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Freshwater seepages and ephemeral macroalgae proliferation in an intertidal bay: I Effect on benthic community structure and food web

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ABSTRACT

Freshwater seepages and ephemeral *Enteromorpha* spp. proliferation create heterogeneity at small spatial scale in intertidal sediment. Macrobenthic community diversity was compared between these two disturbances and their respective control points throughout the year 2007 at the Roscoff Aber Bay (Western English Channel, France). In March and September 2007, trophic community pathways of characteristic species were additionally studied using stable isotope ratios of carbon and nitrogen. The low salinity recorded at the freshwater seepage induced the exclusion of the main bioturbator and the presence of omnivores which modified the community composition by biotic pressure. Moreover, food web analyses clearly highlighted a separation at small spatial scale between the two trophic pathways of the impacted area and its control. On the contrary, little differences were observed owning to the ephemeral *Enteromorpha* spp. proliferation. This suggested a progressive and diffusive disturbance which was applied from the algal mat to the nearby area. However, seasonal changes were observed. First, the algal expansion phase increased the macrofauna diversity and foraminifers' abundance (meiofauna) and then acted as a physical barrier decreasing sediment and water column exchanges and decreasing the fauna diversity. This study highlights the need to take into account small spatial heterogeneity to avoid misinterpretations in intertidal ecology studies.

1. Introduction

Intertidal zones are subjected to large environmental fluctuations due to the alternation of emersion–immersion periods. This creates a physico-chemical gradient of constraints responsible for the vertical distribution of numerous benthic fauna. Although the structure of intertidal systems has been widely described at large scale (Raffaelli and Hawkins, 1999, for review), smaller spatial scale may present some heterogeneity in benthic community and less attention has been given to their structural patterns.

Heterogeneity at small spatial scale may result from two common phenomena in intertidal sediment: freshwater seepages and ephemeral macroalgae proliferation. Freshwater seepage occurs when underground water naturally discharge through permeable marine sediments (Johannes, 1980). This discharge is continuous through time but its extent varies proportionally with the volume of freshwater flow (Glover, 1959). Ephemeral macroalgae blooms are regularly observed worldwide on intertidal flats (Valiela et al., 1997), and follow coastal water nutrient enrichment (Valiela et al., 1992). In temperate regions, these blooms occur mainly from spring to late autumn in shallow estuarine ecosystems and their frequency, magnitude and persistence have increased in many areas over the past decades (Pihl et al., 1996; Cummins et al., 2004). The impact of freshwater seepage on diversity and abundance of the benthic communities has only been studied in intertidal sand flat of Delaware (US, Miller and Ullman, 2004) or at the northern end of Sylt (German Wadden Sea, Zipperle and Reise, 2005). Ephemeral macroalgae blooms have been much studied (Smith, 1955; Flach, 1992; Norkko and Bonsdorff, 1996; Modig and Olafsson, 1998; Bolam et al., 2000). Both disturbances generated large change in diversity and abundance of the benthic communities. In addition, the effect of seasonal proliferation of green macroalgae on food web structure has been well studied in Mondego estuary, Portugal (Patrício et al., 2004, 2006; Patrício and Marques, 2006). To our knowledge consequences on trophic functioning of freshwater seepage were never studied.

The spatial complexity of intertidal areas, variations in water and organic matter exchange and potential sources of nutrients make

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food web analyses rather difficult at small scale. Stable isotope ratios of carbon and nitrogen are frequently used in coastal habitats to discriminate which primary producers support the food web (e.g., DeNiro and Epstein, 1978; Fry and Sherr, 1984; Riera and Hubas, 2003). They have also been proved to be powerful tools to address issues concerning matter transfers between adjacent systems (Schaal et al., 2008).

The structure and functioning of the intertidal Roscoff Aber Bay (Western English Channel) was well described along the vertical gradient (Hubas, 2006; Hubas et al., 2006). Spatial heterogeneity of meio and macrofauna was evidenced along a granulometric gradient but areas subjected to freshwater seepages or ephemeral blooms were not considered.

The aim of the present study was to assess and compare the effect, both on the diversity and functioning of this small tidal bay, of two widespread phenomena altering intertidal sediments: freshwater seepages and proliferation of ephemeral macroalgae. In the present paper, (1) the effect of these disturbances on the diversity of meio and macrofauna was characterized and (2) the consequences on the food web structure were analysed. In a second paper, the effects on the meio and macrofauna biomass and the global benthic metabolism were evaluated during low tide using benthic chambers.

2. Materials and methods

2.1. Study sites

The Roscoff Aber Bay (Fig. 1) is a small intertidal bay entirely located above mid-tide level (Chauris, 1988). The bay is subjected to a low but constant freshwater input from a small stream (Rullier, 1959) and includes various types of sediment from muddy to sandy. Two particular areas, separated by 300 m, were studied in this bay: a large muddy freshwater seepage (about 300 m^2) in the South (FW here after) and a sandy area affected by seasonal proliferation of green algae (*Enteromorpha* spp.) in the East (E here after).

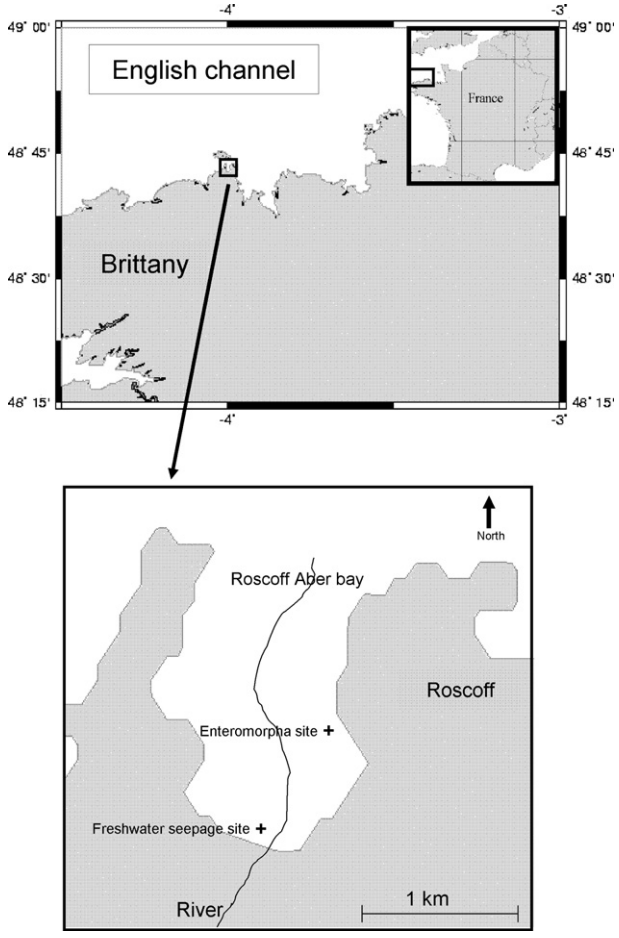

Fig. 1. Study sites in Roscoff Aber Bay (France).

2.2. Sampling and preparation of samples

For each site (freshwater seepage and Enteromorpha sites), a control point with similar sediment feature was selected at less than 10 m away from the impacted points (C_{FW} and C_E here after). Macro and meiofauna were sampled at low tide on these four points (FW, C_{FW}, E and C_E) from February to December 2007 (7 sampling dates). Three sediment quadrats (0.1 m^2, 10 cm depth) were sampled for macrofauna (<2 mm) analyses that are sufficient to estimate the general feature of diversity. Organisms were identified at the species level and their biomass expressed in Ash Free Dry Weight (AFDW). Three sediment cores (2.9 cm^2, 2 cm depth) were sampled for meiofauna analyses. Meiofauna was extracted from the sediment using colloidal silica soil Ludox™ HS-40 (de Jonge and Bouwman, 1977) as described in Burgess (2001). Major meiofauna taxa were identified.

The freshwater seepage was characterized by its salinity measured in interstitial water during emersion (triplicates, taken at 3 cm depth) at the FW point and compared to C_{FW} point. The ephemeral macroalgae blooms were characterized by measuring the Dry Weight (DW) of the *Enteromorpha* found in macrofaunal cores (triplicates, 0.1 m^2).

Additional samplings were done in March and September 2007 to collect sources (organic matter and principal macroalgae) and macrofauna for carbon and nitrogen analysis purpose.

Suspended Particulate Organic Matter (POM) was obtained from different water samples (seawater, marine POM and stream water, river POM). 20 L seawater was collected at ca. 50 cm depth during high tide at mid distance from the Freshwater seepage and the Enteromorpha sites. 2 L stream water was collected at low tide upstream of the Aber Bay. Both samples were immediately filtered on a precombusted Whatman GF/F glass fiber filters. Sedimented Organic Matter (SOM) was collected by scraping the upper 2 cm of sediment at low tide in each point. The main algae, *Enteromorpha* spp. and *Fucus spiralis* on small rocks, were collected by hand at low tide and cleaned manually of their epiphytes. Main macrofauna species (twelve taxa in each site) were collected at low tide by sieving sampled sediment (10 cm depth). In order to evidence a possible disturbance effect on the organism diet, this study particularly focused on the species both present in the impacted point (FW or E) and in the control one (C_{FW} or C_E). Macrofauna was starved (12 h in 0.7 μm filtered seawater) to clear their guts. All samples were acidified (1 M HCl) in order to remove carbonates and rinsed with distilled water. Afterward, all samples were dried until constant weight (60 °C, 48 h). Macrofauna and macroalgae were ground to powder using a mortar and pestle before being freezed at −32 °C for preservation.

2.3. Stable isotope analyses

Isotopic analyses were performed at individual scale except for small organisms where several individuals were pooled to obtain sufficient body mass (1 mg DW). Carbon and nitrogen isotope ratios were determined using a Flash EA CN analyser coupled with a Finnigan Delta Plus mass spectrometer, via a Finnigan Con-Flo III interface. Data were expressed in conventional δ unit notation, where $\delta X = [(R_{sample}/R_{standard}) - 1] \times 10^3$, with $R_{sample} = {}^{13}C/{}^{12}C$