ARTICLE IN PRESS

Journal of Sea Research xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Sea Research

journal homepage: www.elsevier.com/locate/seares

Seasonal and interannual variability of mesozooplankton in two contrasting estuaries of the Bay of Biscay: Relationship to environmental factors

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ARTICLE INFO

Keywords:
Zooplankton
Estuary
Time series
Seasonal variation
Interannual variation
Bay of Biscay

ABSTRACT

Seasonal and interannual variations of total mesozooplankton abundance and community variability were assessed for the period 1998–2005 at 3 salinity sites (35, 33 and 30) of the estuaries of Bilbao and Urdaibai (southeast Bay of Biscay). Spatial differences in mesozooplankton seasonality were recognized, both within and between estuaries, related to differences between sites in hydrodynamic features and anthropogenic nutrient enrichment that drive phytoplankton biomass seasonal cycles. The within estuary seasonal differences in mesozooplankton community were mainly shown through seaward time-advances in the seasonal peak from summer to spring along the salinity gradient, linked to differences in phytoplankton availability during the summer, in turn, related to nutrient availability. These differences were most marked in the estuary of Urdaibai, where zooplankton seasonal pattern at 35 salinity (high tidal flushing) resembled that of shelf waters, while at 35 of the estuary of Bilbao zooplankton showed an estuarine seasonal pattern due to the influence of the estuarine plume. Cirripede larvae contributed most to the mesozooplankton seasonal variability, except at the outer estuary of Bilbao, where cladocerans and fish eggs and larvae were the major contributors, and the inner estuary of Urdaibai, where gastropod larvae contributed most. Total mesozooplankton increased at 30 salinity of the estuary of Bilbao and 35 salinity of the estuary of Urdaibai. Interannual variability of mesozooplankton at the lowest salinity of the estuary of Bilbao was mainly accounted for by copepods due to the introduction of non-indigenous species during estuarine rehabilitation from intense pollution. However, bivalve larvae and gastropod larvae showed the highest contributions at 35 salinity of the estuary of Urdaibai. At the rest of sites, the opposite interannual trends of polychaete larvae and hydromedusae generally made the highest contribution.

1. Introduction

Mesozooplankton are the fundamental link between primary producers and upper trophic level consumers in marine food webs, and play a relevant role in the biogeochemical cycles in the ocean (Dam 2013). Moreover, they are ectotherms with short generation times, capable of responding fast to environmental changes (Dam 2013). Indeed, zooplankton live in ever changing ecosystems, under the influence of multiple stressors. Hydro-climatic changes are important drivers of marine ecosystem variability (Hewitt et al. 2016) and zooplankton variability (Beaugrand and Ibanez 2004; Marques et al. 2014), but direct anthropogenic factors can also have paramount effects on marine ecosystems (Blaber et al. 2000; Islam and Tanaka 2004), in general, and on zooplankton in particular (Verity and Borkman 2010). This is most evident in nearshore coastal and estuarine systems that are subject to high human pressures, such as port activities, industrial and domestic waste disposal, dredging, land reclamation or fisheries and aquaculture (McLusky and Elliott 2004), and even to remediation actions in disturbed areas (Borja et al. 2010), which drive variations of biological communities at different temporal scales. In temperate waters zooplankton show marked seasonality (Miller 1983), but they can also show long-term trends and regime shifts (Beaugrand and Ibanez 2004; Beaugrand et al. 2014; Uriarte et al. 2016). However, despite the potential of zooplankton to be exceptional beacons of environmental change (Richardson 2008; Beaugrand et al. 2009), knowledge about the impact of multi-stressors on coastal and estuarine zooplankton is still scant (Vieira et al. 2015), partly because of the scarcity of long-term time series (Buttay et al. 2015), which are particularly limited in southern Europe (Vieira et al. 2015).

Besides temporal changes, estuaries also show strong spatial variations across and within systems. Estuaries are characterized by a marked heterogeneity across systems due to differences in latitude,

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http://dx.doi.org/10.1016/j.seares.2017.05.002
Received 4 November 2016; Received in revised form 2 May 2017; Accepted 7 May 2017

climate, origin, geomorphology, hydrological regime, degree and type of anthropogenic impact, amongst others. Also, since estuaries are transition systems between continents and oceans, they show high spatial variations along the longitudinal axis, mainly in salinity, but also in hydrodynamic features, sediment characteristics, nutrients, pollutants and others (Knox 1986). These environmental variations can be responsible for spatial differences in zooplankton distribution (Uriarte and Villate 2004; Marques et al. 2007) and, as a consequence, temporal variations of zooplankton can also differ between salinity zones across and within estuaries.

To the best of our knowledge, on the Iberian coast of the Bay of Biscay, the only two estuaries for which zooplankton time series derived from regular monitorings along their longitudinal axes exist are the estuaries of Bilbao and Urdaibai. These are systems located near each other on the Basque coast that share the same climate, but have contrasting geomorphology, hydrodynamic characteristics, degree of anthropogenic influence and ecological status (Franco et al. 2004). These similarities and differences make them ideal systems to distinguish the effects of climate factors from direct anthropogenic driving forces.

Comparisons of temporal and spatial variations in the distribution of major groups of mesozooplankton between these two estuaries have been carried out in previous studies. Uriarte and Villate (2004) showed a clear influence of salinity and pollution on the spatial distribution and abundance of most mesozooplankton groups when they compared different salinity sites along the longitudinal axis of these two estuaries, but they made no comparisons of temporal variations. Albaina et al. (2009) dealt with spatial and temporal variations, but only for a period of < 2 years, over which they detected initial signs of recovery of the mesozooplankton community in the estuary of Bilbao in response to the improvement in water quality. Therefore, a need for investigating in greater detail the temporal (both seasonal and interannual) variations in mesozooplankton at different salinity sites in these estuaries has been identified.

Taking these considerations into account, the aims of the present work were to assess at different fixed salinity sites along the longitudinal axis of the estuaries of Bilbao and Urdaibai (i) the seasonal and interannual variations of the mesozooplankton community, (ii) the contribution of the various holoplankton and meroplankton groups to each type of temporal variability in the mesozooplankton community and (iii) the influence of environmental factors on the main temporal variations of the mesozooplankton community.

2. Material and methods

2.1. Study area

The estuaries of Bilbao (also known as Ibaizabal-Nerbioi estuary or Nervión estuary; 43°23′N, 03°07′W) and Urdaibai (also known as Gernika estuary, Mundaka estuary or Oka estuary; 43°22′N, 02°43′W) are located near to each other (Fig. 1), and share the same temperate-oceanic climate with moderate winters and warm summers. However, they differ largely in morphology, hydrodynamic features and water quality.

2.1.1. Estuary of Bilbao

The estuary of Bilbao is ca. 23 km long and it is divided in two areas: the intermediate-inner channelized area constituted by a 15 km long, narrow (50–150 m) and 2–9 m deep man-made channel and a wider (ca. 3.8 km) and deeper (10–25 m) outer area called the Abra harbour. The estuary is partially mixed in the outer area and highly stratified in the inner area. High salinity waters (> 30) usually penetrate as far as the upper reaches at the bottom, while freshwater flows seaward at surface and is progressively mixed with seawater. The main rivers flowing into this estuary are the Ibaizabal and Nerbioi. Except for short periods of high river discharge, euhaline waters (salinity > 30) dominate within the estuary (Intxausti et al. 2012; Villate et al. 2013). The natural features of the estuary were dramatically modified by urban, industrial and port developments. Due to land reclamation and channelization works, the estuary has lost most of its original intertidal areas (Cearreta et al. 2004). By the 1970s, extremely low oxygenation together with high organic matter and heavy metal concentrations characterized the estuary (Cearreta et al. 2004), which gave rise to extensive azoic benthic areas (González-Oreja and Saiz-Salinas 1998). At present the estuary is in a rehabilitation process, as a result of the implementation of a Comprehensive Plan for the Sanitation of the Metropolitan Area of Bilbao since 1979, new environmental protection policies and the industrial decline in the area surrounding the estuary, which have caused a significant decrease in heavy metal concentrations, ammonia and organic matter loading, and an increase in oxygenation and biodiversity (García-Barcina et al. 2006; Borja et al. 2010; Pascual et al. 2012; Villate et al. 2013). In the middle reaches, the estuary receives discharges from a waste water treatment plant where secondary treatment began to be applied in 2001 (Franco et al. 2004).

2.1.2. Estuary of Urdaibai

The estuary of Urdaibai, with a maximum and minimum width of 1.2 km and < 20 m in the outer and inner areas respectively, is shorter (12.5 km), shallower (mean depth of 3 m) and physically much less modified than the estuary of Bilbao. The central channel is bordered by salt marshes and muddy intertidal areas at its upper and middle reaches and by relatively extensive intertidal flats (mainly sandy) at its lower reaches. The watershed area is small and river inputs are usually low when compared to the tidal prism. As a consequence, most of the estuary is seawater-dominated at high tide, with high salinity waters in the outer half and a stronger axial gradient of salinity towards the head, where it receives the freshwater inputs from its main tributary, the Oka river (Villate et al. 2008). In the outer zone, tidal flushing is so high that waters of salinities > 34 are flushed out of the estuary with each tidal cycle. The outer half of the estuary remains well mixed most of the time, and the inner half is partially stratified. In the upper reaches, the estuary receives relatively large amounts of nutrients and organic matter from an old primary waste water treatment plant (Franco et al. 2004).

2.2. Data collection

Samplings were carried out monthly at high tide during neap tides for the period 1998–2005 at the sites of 35, 33 and 30 salinity in the estuaries of Bilbao (B35, B33 and B30) and Urdaibai (U35, U33 and U30). The changing spatial zonation of salinity in the estuaries of Bilbao and Urdaibai due to the effect of tides and river discharge was the reason for not sampling at fixed points, but at fixed salinity zones, using thus a lagrangian type of sampling strategy, as in other estuarine zooplankton studies (e.g. Kimmerer et al. 1998). At each site vertical profiles of salinity, temperature and dissolved oxygen were obtained using a WTW multi-parameter water quality meter, but only data from the depth of zooplankton sampling have been used in the present study. Salinity stratification index (unitless) was calculated as the maximum difference in salinity at 0.5 m depth intervals as in previous studies (Villate et al. 2013; Iriarte et al. 2015).

Zooplankton were collected from mid depth, below the halocline (usually at 3–5 m), by horizontal tows of a 200 μm mesh size ring net (25 cm of mouth diameter; 100 cm long) equipped with a digital flow meter. Water samples were taken with a Niskin bottle for chlorophyll *a* measurements at the same depth of zooplankton collection. Secchi disk depths were also measured at each sampling site.

Zooplankton samples were preserved in 4% borax buffered formalin seawater solution. Identification and counting to the lowest possible taxonomical level was performed using a microscope, but only the main coarse holoplankton (i.e. copepods, appendicularians, cladocerans, chaetognaths, siphonophores, doliolids and *Noctiluca*) and meroplank-