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Research in a RAMSAR site: The Cananéia-Iguape-Peruíbe estuarine-lagoon complex, Brazil

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Wetlands are ecosystems at the interface between terrestrial and aquatic environments, whether continental or coastal, natural or artificial, permanently or periodically flooded or with waterlogged soils and, as a result, they consist of a special system of multiple interest. In these areas, the waters can be fresh, brackish or salty, with plant and animal communities adapted to their water dynamics (Ministério do Meio Ambiente, 2015). It is very important to understand the abiotic and biological properties of wetlands in order to develop integrated strategies for the management and conservation of these areas and their associated biodiversity. These regions are among the most productive environments in the world and are essential for human survival, as they generate various ecosystem services of provision, regulation, support and culture (Ramsar, 2023a). One of the most effective strategies for the conservation of coastal or tidal wetlands is the establishment of Marine Protected Areas (MPA), as they are important for the development of species and maintenance of ecosystem dynamics. The Convention on Wetlands or Ramsar Convention on Wetlands (Ramsar Convention Secretariat, 2016) currently includes over 2,400 Ramsar Sites around the world, which cover more than 2.5 million square kilometers (Ramsar, 2023a). In Brazil there are 27 Ramsar sites, which are priority wetlands areas for international conservation (Ramsar Sites Information Service, 2023). In São Paulo State, the Cananéia-Iguape Estuarine-Lagoon Complex (CIELC) integrates the Cananéia-Iguape-Peruíbe Environmental Protection Area (CIP-EPA) as a Biosphere Reserve (UNESCO) (ICMBio, 2020) and, in 2017, it was included in the Ramsar list of wetlands of international importance (Ramsar, 2017), which makes it a priority area for conservation.

Conservation units are constantly subject to the input of organic and inorganic compounds related to natural disturbances such as tidal dynamics, rainfall, storms and hurricanes, and to anthropogenic activities such as sewage disposal and engineering works. These issues generally modify hydrobiogeochemical characteristics and processes and, as a long-term consequence, promote restrictive and/or adverse effects on living organisms by changing their ecophysiological responses. In this context, this special issue aims to present various scientific studies carried out in the CIELC, covering aspects of water chemistry

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and its biogeochemical dynamics, as well as some biological profiles. This volume contains studies on important representatives of the local biota of the CIELC, such as birds and abundant fish taxa of ecological and commercial importance to the local beachcombers and fishermen communities, as the Aridae catfish (*Cathorops spixii* and *Genidens genidens*), as well as the integration of abiotic parameters (e.g. water chemistry) and the evaluation of the impact of anthropogenic actions, such as sewage dumping on the health of the local ichthyofaunal biota. These investigations contribute to monitoring and managing the environmental conditions of this important Ramsar site.

The Cananéia-Iguape Estuarine-Lagoon Complex (CIELC) is protected by regional public policies and by Federal Law 7,661/1988, which establishes the National Coastal Management Plan (PNGC) as part of the National Environmental Policy and the National Marine Resources Policy and the State Coastal Management Plan (PEGC), established by State Law 10,019 of July 3, 1998. These plans are responsible for demarcating protected areas and establishing governance, management and use plans for the conservation units in the complex (ICMBio, 2020).

The southern region of the CIELC is relatively well-preserved, but the northern section is subject to anthropogenic inputs originating from the Ribeira de Iguape river outflow via Valo Grande artificial channel. The estuary sandbar that connects the sea to the internal part of the complex has played an important hydrodynamic role over the years, with changes in flow and geomorphology due to the erosion processes, both natural and forced by anthropogenic influence, as those that resulted from the construction of Valo Grande channel.

Some previous studies carried out in the CIELC have monitored the environmental properties of this region, such as Besnard (1950), Kato (1966a, 1966b, 1966c), Teixeira (1968), Tundisi and Teixeira (1968), Miyao et al. (1986), Miyao and Harari (1989), Braga (1995), Tessler and Souza (1998), Braga and Chiozzini (2008), Braga et al. (2009) and Maluf (2009). In recent decades, several scientific studies have been carried out to understand the oceanographic dynamics of the CIELC, considering the circulation patterns of the adjacent shelf and tidal inflows (Camargo and Harari, 1994; Harari and Camargo, 1994; Mesquita and Harari, 2003); the physical and chemical properties of the water (Chiozzini et al., 2008; Chiozzini et al., 2010; Azevedo and Braga, 2011; Aguiar et al., 2013; Souza et al., 2011a, 2011b; Eschrique et al., 2014; Haytsmann, 2018; Mindaugas et al., 2023); sedimentary and geomorphological characterization and metal inputs (Mahiques et al., 2009; 2013; 2014; Cornaggia et al., 2018; Tramonte et al., 2018); geochemical aspects (Amorim, et al. 2008; Barcellos et al., 2005; Aguiar et al., 2008; Perretti and Braga, 2022; Sutti et al., 2022; Millo et al., 2021); the composition of the ichthyofauna (Sadowsky, 1974; Mishima and Tanji, 1981, 1983; Rios, 2001; Contente, 2013; Camargos, 2023); the fishing dynamics and overexploitation of species of commercial and ecological importance to the region (Sadowsky, 1974; Cardoso, 2004; Oliveira, 2011 Jankowsky and Mendonça, 2022; Camargos, 2023); and the impact of anthropogenic disturbances on fish species (Azevedo et al., 2009; 2012a; 2012b; 2013; Pecoraro et al., 2018; Braga et al., 2019; Salgado et al., 2020; Amaral et al., 2021; Morais and Azevedo, 2021). Still in relation to fish, there are studies focused on reproduction, population structure, growth and mortality, as well as xenobiotic effects and responses in species such as *Cynoscion guatucupa, Mugil curema*, *Menticirrhus americanus, Cathorops spixii, Genidens genidens, Genidens barbus* and other ecologically and commercially important fish (Mishima and Tanji, 1983; De Miranda and Haimovici, 2007; Azevedo et al., 2012a; 2012b; Contente, 2013; Fernandez and Dias, 2013; De Carvalho et al., 2019; Albergaria-Barbosa et al., 2017; Mendonça et al., 2020; Amaral et al., 2021; Morais and Azevedo, 2021).

In recent decades, several scientific studies have been carried out on different taxa, such as dolphins, marine mysids, crustaceans and others. In addition, the occurrence of exotic species and their impacts has been investigated, for instance in cases when the shrimp *Litopenaeus vannamei* (native to the eastern Pacific) was observed as a bycatch of fishing activities aimed at native species such as the pink shrimp *Farfantepenaeus* *paulensis* and *F. brasiliensis* and the white shrimp *Litopenaeus schmitti,* in several areas of Cananéia, Iguape and Ilha Comprida estuary (Barbieri et al., 2016). Studies on dolphins have been conducted to record the occurrence of the Guiana dolphin (*Sotalia guianensis*), its local adaptation to environmental features and how human fishing activity can affect its distribution in the CIELC (Godoy et al., 2020; Godoy et al., 2022; Pierry et al., 2023). Ecological studies on abundance, diversity, human impact and environmental drives have been also conducted with marine mysids (Miyashita and Calliari, 2016), gelatinous zooplankton (Cnidaria, Ctenophora, Chaetognatha and Tunicata) (Nogueira Júnior et al., 2019), shrimp such as *Xiphopenaeus* spp. (Gonçalves et al., 2023) and *Penaeus schmitti* (Barioto et al., 2017) and turtles (Mello and Alvarez, 2020).

The CIELC is a long and complex system (the Cananéia and Iguape cities are about 100 km apart) in which an artificial channel links the Ribeira de Iguape River to the estuarine-lagoon complex in the northern part of the system. This freshwater input flows preferentially to the southern part of the system (Cananéia bar) rather than to the Northern bar (Icapara Bar), reaching the Atlantic Ocean and producing an internal salt gradient towards the southern area (Cananéia). The river input is rich in nutrients, mainly dissolved phosphate and silicate. Bastos and Braga (2023) observed the behavior of this silicon, taking into account its inorganic dissolved form (silicate) and its biogenic form and observing that this pattern is related to both the freshwater input from the river and to primary production, in addition to the microphytolithes kept in the soil, where rice was intensively cultivated in the past.

Another important aspect in this region, also related to the strong freshwater flow from the Ribeira de Iguape, is the mangrove forest that sustains biogeochemical processes, influenced by tree roots, organic matter and benthic processes. The carbon element, which is essential for the formation of living matter and the recovery of decomposition processes that eliminate CO_2, plays an important role in this area, due to the C sink/source relationship and climate change. This natural area is a unique setting for observing vertical sediment profiles, processes occurring in the different horizons, the relationship with aerobic and anaerobic conditions and benthic participation. All these properties and processes were studied by Kristensen et al. (2023).

The distribution of rare earth elements (REE) in the sediments of the area was also studied by Chiozzini et al. (2023), who identified important minerals that play a role in the natural increase of REE concentrations in certain regions of the estuary. The authors highlighted several characteristics, such as increased carbonate content, enrichment in light and medium REE, strongly positive Eu anomalies, thorium values below those expected by the regression with REE, among others that indicate that the contamination may originate from phosphogypsum mined in the Ribeira river basin for fertilizer production in the context of global changes in land use and increasing demand for fertilizers, combined with the use of rare earth elements in various technological products. The human use and discharge of these elements into the environment have just begun to be studied in greater depth.

Over the last decades, regional climate change, erosion and increased agricultural runoff have led to an increase in the input of nutrients and particles into rivers, unbalancing the biogeochemical cycle of this suspended material along estuaries as receiving bodies. In this context, particles flows in the euphotic zone respond to natural and non-natural inputs. This productive layer corresponds to an important link in the food chain, which is essential to the dynamics of estuaries. Using a particle trap suspended at the base of the photic zone in some points of the CIELC system, Sutti et al. (2023) evaluated the vertical flow of particulate matter in sedimentation processes of the photic zone under different haline and trophic conditions, showing distinct production and sinking in regions under natural and anthropogenic influence.

Similarly, Moraes et al. (2023) examined seasonal changes in the aerobic respiration and fluxes of inorganic nutrients at the sediment-water interface along a strong salinity gradient in the Cananéia-Iguape estuarine-lagoon complex. These authors also observed how spatial-temporal changes in salinity influenced sediment metabolism, based on the incubation of intact sediment cores in the laboratory, to determine O_2, TCO_2 and inorganic dissolved nutrient fluxes.

Regarding direct anthropogenic disturbances in the CIELC, using multiple abiotic and biological indicators, Silva et al. (2023) assessed water quality and the potential effect of pollution on fish species along the Olaria riverine system, a short aquatic system that crosses the urban center of the city of Cananéia, where it eventually receives untreated domestic wastewater that flows into the Cananéia estuary (CIELC). In this study, the authors observed that the inner area of the Olaria system had dissolved oxygen and nutrients (phosphate [P-PO_4^{-3}], nitrate ([N-NO_3^-], nitrite [N-NO_2^-] and ammonium [N-NH_4^+]) above the maximum established limits for water quality by Brazilian environmental legislation (Conselho Nacional do Meio Ambiente - CONAMA). On the other hand, *Escherichia coli*, which is indicative of human contamination, was found in all the water samples analyzed, indicating a local or point source of domestic wastewater contamination near the Olaria system. Fish species such as *Centropomus undecimalis* (Robalo Flexa) and *Sphoeroides testudineus* (Baiacu pintado) showed toxicogenetic damage, reinforcing the evidence of fish health disorders and exposure to xenobiotics.

The CIELC has around 1,081 species of fauna and flora (ICMBio, 2020). Therefore, this region maintains an exuberant biodiversity and represents a seasonal visiting site for migratory bird populations, mainly in the Ilha Comprida, where there is a long stretch of beach facing directly towards the South Atlantic (Barbieri and Pinna, 2007; Barbieri and Bete, 2013).

In 2016, Barbieri et al. (2023) investigated the presence and variation of the migratory bird population in this area, finding an increase in September/October and a decrease during the winter. This interesting study mentions some details related to tide periods, as well as the monitoring of the birds' migration, as a function of climatic change.

Understanding the environment in which animals live is of fundamental importance to make inferences about ecophysiological processes or simply to elucidate issues related to the interaction of abiotic parameters with marine organisms. In this context, some fish species can be used as target species and bioindicators of environmental disturbances. The wild catfish species *Cathorops spixii* and *Genidens genidens (*Siluriformes, Ariidae) have already been validated as important bioindicators of contamination in the CIELC (Azevedo et al., 2009; Azevedo et al., 2012b). Fish body growth and otolith growth are closely linked (Campana, 1999); the thickness and formation of increments and, consequently, the shape of otoliths, reflect periods of environmental and physiological stress (Morales-Nin, 2000). For this reason, as these structures grow, variations in their size and shape can be detected. Morais et al. (2023) studied the responses of otolith dimensions in Ariid catfish *C. spixii* and *G. genidens* to sexual and temporal changes, throughout the CIELC. In conclusion, the authors highlight that the morphometric data of the lapillus otoliths of these catfish species demonstrate the potential of these metrics to predict temporal variations in aquatic ecosystems with differential hydrobiogeochemical characteristics, such as those observed in the CIELC.

Starting from the knowledge that fish age can be estimated using age rings in calcified structures such as otoliths, Morais and Azevedo (2023) presented a new approach to otolith analysis, based on the assessment of different axes for counting the number of increments, considering measurements along lapillus otoliths at predetermined 90° and 150° axes for Ariid species. In general, the 90º and 150º angles can be used for increment counting, but caution is required for otoliths with the same growth morphology. In any case, the 90º axis provides better visualization of the closest opaque and translucent zones and should be prioritized for increment counting in the Ariid species *C. spixii* and *G. genidens*.

This special issue is an initiative aimed at improving the understanding of this crucial RAMSAR site. By disseminating essential research on this environment, we aim to provide support for other studies in coastal and wetland areas, establishing a solid scientific basis for conservation actions and policies.

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Author Contributions

E.S.B.; J.S.A.: Conceptualization; Writing - original draft; Writing - review & editing.

J.H.; C.G.C.: Writing - review & editing.

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