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Effects of fluvial discharges on meiobenthic and macrobenthic variability in the Vistula River prodelta (Baltic Sea)

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ABSTRACT

The role of environmental variability produced by river discharges in shaping the spatial and seasonal patterns of meiobenthic and macrobenthic communities was studied in the Vistula River (Baltic Sea) prodelta. Seven stations located in the delta front, the plume influence area and the distal zone of the prodelta were visited over the four seasons of 2012. Meiofauna, macrofauna, water (temperature, salinity, and suspended matter) and sediments (grain size, POC, TN, δ^{15}N and δ^{13}C and photosynthetic pigments) were analysed. The seasonal variations in the river discharges (with maximum flows in spring) resulted in a strong temporal variability in the studied environmental characteristics. In the benthic biota, the signals of seasonal variability, if present, were much weaker than spatial zonation. The benthic communities inhabiting the delta front where the main bulk of fluvial materials was deposited were taxonomically impoverished. The richest fauna dwelled within the plume influence area where the physical disturbance ceased and primary marine production was enhanced by river transported nutrients. In the distal zone outside the river influence, the fauna was dominated by deeper dwelling species, and the numbers of individuals and taxa decreased. Factors related to the riverine discharges (i.e., salinity, mineral suspension, POC and δ^{13}C in the water and sediments) were identified as having high correlation with variability in the meiofaunal and macrofaunal community descriptors. Evidently, the interplay of food (i.e., the quantity and quality of organic matter) and disturbance (i.e., the deposition of river transported minerals) constraints shaped the patterns of benthic variability in the prodelta of the second largest river entering the Baltic Sea.

1. Introduction

Despite their relatively small areal extent, marine systems influenced by large rivers play a great role in maintaining global ocean carbon budgets and are the most productive regions in coastal ocean (Bianchi and Alison, 2009). Subaqueous parts of the river deltaic system (prodeltas) typically extend into coastal waters. An intensive accumulation of river transported mineral particles forms dynamic delta fronts. Turbid water plumes extending beyond this region define river boundaries and physically and biogeochemically impact marine waters (Bonifacio et al., 2014, Rhoads et al., 1985). The large amounts of organic carbon in the prodelta system are mixtures of allochthonous (terrestrially derived) and autochthonous (marine primary production fuelled by nutrients transported by the rivers) materials (Doi et al., 2005), which, despite reduced diversity, supports high standing stocks and productivity of pelagic and benthic consumers (Elliott and McLusky, 2002). The quantities and quality of the riverine and marine materials settling to the sea bottom and other environmental and biological parameters and processes change dramatically across prodelta benthic habitats, which are commonly categorized as: 1) the delta front, i.e., areas in the vicinity of the river mouth with the highest loads of river transported materials; 2) the plume area, i.e., areas within the range of the riverine plume influence; and 3) the distal zone, i.e., areas with no or little river impact (Bonifacio et al., 2014, Rhoads et al., 1985).

Over the past 2000 years, European estuaries have been under high anthropogenic pressure. The industrial revolution has increased organic waste discharge in the past century, necessitating construction projects to provide flood protection and land reclamation (McLusky, 1999). Changes in land use (i.e., deforestation, intensive agriculture and urbanization) have increased sediment yield and deposition in river catchments leading to detrimental consequences on the biodiversity and functioning of river-proximal coastal systems (Akoumianaki et al., 2006; GESAMP, 1993). However, construction projects, e.g., river dams, have been shown to improve the nutritious quality of organic matter in the river prodeltas by enhancing phytoplankton production and preventing the accumulation of land-derived vascular plant debris (Bianchi and Alison, 2009). Global changes have also influenced

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estuaries by modifying their biotic and abiotic parameters (Chaalali et al., 2013). Due to more frequent severe weather events such as floods or droughts, the intensity of the river inflows and their effects on coastal ecosystems have changed (Grilo et al., 2011). Higher precipitation during warm periods and increased runoffs during melting seasons may result in increased freshwater input and changes in estuarine water stratigraphy and stronger salinity fluctuations (Scavia et al., 2002). Higher water discharges can improve water quality by diluting nutrients and increasing oxygen concentrations (Struyf et al., 2004) but are accompanied by higher loads of terrestrial (organic and mineral) materials (Syvitski and Andrews, 1994). However, global warming may also result in increased summer warm periods, with decreased precipitation and river discharges and a marinization of an estuary (David et al., 2007). In this scenario, water salinity increases, species compositions have increased marine components and estuaries are more efficiently utilized as nurseries by marine pelagic fishes (Chaalali et al., 2013, Pasquaud et al., 2012).

The recognition of the variability and structure of benthic biota and their interactions with a dynamic estuarine environment is crucial for the understanding of the whole river prodelta system. Benthos is an important element of the energy and matter flow in a river prodelta and contributes in the remineralization of organic matter deposited in estuarine sediment. Organic particles are buried into deeper sediment layers, surface sediments are biologically mixed, and some substances are released into water (Aller et al., 2008; Herman et al., 1999). To a large extent, the fate of terrigenic organic carbon transported by rivers and preserved in marine sediments is regulated by the presence, standing stocks and composition of a range of benthic biota (from microbes to large invertebrates). Only few studies have assessed the relationship between prodelta/estuarine benthic communities and environmental variables (Bonifacio et al., 2014, Chainho et al., 2006; Rhoads et al., 1985; Wijsman et al., 1999). These studies assessed and quantified the relationships among the spatial and temporal variability of biota and such abiotic factors as biochemical descriptors of organic matter in water columns and in sediments. However, the majority of river prodelta benthic studies have been restricted to macrofauna (invertebrates retained on a 0.5-mm sieve), little attention has been paid to smaller invertebrates (meiofauna). Few studies have included both benthic communities (Patrício et al., 2012; Włodarska-Kowalczuk et al., 2007; Montagna and Kalke, 1992).

Vistula is the longest and the second largest river entering the Baltic Sea. During the last 120 years since the opening of an artificial river mouth (‘Przekop Wisły’), the river mouth has moved seaward by 1.5 km (Koszka-Maroń, 2009). A number of studies have investigated the Vistula. Studies have included identifying the pathway of sediment formation from the shallow area at the river mouth to the depositing area in the Vistula prodelta (Zajączkowski et al., 2010; Damrat et al., 2013), the composition, origin and spatial distribution of organic matter in the water column and sediments (Kuliński and Pempkowiak, 2008; Maksymowska et al., 2000), chloropigments in the water column and sediments (Szymczak-Żyła and Kowalewska, 2007), and the hydrochemical and biological impacts of Vistula on the pelagic zone (Ochocki et al., 1995; Pastuszak, 1995). However, the effects of these environmental gradients on benthic fauna have not been investigated. The aim of the present study is to assess the effects of riverine discharges on the spatial and temporal (seasonal) variability of meiofaunal and macrofaunal components of the Vistula prodelta benthic system and to identify the main environmental factors driving the variability in benthic standing stocks (density), diversity and composition. Many of the published studies have been based on materials collected during one (usually summer) season. However, seasonal fluctuations can impose severe changes to the reported patterns observed during the summer and cannot be neglected to understand the function of the estuarine systems (Chainho et al., 2006). We therefore base our study on materials collected over four seasons throughout a year period to determine whether seasonal variations in the riverine discharges significantly alter the patterns of benthic response to the estuarine environmental processes.

2. Material and methods

2.1. Study area

Vistula is the longest river flowing into the Baltic Sea, with a catchment area of 194,000 km^2 (Pruszak et al., 2005). In the past, River Vistula has created a large delta (Żuławy), but since 1895, its outflow has restricted to one artificial channel (Przekop Wisły, Fig. 1).

The average water discharge near the Vistula mouth is 1080 m^3 s^{-1}, varying seasonally from 250 to 8000 m^3 s^{-1} (Cyberski et al., 2006). Maximum discharges are typically noted in spring, due to ice and snow melting in the entire catchment area (Pruszak et al., 2005). In 2012, the river flow varied from 424 m^3 s^{-1} in September to 1810 m^3 s^{-1} in March (Polish Institute of Meteorology and Water Management). In most days of September and October, water discharge did not exceed 500 m^3 s^{-1}. In March and April, daily water discharge exceeded 1200 m^3 s^{-1}. Due to long period of drought during summer, the average annual river flow (798 m^3 s^{-1}) was lower than those reported in the previous years (Polish Institute of Meteorology and Water Management). The annual sediment transport into the Gulf of Gdańsk ranged from 0.7 to 2.2 million tons of suspension (Emelyanov and Stryuk, 2002) or from 0.6 to 1.5 million m^3 of sediment in total (Pruszak et al., 2005). During the year 2012, an average sediment load in riverine waters was 14.1 mg dm^{-3}, varying from approximately 10 mg dm^{-3} during typical river discharges (i.e., January, August, and November) to 30 mg dm^{-3} in spring (i.e., May, Damrat, unpublished data). A study of the sediment pathway from the Vistula mouth to the outer prodelta demonstrated the significant role of sediment redeposition because the Vistula prodelta is highly influenced by waves (Damrat et al., 2013). Two-thirds of the deposited sediment was remobilized and transported to the Gdańsk Basin during winter storms (Damrat et al., 2013). Average sedimentation rates reach 6000 g m^{-2} yr^{-1} with the maximum occurring during spring (March to May) and the minimum between August and January. However, a study on sediment accumulation in decadal time scales (estimated based on ^{210}Pb sediment dating) showed that only 2000 g m^{-2} yr^{-1} of stored material remained at the bottom of the Vistula prodelta (Damrat et al., 2013).

2.2. Sampling

Material was collected from the board of the r/v “Oceania”. Samplings were conducted during the four seasons of 2012: winter (10–11th January), spring (17th May), summer (27th August) and autumn (28th November). Seven sampling stations representing four zones defined by increasing distance from the river mouth were located along two transects starting from station N1 located 2.0 km north of the Vistula river mouth, stations N2, N3, and N4 extending northward (4.3 km, 6.9 km, and 8.9 km) and stations E2, E3, and E4 extending eastward from the river mouth (4.3 km, 8.5 km, and 20.2 km, respectively, Fig. 1). Samplings and measurements conducted at each station and in each season included hydrological measurements, water and sediment samples for geochemical analyses and meiofauna and macrofauna samples. Water salinity and temperature and turbidity were measured in vertical profiles using a Sensordata 204 CTD. Surface and bottom waters (for suspended matter analyses) were collected using a Niskin bottle at each station. Once collected, the samples were vacuum-filtered onto pre-weighed filters (MN GF5 with 0.4-μm openings). Samples of surface sediment for geochemical and meiofauna analyses were collected from a box corer using a syringe (3.5-cm diameter). These sediment samples consisted of upper 1 cm for grain sizes, POC, TN, δ^{15}N and δ^{13}C and photosynthetic pigments, and upper 5 cm for meiofauna (3 replicates). Samples for macrofauna were collected using the van Veen grab (0.1 m^2 catching area, 3 replicates). Sediment samples for geochemical