Estuarine, Coastal and Shelf Science 163 (2015) 93–98

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Short communication

Submarine groundwater discharges create unique benthic communities in a coastal sandy marine environment

Francisco Leitão [a,*], João Encarnação [b], Pedro Range [a], Rüdiger M. Schmelz [c,d], Maria A. Teodósio [a], Luís Chícharo [e]

[a] CCMAR – Centre of Marine Sciences, University of Algarve, Portugal
[b] University of Algarve, Portugal
[c] ECT Oekotoxikologie GmbH, Flörsheim, Germany
[d] University of A Coruña, Science Fac., Laboratory of Animal Biology, Plant Biology, and Ecology, Spain
[e] CIMA - Centre of Marine and Environmental Research, University of Algarve, Portugal

ARTICLE INFO

Article history:
Received 3 November 2014
Accepted 9 June 2015
Available online 17 June 2015

Keywords:
algarve
Portugal
freshwater discharge
macroinvertebrates
marine bio-indicators
subtidal marine coastal areas

ABSTRACT

In this study we assessed the small-scale effects of submarine groundwater discharges (SGD) on macrofaunal assemblages associated with shallow sandy sediments along the south coast of Portugal. Corer samples were collected in a (1) subtidal seep, (2) at the edge of the seep (periphery) and (3) in the surrounding area. Community structure varied across areas, with diversity, species richness and evenness generally low at seep relatively to the surrounding area. Community composition within the seep was reduced to a small number of taxa, although total abundance was similar between seeps and surrounding areas. The seep was characterized by a distinct hydrological environment, with lower salinity and pH, relative to the surroundings sandy areas. More than 93% of the benthic macrofauna in the seep was dominated by *Lumbricillus lineatus* (enchytraeid oligochaetes). This study is the first to record the presence of this euryaline species in Portuguese marine waters. In the surrounding area Spionidae Polychaetes and *Bathyporeia* sp. (Amphipoda) were the most frequent and abundant taxa. These findings provide evidence for a direct association between SGD effect and the composition of benthic marine assemblages. The patchy habitat created by groundwater seep allowed euryhaline species with short and fast recruitment times to occur in a fully marine environment. Whether this pattern is consistent, or only occurs when smooth favorable sea conditions are not superimposed on the groundwater effect remains uncertain.

1. Introduction

Macrobenthic communities have an important role on the structure and functioning of marine ecosystems (Pearson and Rosenberg, 1978). They are in direct contact with the sediment, where multiple changes tend to occur and, due to their limited mobility, benthic communities are sensitive to local disturbances. Furthermore, because of their permanence over seasons, they integrate the recent past (Warwick, 1993) and geological history (Buzas et al., 1982) of disturbances that might not be detected in the water column. The distribution and abundance of macrobenthos generally differs according to: sediment characteristics, organic content, salinity and food availability (e.g. microphytobenthos and phytoplankton), which may be modified by the local hydrodynamic regimen (Snelgrove and Butman, 1994; van der Wal et al., 2008). The response of each community to these stressors depends on its resilience and the specific environmental conditions of the ecosystem. Accordingly, the presence, absence or abundance of a given species within a community can frequently be associated with specific environmental causes.

The role of submarine groundwater discharges (SGD) as a supply of chemical compounds (e.g. nutrients, carbon and pollutants) to coastal areas is well documented. This flow of water through shelf sediments contributes nutrients like silica, nitrogen and phosphorous to the coastal zone (e.g. Leote et al., 2008; Waska and Kim, 2011). Other physical–chemical characteristics of coastal waters, like salinity or temperature, may also be influenced by SGD (Ullman et al.,

* Corresponding author. CCMAR – Centre of Marine Sciences, University of Algarve, Gabinete D12 8005-139 Faro, Portugal.
E-mail address: fleitao@ualg.pt (F. Leitão).

http://dx.doi.org/10.1016/j.ecss.2015.06.007
0272-7714/

2003; Dale and Miller, 2007). The nutrient-rich freshwater water discharged by aquifers into coastal marine systems can increase benthic and water-column primary productivity (Waska and Kim, 2011) and significantly affect the distribution, abundance and diversity of benthic communities (Johannes, 1980; Miller and Ullman, 2004; Zipperle and Reise, 2005; Silva et al., 2012; Encarnação et al., 2013) even in low flow regimes (Herman et al., 2007).

Literature dealing with the effects of SGD on macrofauna is scarce and mainly focused on coastal bays, lagoons or estuaries (Miller and Ullman, 2004; Zipperle and Reise, 2005; Dale and Miller, 2007; Ouisse et al., 2011; Silva et al., 2012). Nevertheless, previous studies have shown that SGD are a natural and widespread phenomenon that influence biological productivity and species distributions (Johannes, 1980). Several benthic species have been associated with the presence of SGD. Different species of Spionidae polychaetes have been found in large abundances in zones under the influence of SGD (Miller and Ullman, 2004; Dale and Miller, 2007). In island of Sylt (German Wadden Sea), a shift in the dominance of *Arenicola marina* to *Nereis diversicolor* and *N. virens* was recorded within a freshwater discharge area (Zipperle and Reise, 2005). In the intertidal zone of Roscoff Aber Bay (France), SGD were shown to influence the macrobenthic community composition by locally enhancing species diversity, with the species *N. diversicolor* and *Corophium volutator* characterizing the seepage zone (Ouisse et al., 2011). Recently, Silva et al. (2012) also found higher abundances of Spionidae polychaetes, *Capitella* spp. and oligochaetes associated with freshwater discharges in the Arade estuary (south Portugal).

Around 10000 years ago a period of fast sea level rise initiated, culminating 8000 years ago, when the relative mean sea level approached −20 m (Dias et al., 2000). Teixeira (1998) described a series of aligned submersed shore scarps along the southern coast of Algarve, probably originated during this period, one of them located in front of Olhos de Água, called "Pedra dos Arrifes" at −13 m. The present sea level was reached 3500 years ago, during a period when the geological and hydrogeological conditions were similar to modern conditions, namely water-bearing formations composed of detritic-carbonate rocks discharging through intertidal and subtidal seeps (Dias et al., 2000). The existence of intertidal SGD in Olhos de Água was first described in 1841 by João Baptista Lopes in a document concerning the Algarve "kingdom" (Lopes, 1841). The existence of subtidal seeps off Olhos de Água beach was also frequently mentioned by local fishermen, although the exact locations were uncertain. Therefore, we can postulate that benthic fauna communities have adapt SGD discharge across time. Nevertheless, no study has been so far conducted to reveal this issue.

The intertidal seeps in this stretch of coastline were thoroughly mapped during a recently concluded multidisciplinary research project (FREEZE - PTDC/MAR/102030/2008). After several inconclusive surveys of the coastal zone, using multiple oceanographic and remote sensing techniques, a large subtidal seepage area was detected in Olhos de Àgua beach in September 2011. This on-board observation was only possible due to the exceptionally calm sea conditions, which allowed visualization of the freshwater-seawater mixing plume and the re-suspended sediment. In fact, given their usually small size and sparse distribution, the visual detection of seeps in the sea floor is generally only possible by diving close to the bottom, on days with exceptional high visibility and no wave action. We considered that SGD freshwater changes local water physical conditions (salinity, PH) that can be the putative cause of community changes. Therefore, the objectives of the present study were to characterize the benthic fauna of a freshwater seep on Olhos de Água beach and to assess the spatial extent of the influence of subtidal SGD on the shallow coastal sandy macrofauna communities around the seepage area.

2. Material and methods

2.1. Study site

In the south coast of Portugal (Algarve), SGD are only known to occur in the "Olhos de Água" area. This sheltered coast area is characterized by a mesotidal regime (3.4 m) and euhaline conditions (35PSU) (Bettencourt et al., 2003). Wave direction is mainly from W (52%), SE (23%) and SW (18%) and wave height is generally lower than 1 m (68%), with winter storms occasionally creating waves higher than 3 m (Costa et al., 2001). Seepage zones occur in rocky and sandy substrates, extending from the intertidal area of the Olhos de Água beach until the subtidal zone (for a detailed map see Encarnação et al., 2014). Most of the seeps were of small dimension and were located over rocky limestone bed, covered by small proportion of fine sandy sediments. The freshwater source discharged of Olhos de Água is from Quarteira/Algibre groundwater basin.

2.2. Sample collection

Sampling was done in September 2011 in a large subtidal seep (3 m in diameter), located in an area of sandy bottom at 3.5 m depth (37° 05′18″ N; 8° 11′18″ W). The seepage is located at approximately 126 m from the coast line. Samples were taken by SCUBA diving, in three distinct zones: within the seep itself; at the edge of the seep (periphery); and in the area surrounding the seep. The edge of the seep is easy to identify due to a small elevation in borders relatively seep central/bobbling area. Each sample enclosed a randomly selected area of 0.038 m^2 (each sample comprises three corers of 22 cm in diameter). Sediment was collected to 15 cm depth with an air-lift pump and the organisms retained in a 500 μm mesh bag. In both the seepage and periphery zones, two samples were collected (Fig. 1). The surrounding zone was also included in a broader study, focusing on the effects of SGDs on large-scale temporal and spatial variability of benthic macrofauna (Encarnação et al., 2014), so six samples were collected, according to the design used in that study. Samples were preserved in 4% buffered formalin and stained with Rose Bengal until subsequent laboratory analysis. Whenever possible macrofauna was first hand-sorted into major taxonomic groups and then identified to the species level.

The physical–chemical characteristics of seawater (temperature, salinity and pH) were measured at the three sampling zones with a multiparametric probe (YSI6600) in sito by the divers (1 min), during ebb. All variables were measured at the interface between the water column and the sediment surface, at the sites where the benthic samples were taken.

2.3. Data analyses

Data analysis included univariate and multivariate statistical methods. Four ecological indices were applied to the macrofauna abundance data: number of species (S), total abundance (N), species richness (Margalef's d) and Shannon–Wiener's diversity (H′). One-way analysis of variance (ANOVA) was used to test for differences in the ecological indices among sampling areas (significance level of $\alpha = 0.05$). Whenever statistical differences were detected in ANOVA, pairwise comparisons (Holm-Sidak method) were done to identify which sampling areas differed.

Multivariate techniques, namely cluster ordination (group-average linkage) were used for grouping samples. Additionally, permutational multivariate analysis of variance (PERMANOVA) was used to evaluate statistical differences in the community structure among the three sampling areas (seepage, periphery, surroundings). A one-factor PERMANOVA was performed and, as the design