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Freshwater scarcity effects on the aquatic macrofauna of a European Mediterranean-climate estuary

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HIGHLIGHTS

- We assess effects of water scarcity on estuarine community in a 12-year data set.
- Mediterranean-climate estuaries are prone to exacerbated effects of water scarcity.
- The estuarine community showed a dynamic spatial structure due to salinity changes.
- High turbidity altered the structural and functional community characteristics.

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ABSTRACT

In the Mediterranean-climate zone, recurrent drought events and increasing water demand generally lead to a decrease in freshwater input to estuaries. This water scarcity may alter the proper function of estuaries as nursery areas for marine species and as permanent habitat for estuarine species. A 12-year data set of the aquatic macrofauna (fish, decapod and mysid crustaceans) in a Mediterranean estuary (Guadalquivir estuary, South Spain) was analysed to test if water scarcity favours the nursery function of regional estuaries to the detriment of permanent estuarine inhabitants. Target species typically displayed a salinity-related distribution and estuarine salinisation in dry years resulted in a general upstream community displacement. However, annual densities of marine species were neither consistently higher in dry years nor estuarine species during wet years. Exceptions included the estuarine mysid *Neomysis integer* and the marine shrimp *Crangon crangon*, which were more abundant in wet and dry years, respectively. High and persistent turbidity, a collateral effect of water scarcity, altered both the structural (salinity-related pattern) and functional (key prey species and predator density) community characteristics, chiefly after the second drought period of the analysis. The observed high inter-year environmental variability, as well as species-specific effects of water scarcity, suggests that exhaustive and long-term sampling programmes will be required for rigorously monitoring the estuarine communities of the Mediterranean-climate region.

1. Introduction

During the last half of the 20th century, many Circum-Mediterranean river discharges declined more than those implied by reductions in precipitation. This was due to the additional effects of damming, irrigation, and inter-basin water transfers. In contrast, most northern European rivers showed little change in annual discharge and basin precipitation (Milliman et al., 2008). This anthropogenic reduction of freshwater discharge from Mediterranean rivers may lead to a larger extended seawater intrusion in estuaries, resulting in an enlargement of estuarine areas that are used as nursery grounds for marine species (Costa et al., 2007; Fernández-Delgado et al., 2007; Martinho et al., 2007; Pasquaud et al., 2012; Chaalali et al., 2013a). Such estuarine salinisation may increase the occurrence of marine adventitious species (Martinho et al., 2007) as well as typical continental shelf species in the lower portions of estuaries (Able, 2005). Additionally, low river discharge could favour estuarine jellyfish blooms (Muha et al., 2012) and hamper marine recruits' ability to locate estuarine areas by following physicochemical gradients along the estuarine plume (Boehlert and Mundy, 1988; Kingsford and Suthers, 1994; Schlacher and Wooldridge, 1996). Freshwater

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flow into estuaries during periods of rainfall is essential to maintain the structure and function within the estuary and in neighbouring coastal waters. Freshwater flow will flush excess suspended particulates (high turbidity) out of an estuary and enhance the biomass of primary producers propagating to higher trophic levels (Abril et al., 2002; Le Pape et al., 2003; Ludwig et al., 2009; Prieto et al., 2009; González-Ortegón et al., 2012). The prevalence of tides in estuaries during severe droughts may increase the residence time of suspended matter (Uncles et al., 2003), reduce primary productivity, and also affect upper trophic levels by altering both habitat conditions and food availability (Livingston et al., 1997; Wetz et al., 2011; Dauvin and Pezy, 2013).

The long-term consequences of Mediterranean rivers' streamflow on changes in estuarine fauna are not easy to predict because of very large year-to-year variations in precipitation (Dai et al., 2009). In addition, estuarine inhabitants are physiologically adapted to inherent variability (Able, 2005) and make it difficult to detect anthropogenic stressors (Estuarine Quality Paradox; Dauvin, 2007). Despite the high resilience of estuaries (Elliott and Whitfield, 2011), if environmental conditions within each season fluctuate outside their usual variability bounds, there may be resulting changes in species composition and distribution on the short (days, weeks), mid (seasonal) and long (inter-annual) term.

In the case of the Guadalquivir estuary, species composition and spatiotemporal patterns communities are similar to those found in other European estuaries (Marshall and Elliott, 1998; Pasquaud et al., 2012; Maes et al., 2005; Costa et al., 2007; Franco et al., 2008). This is irrespective of the occurrence of African species due to its close location to the northern African coast (Rodríguez et al., 1997; Castañeda and Drake, 2008; Drake et al., 2014). Furthermore, during the last few decades, annual freshwater discharge of the Guadalquivir River has displayed the largest decrease (84%) of all large European rivers (Milliman et al., 2008). When strong and sudden freshwater discharges occurred after drought periods, periods of high and persistent turbidity followed (González-Ortegón et al., 2010b). Large-scale atmospheric circulation patterns explain much of the variability and trends in precipitation and temperature at the regional scale. In the Mediterranean region, extraordinarily dry and wet winter conditions have been linked to the different phases of the North Atlantic Oscillation (NAO) (Hurrell and van Loon, 1997; López-Moreno et al., 2011). The total annual rainfall produced by storms from the Atlantic Ocean tends to show a periodicity of 12 years (Ávila, 2007) and a correlation between NAO and winter precipitation every six-years has also been observed in the last century (Fritier et al., 2012). Thus, exhaustive sampling and long-term studies will be necessary to give consistent insights into how estuarine communities are responding to environmental alterations.

The increased temperatures (higher evaporation) and decreased precipitation expected in the near future for the Mediterranean region could increase pressure on water resources in the river basins (Sanderson et al., 2011). Long-term studies of estuarine assemblages in individual systems are necessary to understand differences among ecosystems in their responses to the expected increase in drought events. Using a 12-year data set of the Guadalquivir estuarine biota, when short (month-to-month) term variability and medium (seasonal) term variability were included, a long-term trend was not observed in the estuarine communities (Cuesta et al., 2006; González-Ortegón et al., 2012). In this study, a re-analysis of this time-series was carried out to get a proper assessment of the response of estuarine assemblages to the expected increase in drought events on an annual basis. We hypothesised that under a scenario of water scarcity and extended seawater intrusion in the estuary, the role of the estuary as nursery ground for marine species would be favoured to the detriment of permanent estuarine inhabitants. Therefore, it would be expected to observe an increase in the estuarine density of marine recruits and/or an enlargement of the habitat used by these species in relation to the grade of drought.

2. Material and methods

2.1. Study area

The Guadalquivir River Basin is located within the Mediterranean-climate region (southwest Spain). However, the river empties into the Atlantic Ocean and tidal influence extends up to the Alcalá del Río dam (at 110 km from the river mouth). Occasionally, during the passage of Atlantic storms, freshwater discharges from the dam may be greater than 400 $m^3 s^{-1}$ and the estuary becomes fluvially-dominated (Díez-Minguito et al., 2012). Conversely, under low river inflow discharge conditions (<40 $m^3 s^{-1}$), the freshwater inflow to the estuary is totally regulated by the dam and the estuary is a well-mixed and tidally dominated system (Vannéy, 1970; Díez-Minguito et al., 2012), with a longitudinal salinity gradient that shows both long-term (seasonal and inter-year) and short-term (tidal and dam management-related) displacements along the river course (Drake et al., 2002). The area situated seaward from the isohaline 5 acts as nursery grounds for marine species (Fernández-Delgado et al., 2007). On average, the isohaline 5 boundary (between the oligohaline and mesohaline zones) is situated 25 km and 35 km upstream from the river mouth at low tide and high tide, respectively; while the isohaline 18 boundary (between the mesohaline and polyhaline zones) is situated 5 km and 15 km upstream at low tide and high tide (Fernández-Delgado et al., 2007). Three sampling sites were selected within this area: Tarfia (mean salinity ± standard deviation: 5.6 ± 3.6), La Esparraguera (11.1 ± 6.6) and Bonanza (21.2 ± 9.6) situated at 32, 20 and 8 km from the river's mouth, respectively.

2.2. Data sets

Biological data analysed in this study correspond to samples collected monthly from September 1997 to August 2009 (except January to April 2009, due to a lack of financial support) at each new moon, from a boat anchored where the water column depth was approximately 3 m at low tide. Four passive hauls were carried out at each sampling station using three 10 m long nets (net opening: 2.5 m wide and 3 m long; mesh size: 1 mm) working in parallel during the first 2 h of the diurnal and nocturnal flood and ebb tides. The total catch was emptied into a calibrated container and its volume was estimated. A subsample (thirteen litres) of the collected material, or the total volume when the catch was smaller, was randomly sampled using a calibrated beaker. In the laboratory, nektonic and hyperbenthic (fish, decapod and mysid crustaceans) organisms were sorted into species and counted.

Water temperature (°C), salinity and turbidity (NTU) were measured in the field at the start of each haul. The current speed during sampling was estimated with a digital flowmeter (HYDRO-BIOS®, 438 110) placed near the nets. Freshwater discharges from the Alcalá del Río dam were obtained from the Regional River Authority (Confederación Hidrográfica del Guadalquivir) database (http://www.juntadeandalucia.es/agenciadelagua/saih/DatosHistoricos.aspx). Rainfall in the estuarine area was obtained from the meteorological station of "El Palacio" located at Doñana National Park (http://www-rbd.ebd.csic.es/Seguimiento/mediofisico.htm) and rainfall at basin level was obtained by averaging rainfall at ten locations upstream the dam (for more details see González-Ortegón et al., 2012).

2.3. Data analysis

According to the objective of the study, the short-term temporal (monthly and seasonal) variability of all recorded variables was removed by averaging discrete (monthly) data into annual (water year) means. Taking into account the local seasonal rainfall pattern (González-Ortegón and Drake, 2012), a water year was considered as the 12-month period between September 1st of one year and August 31st of the next year and it was designated by the calendar