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Cyclopoid copepods as bioindicators of eutrophication in reservoirs: Do patterns hold for large spatial extents?

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ABSTRACT

Some species of copepods are sensitive to water quality oscillations from natural or anthropogenic causes. Information on basic ecological attributes such as abundance can be helpful in the context of hydric resources monitoring. Our study analyzed if the abundance of 22 copepod species of the second largest basin of South America was more associated with variables oscillating by natural or anthropic causes, contrasting among oligotrophic, mesotrophic, and eutrophic reservoirs. Our aim was to identify and understand the abundance of species with potential to monitor water quality in large scale assessments. Potential bioindicators would have different abundances in eutrophic, mesotrophic and oligotrophic sites and would not oscillate according to natural characteristics of reservoirs (water temperature, air temperature, and depth). Two species were sensitive to eutrophication and were not related to natural characteristics of reservoirs, that is, they were suitable for biomonitoring the La Plata Basin. *Thermocyclops minutus* negatively responded to eutrophication, while *Acanthocyclops robustus* responded positively. Additional exploratory analyses identified that Copepod abundance was related to total phosphorus, chlorophyll-a concentration, water transparency, total suspended matter, and depth. *Metacyclops mendocinus*, *Acanthocyclops robustus*, *Mesocyclops meridianus*, *Mesocyclops ogunnus*, and *Thermocyclops decipiens* were abundant in eutrophic reservoirs, and *Thermocyclops minutus*, and *Thermocyclops inversus* were associated with higher water transparency, typically oligo/mesotrophic reservoirs. Overall, we found that cyclopoids are highly affected by eutrophication, and species abundance could be used to monitor reservoirs and anticipate potential impacts on water quality in large-scale biomonitoring schemes.

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1. Introduction

Freshwater copepods constitute a functional link between phytoplankton and bacterioplankton and higher trophic levels, such as fish and invertebrate larvae. Due to this important relationship with all taxonomic groups in aquatic environments, the population abundance of these organisms as well as richness, diversity, and biomass can be viewed as an interesting indicator of the overall ecological condition of the whole water body (Landa et al., 2007; Santos-Wisniewsky and Rocha, 2007; Silva, 2011).

A current challenge in monitoring studies is to separate the natural fluctuation of bioindicator populations from the fluctuation related to anthropic impacts in order to find suitable indicator species. In this sense, interesting bioindicator taxa are those who have any biological or ecological characteristic (i.e., density, body size) strongly influenced by anthropic impacts and weakly influenced by natural fluctuations (Bonada et al., 2006). Certain neotropical copepod species are particularly sensitive to several environmental variables and can potentially serve as indicators of distinct trophic stages (Matsumura-Tundisi and Tundisi, 2003), including artificial lakes near large cities that receive large quantities of sewage, resulting in high values of nutrients and chlorophyll.

Eutrophication is a detrimental process characterized by the enrichment of aquatic systems mainly by nitrogen and phosphorous (Serafim-Júnior et al., 2010). The increased of primary

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productivity caused by nutrient enrichment strongly affects species of zooplankton, macroinvertebrates, and fish and ultimately can affect all those that directly or indirectly make use of the contaminated water from eutrophic reservoirs (Serafim-Júnior et al., 2010). Moreover, eutrophication of reservoirs also has an economic impact on lakefront property values, drinking water prices, and availability and spending on the recovery of endangered species (Dodds et al., 2008). Due to all these potential impacts, it is imperative to develop biomonitoring schemes that enable anticipating the eutrophication of reservoirs.

In general, zooplankton abundance is positively correlated to high values of chlorophyll-a (generally dominated by few species) and nutrients (especially N and P) and negatively to conductivity (sewage) and low dissolved oxygen. Besides these general trends, individual response of each species is less known and would be desirable to simplify biomonitoring schemes by using a smaller number of species with the best response to eutrophication.

Studies have considered only restricted or intermediary spatial scales and have still not focused on relations between copepods and water quality or eutrophication in an entire large river basin. Since generalizations are one of the most desired aims in biomonitoring (Bonada et al., 2006), studies encompassing biological responses along a large environmental gradient could provide information about general bioindicators for this scale. In this sense, here we investigated the La Plata Basin, which is the second largest basin in South America, and it has one of the most highly concentrated human populations in the continent. From a large-scale perspective, the basin is composed by important rivers such as the Parana, Paraguay, and Uruguay rivers and by several reservoirs mainly in the upper part of the basin. Many rivers are almost totally dammed and are severely impacted by large quantities of sewage produced every day by large cities.

The aim of this study was to identify which species of cyclopoid copepods exhibit consistent trends of abundance in reservoirs along an environmental gradient of anthropogenic impact in a large river basin. We applied a combination of statistical filters to select bioindicator species of trophic states of reservoirs using established methods for biomonitoring (Barbour et al., 1996; Hering et al., 2006; Saito et al., 2015). We further explored the relationships between cyclopoids and limnological variables using two different exploratory statistical techniques aiming to understand the specific response of individual species to natural and anthropic variables.

2. Materials and methods

2.1. Study area and sampling design

Approximately 60% of the upper Paraná River, which is the main drainage of La Plata Basin, is already dammed for hydropower generation and has only a few free lotic stretches. The opposite situation is found in the middle and lower stretches where reservoirs are almost absent, and an increase in turbidity and suspended matter naturally occurs below the mouths of tributaries. A similar pattern is observed in the Uruguay River, but the difference is that a large reservoir has built up in the middle-lower stretch. Few reservoirs have been constructed in the headwaters of the Paraguay River and none in the main channel.

Some important tributary rivers of the upper Paraná River drain large cities in the headwaters, totaling more than 27 million people (e.g., Curitiba, São Paulo, Campinas), and have along their courses a series of cascade downstream reservoirs that exhibit a longitudinal decrease in nutrients, chlorophyll-a, and eutrophication along the cascade (Barbosa et al., 1999; Silva et al., 2005). However, this phenomenon does not occur in parallel in large rivers without the influence of large cities in the headwaters, where nutrients and eutrophication sources have local influence, for example, in arms and tributary mouths (Nogueira et al., 2008).

In this study, we sampled the largest area of the La Plata River Basin possible, covering approximately 70% of the basin (for a total of 3,100,000 km^2); the basin extends to Argentina, Brazil, Bolivia, Paraguay, and Uruguay. Triplicate samples were obtained twice from 30 sites in the basin, during summer and winter of 2010. Fifteen reservoirs were selected (samples from the lacustrine zones adjacent to the dams and from riverine zones in the upstream [tail zone]) (Fig. 1). All of the sampled reservoirs exhibited a water retention time greater than 15 days, which is considered the limiting lower period for the development of certain regional copepod species (Rietzler et al., 2002).

2.2. Environmental variables

Thirteen environmental variables were measured in conjunction with zooplankton sampling. Several variables were measured in situ: water temperature, pH, electrical conductivity, and dissolved oxygen were quantified with a multiparameter Eureka Manta-2 probe; depth was measured with a SpeedTech probe; water transparency (m) was determined with a Secchi disk; and air temperature was measured with a mercury thermometer. Water samples were collected with a Van Dorn bottle for subsequent laboratory analyses of total nutrient concentrations (phosphorus and nitrogen), suspended matter (total, inorganic, and organic), and chlorophyll-a. In deeper stations (>30 m), water samples were obtained from four to six depths according the local depth but always including at least the surface, middle, and end of the euphotic zone and near the bottom. For example, in reservoirs with 40 m depth, we took four samples, and in 150 m reservoirs, we took 6 samples. Shallow sites (< 15m) were sampled at three depths, at surface, middle and close to the bottom. The mean depth of sampling sites is available in Supplementary file 1. Mean values among depths were calculated for subsequent analyses.

Using the values of total phosphorus, chlorophyll-a, and water transparency, we calculated a classic trophic state index for lakes (Carlson, 1977) to characterize the trophic level of the sampled sites.

2.3. Zooplankton sampling

Zooplankton triplicate samples were obtained with vertical hauls in the water column (from just above to the bottom to the surface) at each sampling station. The water volume was determined with the cylinder volume formula (=π.raius of the plankton net height). In deeper stations, the vertical hauls reach an extension of 40 m. The minimum and maximum sampled volume used was 400 L and 1884 L, respectively. Conical plankton nets of 68 μm mesh size modified with an anti-reflux bulkhead were used, and the samples were fixed with 4% formalin solution.

Copepods were identified under optical microscopy (Zeiss Standard 20 and 25) with specialized references (as cited in Perbiche-Neves et al., 2014). Adult males and females of all species were identified. Quantitative analyses were conducted in subsamples obtained by a Stempel sampler, considering at least 500 individuals per sample or the entire sample in case of low abundance and using acrylic chambers under a stereomicroscope. Abundance was expressed in individuals per cubic meter (ind m^{-3}).

2.4. Data analysis

2.4.1. Selecting copepod bioindicators

We used a combination of statistical filters to select bioindicator species of trophic states of reservoirs for large-scale biomonitoring programs. The use of these filters was based on established meth-

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