Effects of a La Niña event on hydrological patterns and copepod community structure in a shallow tropical estuary (Taperaçu, Northern Brazil)

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Abstract

The influences of the 2011 La Niña event on the hydrological patterns and copepod community structure were investigated in a shallow tropical estuary, the Taperaçu, in northern Brazil. Specifically, this study aimed to explore the response of the most dominant copepod species and ecological indices (diversity, evenness and richness) to temporal changes in rainfall regime and water parameters in a tropical meso-macro tidal setting. Zooplankton samples were collected from three sampling sites using a conical plankton net (120 μm mesh), with both water and zooplankton samples analyzed by standard methods. In 2011, the physical, chemical and biological parameters of the water were exacerbated by increased rainfall levels resulting from the La Niña event. This resulted in a reduction in the salinity and an increase in dissolved nutrient concentrations and phytoplankton biomass in the study area. These conditions had a direct effect on the monthly dynamics of copepods as a whole, and in particular of five species, O. oswaldocruzi (169,090 ± 254,609 ind. m⁻³; p < 0.0001), P. acutus (301,133 ± 518,065 ind. m⁻³; p < 0.05), P. marsi (329,391 ± 563,009 ind. m⁻³; p > 0.05), O. hebes (40,888 ± 64,893 ind. m⁻³; p < 0.05) and A. tonsa (10,680 ± 13,877 ind. m⁻³; p > 0.05), all of which were represented by higher densities in February. An extremely high recruitment rate of copepod nauplii was also observed during this month (3,088,309 ± 5,206,645 ind. m⁻³; p < 0.05), with this peak in density thus overlapping that of the adult forms. The anomalous period of rainfall was also reflected in reduced species richness and diversity, which not only affected the structure of the copepod community, but may also have provoked shifts in trophic dynamics at higher levels, such as zooplanktivorous fishes.

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1. Introduction

The Amazon coast of northern Brazil corresponds to almost one third (2500 km) of the country’s coastline, and is characterized by the largest continuous belt of mangrove found anywhere in the world, and dozens of islands and estuaries, including the mouth of the Amazon River. The physiography of this region is quite distinct from that of other coastal systems in Brazil and other parts of the world, due to its unique configuration of meteorological (high rainfall and elevated temperatures with reduced thermal variation) and oceanographic features, including its semi-diurnal macrotides, strong currents, an extensive, flat continental shelf, and the immense fluvial discharge of freshwater, sediments, and nutrients (Figuerola and Nobre, 1990; Geyer et al., 1996; Silva et al., 2013).

In some other mangrove environments around the world (Rios-Jara, 1998; Chew and Chong, 2011), oscillations in zooplankton populations may be associated with those in the primary production, i.e., the availability of phytoplankton, benthic microalgae, and mangrove detritus, which are driven by physical and chemical variables. Amazonian estuaries are highly productive ecosystems, contributing to the synthesis of organic material, and providing a critical habitat for benthic, planktonic, and nektonic organisms, as well as for migrating birds and marine mammals. As these environments are extremely complex, it is virtually impossible to define any single factor that regulates the distribution of the zooplankton community, but given the lack of any major seasonal variation in temperature in the equatorial region, fluctuations in the salinity of the water may...
be the primary determinant of the spatial and temporal dynamics of the community in Amazonian estuaries (Magalhães et al., 2006, 2009a,b, 2010, 2011, 2013; K.G. Costa et al., 2013; R.M. Costa et al., 2011; Palma et al., 2013). At low latitudes, fluctuations in salinity are driven mainly by changes in rainfall levels and fluvial discharge (Nittrouer and DeMaster, 1986), and to a lesser extent by macrotidal forcing, which in Amazon estuaries ranges from 4 m to 12 m (DHN, 2015).

Longitudinal gradients in salinity have a direct effect on the spatial partitioning of zooplankton in estuaries, with species being segregated according to their respective ability to osmoregulate (Lawrence et al., 2004). Short- or long-term changes in salinity may also affect the dynamics of zooplankton communities, especially in terms of the dominant copepod species (Primo et al., 2009; Muxagata et al., 2012; Chew et al., 2015). Shifts in salinity may have a marked effect on phenomena such as egg production, the development and survival of nauplii, feeding and swimming (Cervetto et al., 1999; Peck and Holste, 2006; Callari et al., 2008; Kaminiski et al., 2014). These changes are determined by climatic variations that can also affect other physical-chemical variables (Nybakken and Bertness, 2005), and understanding exactly how salinity and other hydrological parameters affect zooplankton communities will be essential to the prediction of the effects of climate change on the structure of these communities (Marques et al., 2007).

In the Amazon region, long-term variation in rainfall levels results from a complex of climatic factors (Marengo, 2004), such as the cyclical La Niña and El Niño events. The last La Niña event developed in mid-2010, and was induced by precipitation anomalies over northern South America (including the Amazon coast), as well as Australia and South-east Asia (Boening et al., 2012), resulting in extensive flooding (Trenberth and Fasullo, 2012). The 2010/11 La Niña was a moderate to strong event (NOAA, 2014), the effects of which were recorded on the Amazon coast mainly during the 2011 rainy season. The increase in precipitation levels resulting from a La Niña event tends to have serious environmental and social consequences for whole Amazon region (Gratiot et al., 2008; Boening et al., 2012). While increasing rainfall levels and fluvial discharges on the Amazon coast (in the Amazon and other 23 estuaries), little is known of the impacts of this process on the salinity and other physical-chemical parameters of the coastal waters, and the impacts of this variation on the local plankton community.

One of the few known effects of La Niña on plankton dynamics in this region is a tendency for an increase in phytoplankton biomass (chlorophyll-a), related to the higher input of dissolved inorganic nutrients resulting from the increase in both rainfall and fluvial discharge (Pereira et al., 2013). However, no ecological studies have focused specifically on the zooplankton dynamics on the Amazon coast during anomalous periods of climate, such as a La Niña event. Along the west coast of America off Peru (Ayón et al., 2008) and California (Hayward, 2000; Marinovic et al., 2002) La Niña events tend to intensify resurgence processes, affecting plankton communities through an increase in phytoplankton and zooplankton biomass, with knock-on effects at the highest trophic levels (Tutasi et al., 2011). These events usually have a positive impact on the fishing industry of western America. As many commercially-important fishery resources, including fish and shellfish species, have a planktonic larval phase, the modifications of ecological processes provoked by La Niña may enhance recruitment rates and contribute to adult migrations.

Given these considerations, the present study investigated the impact of a La Niña event on the structure and function of the local copepod community, exploring the link between the anomalous conditions, the hydrology, hydrodynamics, and the zooplankton in a shallow tropical estuary in northern Brazil – the Taperacu – which has unique characteristics, including the absence of fluvial discharge, a small catchment area, shallow waters, and strong tidal currents. The focus on the copepods as a key zooplankton group in the study area was related to their capacity to act as an indicator of disturbances in the aquatic environment, given that they typically reach high densities, but low species diversity and richness under conditions of stress (of natural or anthropogenic origin). Copepods are also the most prominent zooplankton group in the Taperacu estuary, where they typically account for 50–90% of total zooplankton abundance (Costa et al., 2008; Magalhães et al., 2015).

The findings provide useful insights into zooplankton dynamics in the context of La Niña events in similar systems in Brazil and in other parts of the world. We hypothesize that this event had an important effect on local hydrological conditions, in particular salinity and food availability (i.e. phytoplankton productivity), which in turn affected the structure and dynamics of the copepod community in the study area.

2. Materials and methods

2.1. Study area

The Taperacu is a small Amazonian estuary (~30 km in length) located on the coastal plain of Bragança, in the northern Brazilian state of Pará, approximately 200 km to the east and south of the mouth of the Amazon River (Fig. 1). This estuary has a water surface area of 21 km² and a catchment of approximately 40 km² (Araújo and Asp, 2013). It is classified as a permanently open estuary, characterized by high turbidity (mean = 378.1 NTU), shallow waters (mean depth = 4.2 m), and strong tidal currents, of up to 2.0 m s⁻¹ (Asp et al., 2012). This system is dominated by semidiurnal meso-macro tides, with ranges of approximately 5 m, reaching 6 m during equinoctial spring tides and 3–4 m during neap tides (DHN, 2015). These features distinguish the estuaries of the Amazon coast from those of other regions of Brazil.

Morphologically, the Taperacu estuary is funnel-shaped with extensive sandbanks running down its middle. Internal water circulation is typical of shallow estuaries, with a marked vertical homogeneity in salinity and temperature (Asp et al., 2012). This, together with the lack of any effective fluvial discharge and the small catchment area – characterized by a sporadic and minimal influx of freshwater – hinder the formation of any systematic horizontal gradient in hydrological characteristics, especially during the less rainy months (Magalhães et al., 2015).

The region’s climate is hot and humid, with a rainy season between January and June, and a dry – or less rainy – season between August and December (Moraes et al., 2005). Approximately 75–85% of annual precipitation falls during the first half of the year (INMET, 2015), when the Intertropical Convergence Zone (ITCZ) shifts to the southern hemisphere, provoking an increase in rainfall levels, whereas in the second half of the year, the ITCZ shifts back to the northern hemisphere, creating drier conditions (Marengo, 1995). Mean annual rainfall is 2500 mm, although major deviations from this value are not uncommon, as observed during the past 29 years, when a number of La Niña, El Niño and drought events were recorded (Fig. 2a). These rainfall data were acquired hourly each day between January 1982 and December 2011 by the Brazilian Institute of Meteorology (INMET–Tracuateua station). Local mean monthly air temperatures range between 25.2 and 26.7 °C, with a daily amplitude of 20.4–32.8 °C (Schories and Mehlig, 2000).

Human influence in Taperacu estuary is limited, with low levels of occupation along its margins. This estuary is part of the Caeté-Taperacu Marine Extractivist Reserve, in which renewable natural resources (e.g. crabs, fishes, mollusks and firewood) are harvested by the traditional local populations resident within its limits. The Taperacu estuary is bordered by dense and relatively well-developed mangrove forests, with trees of up to 20 m in height, and a complex network of tidal creeks which link it to the neighboring Caeté estuary and Maiáï Bay. The input of nutrients and organic matter from the local mangroves controls both primary and secondary production in these estuaries and the adjacent habitats of the Amazon coast (Dittmar and Lara, 2001; K.G. Costa et al., 2013; R. M. Costa et al., 2011).