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Ecological and toxicological responses in a multistressor scenario: Are monitoring programs showing the stressors or just showing stress? A case study in Brazil

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HIGHLIGHTS

- Data on water quality of urban reservoirs has been statistically analyzed.
- Analysis was focused on community and bioassay responses and stressors.
- Data showed spatial and temporal lacks and non-compliances for some parameters.
- Bioassays and planktonic community demonstrated impairments in biota.
- Physical and chemical data compiled do not completely explain biological responses.

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ABSTRACT

The Metropolitan Region of São Paulo (MRSP) is located in the Brazilian State of São Paulo and reservoirs in this region are vital for water supply and energy production. Changes in economic, social, and demographic trends produced pollution of water bodies, decreasing water quality for human uses and affecting freshwater populations. The presence of emerging pollutants, classical priority substances, nutrient excess and the interaction with tropical-climate conditions require periodic reviews of water policies and monitoring programs in order to detect and manage these threats in a global change scenario. The objective of this work is to determine whether the monitoring program of the São Paulo's Environmental Agency, is sufficient to explain the toxicological and biological responses observed in organisms in reservoirs of the MRSP, and whether it can identify the possible agents causing these responses. For that, we used publicly available data on water quality compiled by this agency in their routine monitoring program. A general overview of these data and a chemometric approach to analyze the responses of biotic indexes and toxicological bioassays, as a function of the physical and chemical parameters monitored, were performed. Data compiled showed temporal and geographical information gaps on variables measured. Toxicological responses have been observed in the reservoirs of the MRSP, together with a high incidence of impairments of the zooplankton community. This demonstrates the presence of stressors that affect the viability of organisms and populations. The statistical approach showed that the data compiled by the environmental agency are insufficient to identify and explain the factors causing the observed ecotoxicological responses and impairments in the zooplankton community, and are therefore insufficient to identify clear cause–effect relationships. Stressors different from those analyzed could be responsible for the observed responses.

1. Introduction

Preservation of the structure and function in freshwater ecosystems is needed to ensure economic, cultural, and recreational benefits for humans (Turner and Daily, 2008). For this reason, the identification and control of potential threats that might impair freshwater ecosystems are required in order to ensure consistent quality of the water supply.

Chemical pollution in water bodies is a well-known factor that decreases water quality for human uses and can affect freshwater populations in terms of their abundance, distribution, and interactions with other organisms and the environment, consequently causing effects on the ecosystem (Brack et al., 2005). Other environmental factors

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(nutrient excess, species interactions, introduction of invasive species, climate variations, habitat loss, physical alterations of the river, or overexploitation of water resources) can also be responsible for changes in freshwater ecosystems (Ricciardi et al., 2009). For this reason, the diagnosis, prediction, and forecasting of the impacts of toxic substances requires their discrimination from other stresses in order to obtain reliable cause–effect relationships between chemical pollution and impacts on freshwater populations. The use of statistical methods is a powerful and inexpensive method for the identification of significant relationships and possible explanation of cause–effect linkages (Brack et al., 2005), but requires strong data sets obtained in monitoring programs.

Monitoring programs are used to obtain information concerning the quality of water bodies, using measurements of chemical, physical, hydromorphological, biological, or other related parameters. Generally, routine monitoring of water bodies is performed for specific purposes, such as assessing the conformity of measured parameters to quality standards for human uses (recreational, agricultural, industrial, and tap water) and/or quality standards intended to protect the diversity and functionality of aquatic ecosystems.

A global change scenario entails the appearance of new stressors, such as the alteration of climatic patterns (including drought and temperature increase) or changes in economic, social, and demographic trends (Stevenson and Sabater, 2010; Carpenter et al., 1992). All these new stressors and changes imposes new challenges for management of the quality and availability of water resources, as well as the conservation of aquatic ecosystems, and requires periodic reviews of water policies and monitoring programs (Araújo et al., 2014; Pahl-Wostl, 2007).

In developing countries, biodiversity and water security are likely to be threatened, if no efforts are made to protect water resources (Vorosmarty et al., 2010). Apart from changes in climatic patterns, South America (and especially Brazil as an emerging economy) is facing various other challenges: a) fast growth of populations in urban areas (Varis et al., 2006); b) development of crop areas and high consumption of water, pesticides, and fertilizers (Barletta et al., 2010; Carvalho, 2006; Agostinho et al., 2005; Tundisi, 2003); c) growth of the cattle industry and high levels of water consumption and land use change (Bell et al., 2010); d) development of industry, with weak environmental legislation (Agostinho et al., 2005; Tundisi, 2003); and e) poor sewage treatment infrastructure (Barletta et al., 2010; Agostinho et al., 2005; Tundisi, 2003). All these factors will diminish ecological quality, and increase water consumption and the cost of ensuring a clean and consistent source of water to supply the needs of citizens and economic activities.

The economic, social, and demographic changes in this region, and elsewhere around the world, imply the emergence of new chemical threats to freshwater resources, involving new emerging pollutants (Richardson and Ternes, 2014; Petrovic et al., 2011), as well as the classical and well-known priority substances. Therefore, the review of water management policies requires studies aimed at defining and prioritizing the chemical substances that could pose the greatest risks to humans and ecosystems, as well as studies focused on the adaptation of monitoring procedures to enable the detection and quantification of these new substances. Such studies have mainly been performed in the USA and the European Union (Fàbrega et al., 2013), and are scarce in South America.

Economic development in South America implies increasing requirements for energy production and water storage. This motivated the construction of a large number of reservoirs in the region during the 20th and 21st centuries, which provide recreational services and play an important role in economic development (Tundisi et al., 1998). Despite of their importance, reservoirs, and in general, water bodies in South America are suffering anthropic pressures which diminish water quality and ecological status (Barletta et al., 2010; Carvalho, 2006; Agostinho et al., 2005; Tundisi, 2003). In addition, some of the South American reservoirs are under the influence of a tropical climate (Tundisi, 1990), with conditions that enhance primary production (high temperature, high and constant solar irradiation, frequent thermocline instability) but that can cause problems for aquatic organisms, due to rapid oxygen depletion in the bottom, cyanobacteria blooms, and rapid changes in water column stability (Lewis, 1987; Tundisi, 1990). For example, in Brazil, environmental agencies and researchers have reported that the biological and chemical quality of many reservoirs under urban influence are highly impacted by inflows of untreated wastewater containing high levels of pollutants, including nutrients and organic matter, leading to the eutrophication of these water bodies as well as decreased biological diversity (Braga et al., 2006; CETESB, 2013; Fontana et al., 2014). These evidences suggest that the organisms inhabiting these reservoirs are exposed to multiple stressors and policies improving management should be applied (Tundisi and Matsumura-Tundisi, 2003).

The objective of this work is to determine whether the data compiled by water agencies, in addition to establishing compliance (or not) with national laws, are sufficient to be able to explain the toxicological and biological responses observed in organisms in reservoirs, and whether these data can be used to identify the possible agents causing these responses. In other words, we want to know if the data compiled in the monitoring programs can identify stressors, or if it only provides indicators of stress.

To accomplish this objective, as case study, we used publicly available data on water quality compiled by a Brazilian environmental agency (Environmental Sanitation Technology Company, CETESB) in its routine monitoring program in the Metropolitan Region of São Paulo. Firstly, we performed a general overview of these data, and then we applied a chemometric approach to analyze the responses of biotic indexes and toxicological bioassays, compiled by the environmental agency, as a function of the physical and chemical parameters monitored.

Identification of possible stressing agents is a first step for the creation of policies aimed at the elimination or mitigation of these stressors, with the possibility of restoration of the ecosystem, or at least the avoidance of its total degradation.

This is the first time that such a study has been performed in South America, and the results and conclusions should be useful to water managers and policymakers involved in the protection of water resources and ecosystems.

2. Materials and methods

2.1. Study site

In this study, we analyzed data obtained by CETESB in the monitoring program of urban reservoirs under the influence of the Metropolitan Region of São Paulo (MRSP, see Fig. 1). The MRSP is the largest urban and industrial complex in South America and it is located in the Brazilian State of São Paulo (Braga et al., 2006). The MSRP has experienced dramatic and unplanned growth in the last 50 years, and now includes the city of São Paulo and a further 39 municipalities, with a total population of around 21,000,000 inhabitants and an area of 8000 km^2. The main land use in the MRSP is for urban and industrial purposes (Braga et al., 2006; Drucrot et al., 2005; Formiga-Johnsson and Kemper, 2005; SEADE, 2015), and the reservoirs in this region are vital for water supply and energy production (Tundisi et al., 1998; Ducrot et al., 2005). These reservoirs are under the influence of a tropical climate, with conditions that enhance primary production (high temperature, high and constant solar irradiation, frequent thermocline instability) but that can cause problems for aquatic organisms, due to rapid oxygen depletion in the bottom, cyanobacteria blooms, and rapid changes in water column stability (Lewis, 1987; Tundisi, 1990). In addition, environmental agencies and researchers have reported that the biological and chemical quality of many reservoirs under the influence of the MRSP is highly impacted by inflows of nutrients and toxicants, eutrophication