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Marine bioinvasions: Differences in tropical copepod communities between inside and outside a port

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ABSTRACT

The difficulty of detecting non-indigenous species (NIS) in marine environments is an "invisible problem" in areas where plankton monitoring does not occur. In this study, we investigated the dominance of the NIS *Temora turbinata* and copepod community structure in two tropical marine habitats: inside an offshore port, which had turbid and calm waters, and outside the port, which was more hydrodynamic. Our study area was on the northeast coast of Brazil. We found 17 taxa of Copepoda, which were dominated by *T. turbinata* and the congener, *T. stylifera*. The high average density of the NIS (21.03 ind./m^3) was in stark contrast with that of the native copepods (0.01–3.27 ind./m^3). The NIS density was negatively correlated with the species richness and evenness of the native community, was significantly higher inside the port than outside, and was positively correlated with phytoplankton density. A multivariate analysis revealed that there was a significant difference in copepod community structure between inside and outside the port; outside the port, the community was more diverse, and the native *T. stylifera* was more abundant. We found that tropical copepod communities inside an offshore port have low diversity, and probably have little biotic resistance against NIS invasions. Our results, combined with those previously obtained, highlight the need to study the spatial distributions of NIS and native species in pelagic environments.

Regional index terms

South Atlantic
Brazil
Port of Pecém

1. Introduction

Invasive species have complex multilevel effects on affected ecosystems (Liu et al., 2014; Ojaveer et al., 2014). Despite their ecological and socioeconomic relevance, it is alarming how little is known about marine biological invasions, particularly those driven by small invertebrates and microscopic organisms (Marques, 2011). Among these mostly ignored organisms, zooplankton are an important, although neglected, component of biological invasions, and their effects on the trophic ecology and community equilibrium of marine systems are poorly understood (Svetlichny and Hubareva, 2014).

Copepods are a major component of marine zooplankton in terms of biomass, diversity, and abundance (Miyashita et al., 2009; Atkinson et al., 2012). These organisms constitute a link in the food chain (in water column and benthic-pelagic coupling processes), participate in nutrient cycling, and include species that act as ecological indicators (McCollin et al., 2008; Campos et al., 2017). Marine bioinvasion research has focused on macroorganisms such as benthic invertebrates (Boets et al., 2011; Marques et al., 2013; Çinar and Bakir, 2014; Evans et al., 2017) and gelatinous macrozooplankton (Van Walraven et al., 2013; Augustine et al., 2014; Vansteenbrugge et al., 2015; Malej et al., 2017), but copepods, as important trophic and biogeochemical links, require further study.

Studies describing mesozooplankton bioinvasions in marine ecosystems have been conducted in the Indo-Pacific and North Atlantic Oceans, and in the Black and Mediterranean Seas (Delpy et al., 2012; Gubanova et al., 2014; Svetlichny and Hubareva, 2014; Meier et al., 2015). Tropical studies are few in number, and some locations are

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virtually undiscovered or underrepresented when NIS are monitored and studied. The lack of scientific knowledge, and the difficulty of detecting and managing invasive species, results in bioinvasion by microscopic organisms becoming an "invisible problem" in marine environments. The plankton of the South Atlantic Ocean seems to be a particularly neglected subject of inquiry (Farrapeira et al., 2011; Rocha et al., 2013). This area has seen significant transoceanic ship traffic, but the consequences of maritime transport, including the introduction of benthic NIS into marine ecosystems, have only recently begun to receive appropriate academic and governmental attention (Rocha et al., 2013; Castro et al., 2017).

Along the western coast of the Atlantic, three species of planktonic copepod of the genus *Temora* (*T. longicornis*, *T stylifera*, and *T. turbinata*) have been recorded (Bradford-Grieve et al., 1999), and *T. turbinata* Dana, 1849 is a non-indigenous species (NIS) on the Brazilian coast. *T. turbinata* did not occur in the tropical Southwestern Atlantic Ocean before 1993 (Araújo and Montú, 1993), and may have been introduced with ballast water from ships (Ferreira et al., 2009). Before the establishment of *T. turbinata*, the only representative of the genus on the Brazilian coast was *T. stylifera* (Ferreira et al., 2009). The NIS *T. turbinata* is a widespread coastal and oceanic species (Björnberg, 1981; Bradford-Grieve et al., 1999), and is tolerant of a wide range of conditions (Bradford, 1977; Campos et al., 2017).

In this study, we investigated the dominance of *T. turbinata* and copepod community structure in two tropical marine habitats: inside an offshore port, which had turbid and calm waters, and outside the port, which was more hydrodynamic. This sampling design can elucidate the ecology of invasive planktonic organisms in tropical marine ecosystems. By means of comparison two copepod assemblages, this study indicated the clear impact of oceanographic regime (circulation pattern and flows) on the zooplankton communities and the dominance of the NIS in the region. The main objectives were to (1) analyze the distribution patterns of this NIS inside and outside an offshore port, and (2) to provide a baseline assessment of copepod assemblages and the dominance of *T. turbinata* and the native *T. stylifera*.

2. Materials and methods

2.1. Study area

The tropical coast of Brazil (tropical Southwestern Atlantic Coast) extends from the Maranhense Gulf (2°00′S) to the Paraíba do Sul coastal plain (21°50′S). It comprises three sectors: northern (2–5°S), northeastern (5–12°S), and eastern (12–21°S). Our study area was on the northern coast near the equator, which can be classified as tropical semiarid. This coast contains vast areas of active and stabilized sand dunes, as is typical for semiarid coastal areas. The sea temperature stays within a narrow range of 27 to 29 °C, without any significant seasonal variation (Tsoar et al., 2009). The continental shelf region is characterized by a western boundary current, strong winds, mesotidal regimes, and estuarine discharges. This is a dynamic region, and the origin of many unique features of Atlantic Ocean circulation. One of these is the eastward-flowing equatorial undercurrent, which is fed by the North Brazil Current as it flows along the southwestern coast near the equator (Dias et al., 2013).

Operating since 2002, the Port of Pecém (3°32′S; 38°47′W) is a major port in Latin America because of its geographical location, being relatively close to both Africa and Europe. It is in Northeast Brazil (56 km west of Fortaleza, the capital city of Ceará State), and its offshore terminal is a technologically advanced site that is about 1 km from the shoreline and connected to the land by a bridge.

2.2. Methodology

Samples of the copepod community were taken at 20 stations in both internal (P14 to P20) and external (P1 to P13) areas of the port (Fig. 1). Oceanographic sampling was conducted in the dry season, in October of 2013. The samples were obtained using subsurface plankton nets in 5-min tows, with a conical-cylindrical net (mesh size, 200 µm and mouth diameter, 0.5 m) equipped with a mechanical flow meter. The samples were immediately fixed in 4% formaldehyde buffered with sodium tetraborate (5 g/L).

In addition, physical parameters of the water, such as temperature, pH, dissolved oxygen, and salinity, were measured with a multiparameter probe. Water samples were also analyzed for phosphate, total phosphorus, nitrite, nitrate, ammonia nitrogen, phytoplankton density, and total organic carbon (Strickland and Parsons, 1972; Valderrama, 1981; Edler and Elbrächter, 2010).

Each sample was fractionated in a Motoda box splitter (Omori and Ikeda, 1984) before being divided into subsamples of 1/8 (P1 and P8), 1/16 (P2-P6 and P18-P20), 1/32 (P7, P8, P15, and P16), and 1/512 (P17) of the original. The organisms present were then counted under a stereomicroscope. The species were identified to the lowest taxonomic level possible according to Tregouboff and Rose (1957), Boltovskoy (1981, 1999), and Omori and Ikeda (1984).

The data were analyzed based on the absolute density, relative abundance (%), and frequency of occurrence across stations. The density of copepod species was expressed as the number of individuals per cubic meter of filtered water (ind./m^{-3}). Zooplankton occurrence was classified as very frequent (> 70%), frequent (70–30%), infrequent (30–10%), or sporadic (≤10%). Copepods were analyzed according to the Shannon-Wiener diversity index (H′, $\log_{10}$), Margalef's richness index (d), and Pielou's evenness index (J′).

To elucidate the effects of biological invasions on community structure, we used Spearman's ranked correlations to analyze the relationships between the NIS (*T. turbinata*) density and the community descriptors (H′, d, and J′). We also tested for possible correlations between the abiotic data and NIS density using Spearman's rank coefficient. The Mann-Whitney *U* test was used to compare NIS species density and Shannon-Wiener diversity index values inside the port and outside the port (on the continental shelf), and to assess differences in abiotic variables inside and outside the port.

We conducted a permutational multivariate analysis of variance (PERMANOVA) to ascertain whether copepod community distributions were significantly different between inside and outside the port. The significance level of all the statistical analyses was set to $\alpha = 0.05$ in the software packages Primer 6.0, PAST, and Statistica.

3. Results

3.1. Environmental variables

Temperature, pH, and salinity varied across the stations (27.8–28.0 °C, 7.7–8.1, and 37.5–37.9, respectively). Levels of nitrate (0.13 ± 0.04 mg/L; mean ± standard deviation), nitrite (0.02 ± 0.05 mg/L), ammonia nitrogen (0.03 ± 0.01 mg/L), phosphate (0.03 ± 0.01 mg/L), phosphorus (0.06 ± 0.04 mg/L), phytoplankton density (93,150 ± 35,559 ind./L^{-1}), and total organic carbon (14.99 ± 6.41 mg/L) did not significantly differ between stations inside and outside the port (Mann–Whitney *U* test, $p > 0.05$). Values for the 11 environmental variables measured at each site are shown in Supplementary material 1.

3.2. Copepod community

Individuals from three orders were detected in the study area: Calanoida, Cyclopoida, and Harpacticoida, which collectively comprised 17 species. *Temora turbinata* (NIS) had the highest density among the taxa (Table 1) and the highest relative abundance (78%) among the Copepoda, including its native congener, *Temora stylifera*. *Temora turbinata* was abundant at P15-P19 (inside the port) and was present at all stations, except P14 (Fig. 2A), and was dominant inside the port