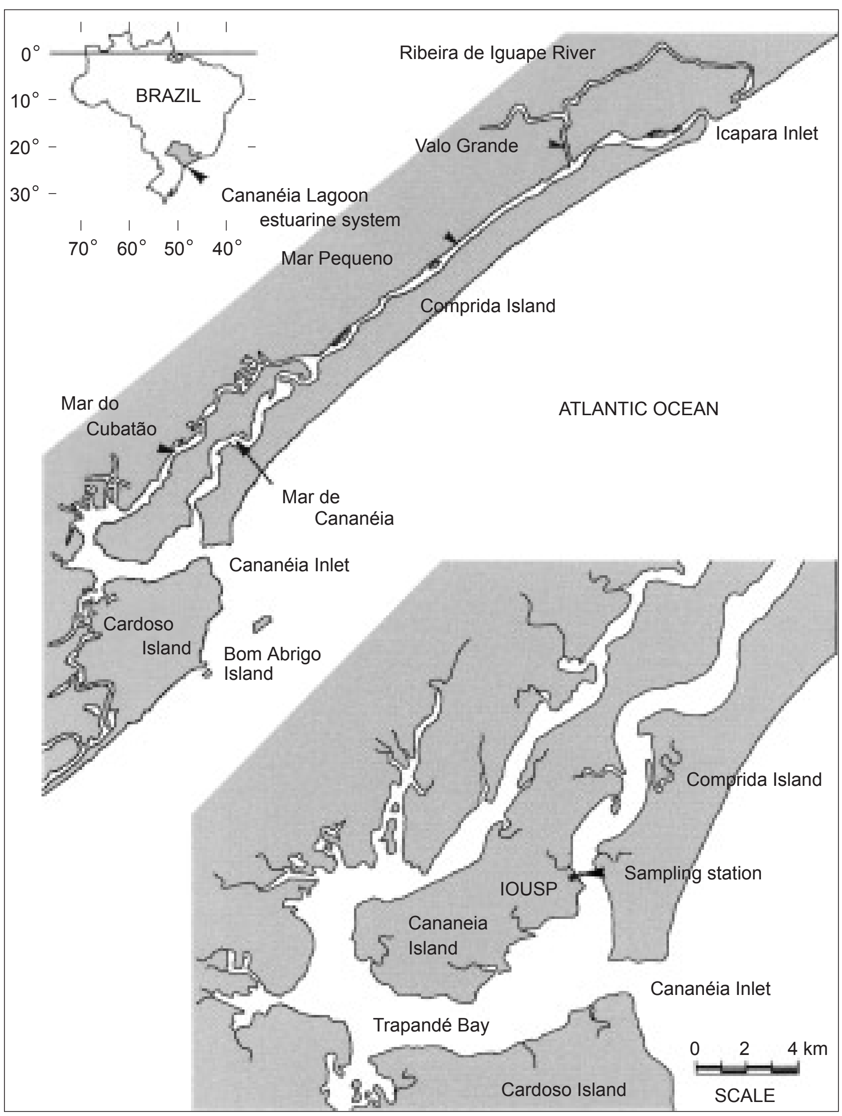

Fig. 1. Map showing the sampling station in the Cananéia Lagoon estuarine system.

MATERIALS AND METHODS

A series of samplings was conducted at a station located in Mar de Cananéia (Fig. 1), from February 1995 through January 1996. On each sampling date, zooplankton samples were taken by vertical tows of a plankton net (with a mouth diameter of 50 cm and a mesh opening of 150 μm) equipped with a flowmeter, from the bottom (at a depth of around 10~12 m) to the surface, at intervals of 4 h during multiple 24-h periods. Net samples were immediately preserved in a buffered formalin-seawater solution (with a final concentration of 5%~10%).

Prior to zooplankton sample collections, water samples were collected every 2 m from the surface to the bottom, using a 3 L Van Dorn bottle. Water temperature was measured with an electronic thermometer. Salinity was determined using an optical refractometer. Usually, 500 ml of water aliquots, collected at 4 depths (0, 2, 6, and 10 m), was filtered onto glass-fiber filters (Whatman GF/F). The chlorophyll *a* concentration of these samples was determined spectrophotometrically after extraction in 90% acetone (Lorenzen 1967). Since zooplankton samples were collected by surface-to-bottom net hauls, mean temperature, salinity, and chlorophyll *a* concentration in the water column were calculated and are presented herein.

Copepods from split samples (1.25% to 40% of the original samples) were identified by species, stage (C1-C6), and sex, and were counted under a microscope. Usually, more than 2000 copepods were analyzed from each sub-sample. Measurements of body length were done randomly for the first around 30~60 individuals of each copepodite stage and species; prosome and total body lengths were measured using an eyepiece micrometer (see Ara 2001 b for details).

The biomass was calculated for each individual based on previously determined length-weight regression equations and the carbon content in dry weight (Ara 1998 2001 b).

The production rate (Pc, mg C m^{-3} d^{-1}) was estimated by the following equation:

$$Pc = \Sigma N \times Wc \times G;$$

where N is the abundance (individuals m^{-3}), Wc is the individual weight (μg C) and G is the individual weight-specific growth rate (d^{-1}). G was estimated using a global model of copepod growth rates presented by Hirst and Lampitt (1998), which is expressed as

$$\log_{10}G = 0.0087T - 0.4902 \log_{10}Wc - 0.7568$$

for broadcast-spawners, and

$$\log_{10}G = -1.7225 + 0.0464T$$

for sac-spawners, where T is the ambient temperature (°C).

RESULTS

Environmental variables

Water temperature showed seasonal variation, ranging from 18.6°C in August to 29.4°C in January (Fig. 2) It was approximately uniform in the water column throughout the year; the difference between the surface and the bottom was 0.7~2.2°C. Salinity varied from 4.5‰ to 33.0‰, and was much lower in February (Fig. 2), which is the rainy season. Chlorophyll *a* concentrations varied from 1.32 to 20.42 μg L^{-1} (Fig. 2).

Abundance

Mesozooplankton were composed of adult and juvenile stages of various taxonomic groups. During the study period, copepods were the most predominant component, constituting 68.1% ~97.7% (with an annual mean of 84.8%) of the total mesozooplankton abundance.

Total copepod (copepodites + adults) abun-

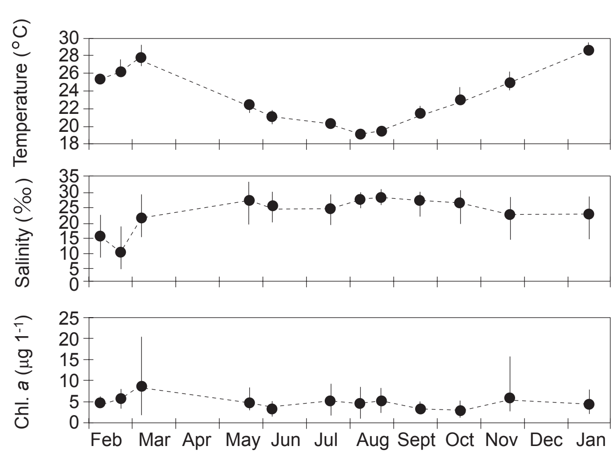

Fig. 2. Seasonal variations in water temperature, salinity, and chlorophyll *a* concentration in the Cananéia Lagoon estuarine system, from February 1995 to January 1996. Closed symbols (●) and vertical bars denote daily mean values in the water column and their ranges, respectively.

dance varied with time; coefficients of variation (SD) were 17.2%~46.4% (with a mean of 31.5%) of the daily mean abundance. On most sampling dates, there was no consistent trend of diel variation in abundance; peak abundance was found randomly at any time of day. There was no statistically significant difference between daytime and nighttime abundances (ANOVA, $p > 0.05$). The night:day abundance ratio varied from 0.65 in August to 1.40 in February, with overall mean of 1.02.

Daily mean abundance of total copepods varied from 1.90 x 10^4 ± 3.27 x 10^3 to 6.55 x 10^4 ± 1.32 x 10^4 individuals m^{-3} (mean ± SD), with an annual mean of 3.33 x 10^4 individuals m^{-3}. The highest densities of total copepods were found in October and January (Fig. 3). In total 37 copepod species were identified from the samples of over 84 occasions during the study periods. The dominant species were *Oithona hebes*, *Acartia lilljeborgi*, *Pseudodiaptomus acutus*, *Parvocalanus crassirostris*, *Oithona oswaldocruzi*, *Euterpina acutifrons*, *Acartia tonsa*, and *Temora turbinata*, constituting 90.9% ± 7.5% to 99.6% ± 0.3% (with a mean of 96.5%) of the total copepod abundances. *Oithona hebes* and *A. lilljeborgi* were consistently present in the plankton throughout the year, but they were rare in February (Fig. 3). *Pseudodiaptomus acutus*, *O. oswaldocruzi*, and *A. tonsa* were abundant in summer, whereas *P. crassirostris*, *E. acutifrons*, and *T. turbinata* were abundant in winter (Fig. 3). Variations of most species were not correlated with time of day, but with salinity: *A. tonsa*, *P. acutus*, and *O. oswaldocruzi* were more numerous at times when salinities were lower, whereas many other species were more numerous at times when salinities were higher.

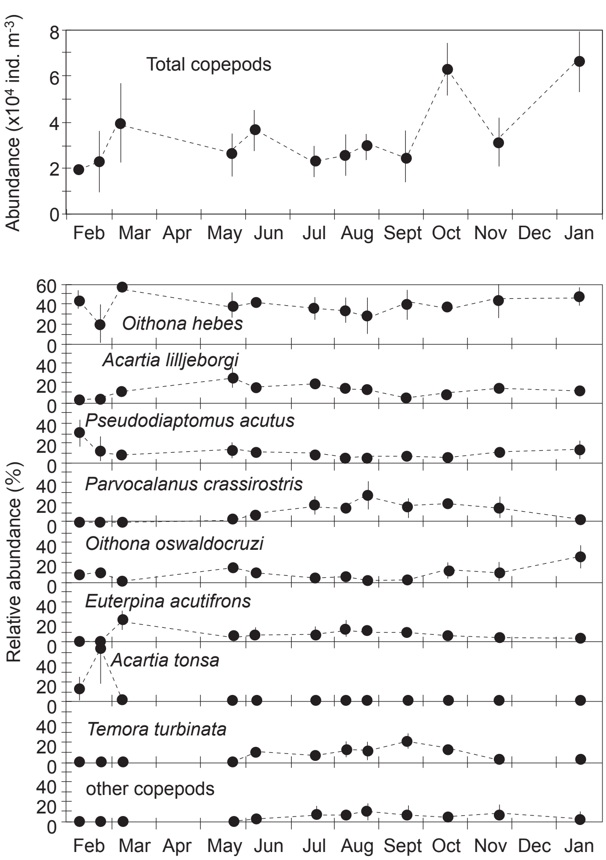

Fig. 3. Seasonal variations in the abundance of total copepods and dominant species in the Cananeia Lagoon estuarine system, from February 1995 to January 1996. The abundance is expressed as the daily mean (●) ± SD (vertical bars).

Biomass and production rates

The biomass of the total copepod community ranged from 23.022 ± 12.080 to 66.775 ± 27.282 mg DW m^{-3} (daily mean ± SD), or from 10.375 ± 5.446 to 30.658 ± 12.520 mg C m^{-3}. The biomass was higher from March to June and from October to January, but was lower in February and September (Fig. 4). The pattern of seasonal variations in biomass of total copepods was more or less similar to that of abundance, although the contributions of *A. lilljeborgi* (with a mean of 24.6%), *P. acutus* (with a mean of 24.1%), and *T. turbinata* (with a mean of 8.3%) to the total copepod biomass were higher than those to the total copepod abundance.

The estimated production rate of the total copepod community varied from 6.183 ± 2.288 to 24.156 ± 9.132 mg DW m^{-3} d^{-1}, or from 2.819 ± 1.044 to 11.106 ± 4.198 mg C m^{-3} d^{-1}. The production rate was higher in March, October, and January, but lower from July to September (Fig. 5). The highest production rate, obtained in January, was overwhelmingly dominated by *P. acutus* (30.9% ± 17.6%), *O. hebes* (25.5% ± 11%), *A. lilljeborgi* (17.9% ± 4.9%), and *O. oswaldocruzi* (16.6% ± 9.7%).

The ratio of daily production rate to biomass (daily *P*/*B* ratio) varied from 0.20 d^{-1} in August to 0.38 d^{-1} in February, with overall mean of 0.27 d^{-1}.

Size-frequency distribution

During the study period, the copepod community was comprised principally of small individuals: on average, individuals of < 1000 μm in total body length contributed 93.1% (daily mean: 85%~97.2%), 69.7% (54.9%~81.8%), and 77.1%

(57.4%~87.9%) of the annual means of total copepod abundance, biomass, and production rate, respectively (Fig. 6). Of the total abundance, 33.3%~47.6% (annual mean: 42.3%) was composed of 500~600 μm individuals such as *O. hebes* (C5, and adult males and females), *O. oswaldocruzi* (C5 and adult males), *P. acutus* (C2), *A. lilljeborgi* (C2) and *P. crassirostris* (C5 females and adult females). This size fraction was also the largest component in terms of biomass and production rate, contributing 25.4% and 28.6% of the total copepod biomass and production rate, respectively. The contribution of 600~1400 μm individuals to the total copepod biomass and production rate was much higher than that of abundance: they contributed only 29.4% of the total copepod abundance, whereas they contributed 62.4% and 55.7% of the total copepod biomass and production rate, respectively. In February, the largest components of the biomass and production rate were comprised mostly of 900~1000 and 1100~1200 μm individuals such as *P. acutus* adult males and adult females, respectively.

DISCUSSION

The copepod community in the Cananéia Lagoon estuarine system is characterized by the numerical predominance of *Oithona hebes*, followed by *Acartia lilljeborgi*, *Pseudodiaptomus acutus*, *Parvocalanus crassirostris*, *O. oswaldocruzi*, and *Euterpina acutifrons*. A similar composition has commonly been observed at the same site (e.g., Matsumura-Tundisi 1972, Tundisi et al. 1973, Almeida Prado-Por et al. 1989) and in other mangrove estuaries along the coast of Brazil (e.g., Almeida Prado-Por and Lansac-Tôha 1984, Rocha 1986, Neumann-Leitão 1994/95). The numerical predominance of *Oithona* species seems to be a general characteristic of mangrove copepod communities worldwide (Robertson and Blaber 1992,

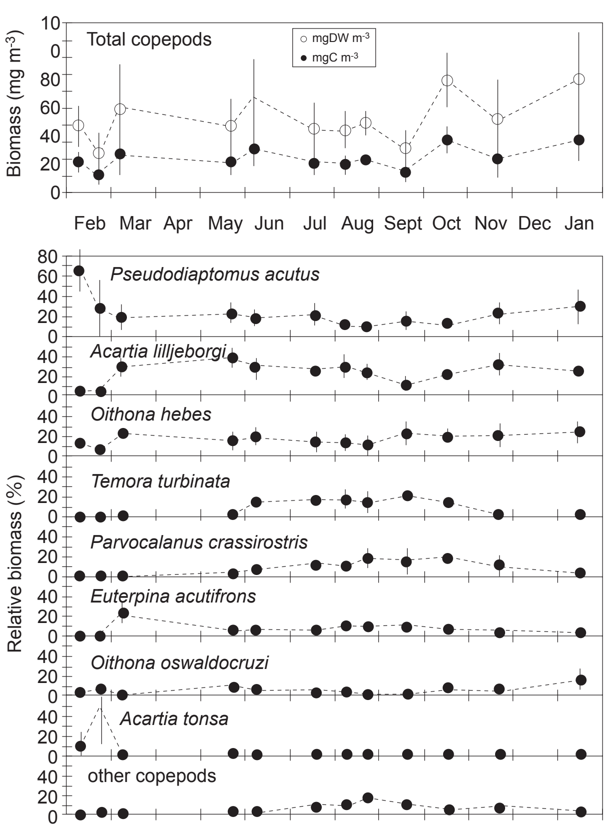

Fig. 4. Seasonal variations in the biomass of total copepods and dominant species in the Cananéia Lagoon estuarine system, from February 1995 to January The biomass is expressed as the daily mean (○ and ●) ± SD (vertical bars).

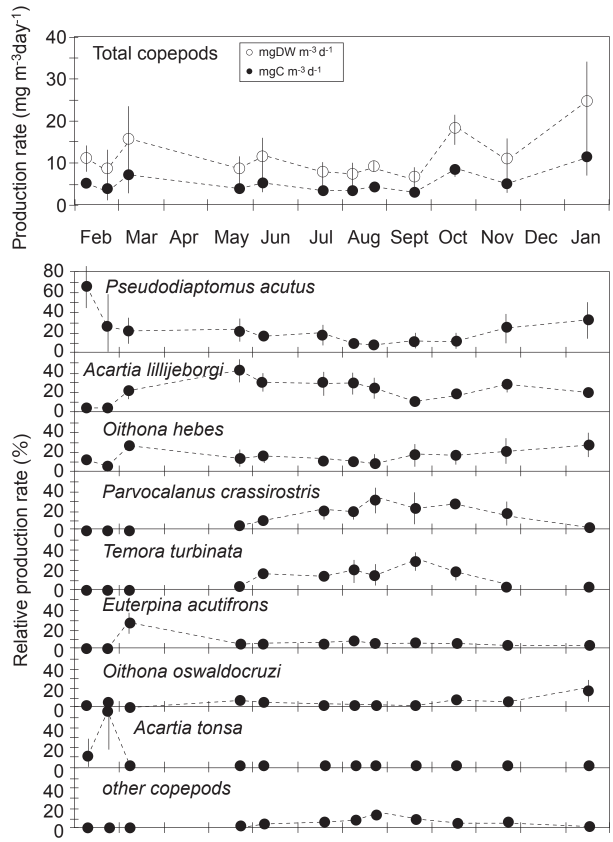

Fig. 5. Seasonal variations in production rates of total copepods and dominant species in the Cananéia Lagoon estuarine system, from February 1995 to January 1996. The production rate is expressed as the daily mean (○ and ●) ± SD (vertical bars).

McKinnon and Klumpp 1998).

It is widely recognized that zooplankton (copepod) abundance in shallow, tidal estuaries fluctuates considerably with time in relation to physico-chemical parameters (e.g., tidal height, salinity) due to tidal cycles (Pillai and Pillai 1973, Sameoto 1975, Lee and McAlice 1979, Dauvin et al. 1998). Consequently, the question arises: How frequently should plankton samples be collected for analyzing temporal (day-to-day and/or seasonal) variations in planktonic copepods in an estuary with such variable ambient conditions? On each sampling date in the present study, zooplankton samples were collected at intervals of 4 h during multiple 24 h periods in order to determine the sampling variability. Abundances of the total and of each copepod species fluctuated drastically with time during the 24 h periods. Therefore, in time-to-time-variable environments such as the Cananéia Lagoon estuarine system, daily means and variation coefficients from the analysis of several samples collected at different tidal phases on each sampling date should be regarded as representative values for analyzing seasonal variations, as mentioned elsewhere (Ara 2001a d 2002). Seasonal variations in abundance were related to temperature as well as salinity, but seasonal occurrence varied depending on species (Fig. 3). Although the peak abundance in March was associated with higher chlorophyll *a* concentrations, their seasonal variations were not synchronized with each other, in particular from October to January (Figs. 2, 3). This can be interpreted as variations in the size composition of the phytoplankton assemblage and the availability of other prey items for copepods in addition to phytoplankton. In the Cananéia Lagoon estuarine system, nanoflagellates (< 30 μm) comprise the dominant fraction of phytoplankton most the year, while the diatom, *Skeletonema costatum*, dominates the phytoplankton standing-stock during summer (Kutner 1975, Brandini 1982, Braga 1995, Sigaud-Kutner 1997). In addition, many workers have found that various mangrove-estuary zooplankters (e.g., copepods) depend on suspended detritus, as well as microalgae (Odum and Heald 1975, Grindley 1984).

One of the most characteristic aspects of the copepod community structure in the Cananéia Lagoon estuarine system is its size composition: the total copepod abundance, biomass, and production rates were contributed mostly by small individuals (Fig. 6). A similar situation was observed in Kingston Harbour, Jamaica, in which individuals < 450 μm (including nauplii) contributed 58% and 67% of the total copepod biomass and production rate, respectively (Hopcroft et al. 1998). The highly skewed copepod community structure toward small individuals can be plausibly explained by 2 possibilities: size/species-selecting visual predation by fish (Fulton 1984a b) and food particle composition (Uye 1994). On the basis of field observations and enclosure experiments, Fulton (1984a b) found that planktivorous fish predators selectively eliminated “larger” copepods (1 mm in body length), whereas “smaller” copepods (0.5 mm) remained. In the Cananéia Lagoon estuarine system, there are many important commercial fish

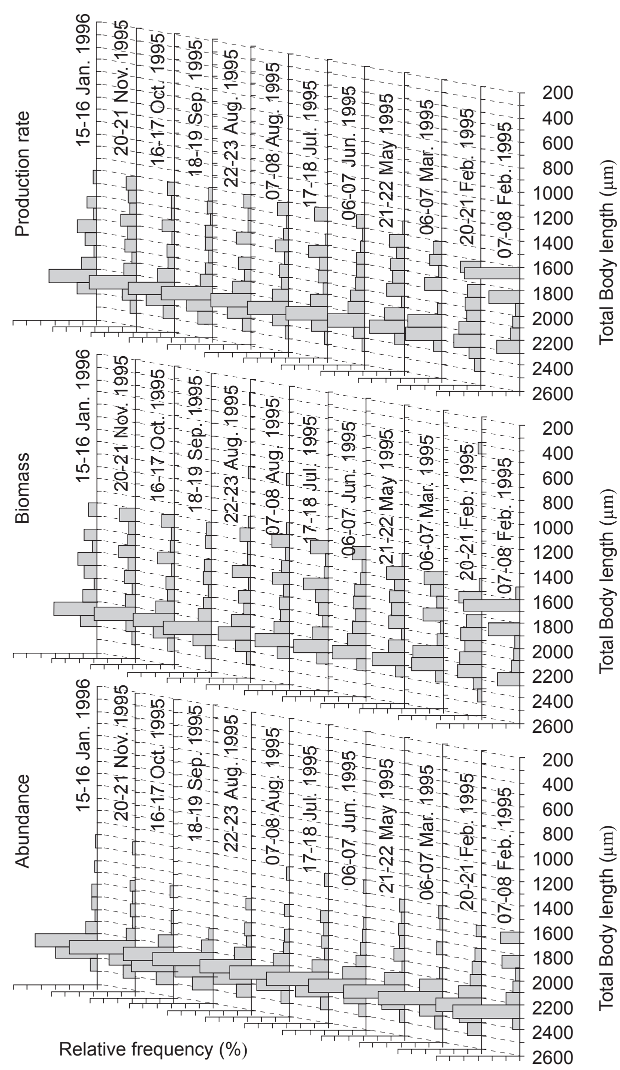

Fig. 6. Seasonal variations in the size-frequency distribution of total copepods in terms of abundance, biomass, and production rate in the Cananéia Lagoon estuarine system, from February 1995 to January 1996.

such as grey mullets (*Mugil curema*, *M. liza*, and *M. platanus*), sardine (*Sardinella brasiliensis* = *S. aurita*), and little anchovy (*Anchoveiella hubbsi*), which enter the estuary from adjacent coastal waters. Most of their earlier juvenile stages are zooplanktivores. In the Cananéia Lagoon estuarine system, food particle composition, i.e. the dominance of nanoflagellates in the phytoplankton assemblage and the water being rich in suspended detritus originated from mangrove litter, as mentioned above, might be also favorable for small copepods, since most of the small suspension-feeding copepods inhabiting mangrove estuaries should be capable of feeding on suspended particles (phytoplankton, detritus, etc.) down to 2.5~5 µm (Kimmerer and McKinnon 1989).

No previous study is available on estimation of the biomass and production rate of the copepod community in the Cananéia Lagoon estuarine system or in other estuarine, lagoonal, and neritic waters along the coast of Brazil. It is difficult to strictly compare the values for biomass and production rates obtained in the present study with those in other studies, because of differences in target animals (size, species, developmental stage), methods of sample collections (frequency, mesh size, type of net tows, etc.) and for estimation (calculation) of biomass and production rate, and units for expressing the values. The present study focused on the copepodite stages (C1-C6), not including eggs and naupliar stages. Juvenile copepodite stages (C1-C2/C3) of small species such as *Oithona* spp., *P. crassirostris*, and *E. acutifrons* were rare in the samples, suggesting insufficient collection of these smaller copepods, which would have passed through the plankton net (with a mesh size of 150 µm) used in the present study. Nonetheless, the annual mean biomass and production rate obtained in the present study were comparable to those for the Inland Sea of Japan (28.898 mg C m^{-3} and 5.276 mg C m^{-3} d^{-1}, Koga 1986; 12.9~20.2 mg C m^{-3} and 2.83 mg C m^{-3} d-1, Uye et al. 1987), Fukuyama Harbor, Japan (39.1 mg C m^{-3} and 6.85 mg C m^{-3} d^{-1}, Uye and Liang 1998) and Kingston Harbour, Jamaica (22.1 mg AFDW m^{-3} and 14.76 mg AFDW m^{-3} d^{-1}, Hopcroft et al. 1998), in which plankton nets with smaller mesh sizes (62~100 µm) were employed for sample collections. Copepod biomass and production rates in tropical and subtropical waters have historically been believed to be lower than those in temperate waters (e.g., Raymont 1983). Much higher biomasses and production rates have been observed in temperate and sub-boreal waters during summer (Durbin and Durbin 1981, Escaravage and Soetaert 1995, Uye and Liang 1998). However, the present study shows that the annual copepod biomass and productivity in a subtropical mangrove estuary can be relatively high compared to other lagoonal, estuarine, and neritic waters of the world. The high copepod productivity in the Cananéia Lagoon estuarine system can be attributed to the year-round high temperatures (Ara 2001a d), the water being rich in particulate organic matter which originates from mangrove litter, and higher rates of egg production and hatching success compared to other estuarine, lagoonal, and neritic waters, as observed for *A. lilljeborgi* (Ara 2001c).

Acknowledgements: I thank Drs. Luiz Roberto Tommasi, Luz Amélia Vega-Pérez, Tsui Hua Liang and Simone Ribeiro Heitor for helpful assistance and valuable comments. This research was financially supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), the Instituto Oceanografico da Universidade de São Paulo (IOUSP) and the Fundação de Estudos e Pesquisas Aquáticas (FUNDESPA).

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