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The allochthonous material input in the trophodynamic system of the shelf sediments of the Gulf of Tigullio (Ligurian Sea, NW Mediterranean)

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A B S T R A C T

The organic allochthonous material input in the benthic system of a NW Mediterranean shelf area was studied using a three-pronged approach, focusing firstly on the evaluation of the sedimentary stable isotope ratios and organic matter (OM) composition, then on the OM recycling processes performed by the microbial organisms, and finally on the potential trophic relationships between the macrobenthic organisms. The highest allochthonous signal, indicating continental input, was observed within the 50-m isobath, while at the 80-m isobath the marine signal was higher, pointing to a rather low continental influence approximately 5 km from the shore. Heavier rainfall, often generating abrupt allochthonous inputs by river outfalls, led to a wider spread of fine sediment particles. Carbohydrates were the compounds that best represented the continental input and these compounds were associated with potential recycling activities by microbiota, pointing to the entry of these C-containing allochthonous materials into the microbial food web. The macrofaunal deposit-feeders used sedimentary OM characterised by a continental signature as a food source, although the isotopic ratios of the organisms also pointed to selective feeding on materials that had a marine signature, especially at our offshore sampling stations. Predators fed on deposit- or suspension-feeders, with a potential selection of the latter during the highest inputs of continental materials occurring in winter.

1. Introduction

Continental inputs in coastal areas are largely carried by rivers, and they are a heterogeneous mixture of organic matter (OM) with different chemical features and origins (soil, vegetal debris, freshwater production etc.) (Tesi et al., 2007). These inputs enter the coastal area at different rates, depending on the morphology of the coastline, the catchment area and marine hydrodynamic conditions. In small river systems a higher temporal coherence between river discharge and sea conditions has been recorded. A huge input of continental materials at sea is often contemporaneous with rainfall events, leading to differences in OM quality and fate between small rivers and large river systems (Wheatcroft et al., 2010).

In coastal areas phytoplankton production is generally the main source of OM, together with benthic production. Autochthonous primary production strongly sustains secondary production (Chanton and Lewis, 2002). The presence of allochthonous inputs, such as those due to river outflow, may further increase the general productivity (Darnaude et al., 2004; Cresson et al., 2012) and allow the presence of ecoclines (Attrill and Rundle, 2002). In oligotrophic conditions the allochthonous inputs may play a higher role in sustaining the ecosystem with organic nutrients, due to limited autochthonous production. Nowadays, such processes may have a heavy anthropogenic signature (Halpern et al., 2007; Muniz et al., 2010; Venturini et al., 2012), especially in small river systems (Wheatcroft et al., 2010). The release of huge quantities of human-derived materials into the environment points to the need for a better understanding of the fate and pathways of allochthonous inputs in the coastal system and, subsequently, in the deep waters of the sea (Wheatcroft et al., 2010).

The chemical characterisation and the stable isotope ratios of OM have been used to identify its origin and potential lability. Carbon sources (allochthonous as well as autochthonous) display peculiar C and N isotopic ratios that are widely used as a proxy for discriminating between the multiple sources of OM (from riverine inputs to benthic and pelagic marine producers for instance, Bănaru

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et al., 2007; Cresson et al., 2012). Terrestrial plant debris carried by riverine inputs generally shows lower $\delta^{13}C$ values (from −28 to −25‰ and down to − 30‰ if C3 plants such as deciduous and coniferous trees are dominant, Sanchez-Vidal et al., 2013) than marine phytoplankton (from −22 to −19‰) (Hedges et al., 1997). Within the different components of the OM, the OC/TN ratio has been used as an indicator of trophic quality but also of terrigenous influence (the higher the ratio, the lower the trophic quality and the higher the terrigenous influence, Goñi et al., 2003, Burone et al., 2013 Cresson et al., 2012). The transfer of OM through the food web may be followed starting from the consumption and degradation of detrital OM by microbes, carried out especially (but not exclusively) by bacteria. Due to their small size, bacteria have firstly to cut the polymeric compounds into smaller units by means of extracellular enzymatic activities, whose features have been considered as proxies of OM turnover and bioavailability (Manini et al., 2003; Caruso et al., 2005). Once the OM components are channelled along the microbial food web and are reworked in the sediment, metazoans may benefit from this food source. This supply may be studied by focusing on its lability or refractivity to consumption, measuring the TN or lipid content to assess the lability and carbohydrate and OC content as an indicator of the semi-labile/refractory fraction (Cresson et al., 2012; Venturini et al., 2012; Arndt et al., 2013). The complexity of the food web may be studied by determining the isotopic ratios of the organisms. The $\delta^{15}N$ values of the organisms have been used to define the trophic level. Lower values are characteristic of low trophic levels (deposit-feeders, for instance), while predators show the higher values (Darnaude et al., 2004; Martinetto et al., 2006). The $\delta^{13}C$ values are often considered less useful for the determination of the trophic position (Eggers and Jones, 2000), but they can provide information on the origin of the C supply for consumers.

In the present study we aimed to define the extent of the continental input in the shelf area of the NE Ligurian Sea (NW Mediterranean), characterised by oligotrophic conditions. Different scales and ecological processes were considered. Firstly we aimed to assess the spatial extent of the input of continental OM in the sediments during the lowest and the highest freshwater input periods. We focused on sedimentary organic tracers to characterise the allochthonous inputs in the microbial food web. Finally we tested the trophic relationships between the small metazoans of the sediment (macrofauna), determining whether direct relationships could be established between sedimentary OM, deposit-feeders, suspension-feeders and predators.

2. Material and methods

2.1. Study site

The Entella River is one of the main natural rivers of Liguria, flowing into the Gulf of Tigullio (Fig. 1). The Entella R. itself is 8 km long and, together with its three main tributaries, has a total length of ca. 38 km, with a catchment area of 372 km^2 (Tomaselli et al., 2009). The Entella R. discharge is rather low, on average 20 $m^3 s^{-1}$ during autumn and winter and less than 10 $m^3 s^{-1}$ during summer (Tomaselli et al., 2009). However, in recent years, overflow occurred every autumn, spreading continental-derived material in the entire Gulf of Tigullio area. The Entella R. flows through rural and highly urbanised areas, where agriculture and small manufacturing activities occur. The population is more than 71,000 inhabitants, increasing to 90,000 during the summer (Regione Liguria, www.ambienteinliguria.it). Sometimes pollution events (such as the appearance of hydrocarbons or sewage on the water surface) have been reported by local newspapers and personal observations.

In the Gulf of Tigullio (Fig. 1) the main coastal current flows from SE to NW, carrying the continental waters towards the Portofino Promontory, although a nearshore eastward current sometimes occurs (Doglioli et al., 2004). Wind forcing, which is known to deeply influence the surface-water movement (Astraldi and Manzella, 1983), may spread the continental water in the entire area or rapidly carry it offshore (Doglioli et al., 2004). Several towns along the sea-shore (Fig. 1) have more than 65,000 inhabitants (up to 180,000 with the tourist contribution). An offshore fish-farm, on the 30–40 m isobath, lies to the east of our sampling stations. At the Entella R. mouth occasional and irregular meadows of *Cymodocea nodosa* have been observed, at between 10 and 20 m depths, while to the west small patches of *Posidonia oceanica* have been recorded, increasing in surface area approaching the Portofino Marine Protected Area (Diviacco and Coppo, 2006).

2.2. Sampling

Samplings were carried out in summer (July 2012) and winter (February 2013) on the continental shelf from the Portofino Promontory to the area of the Entella R. (Fig. 1). The two periods were those characterised by the minimum and maximum river discharge, which have variable delays with respect to the rainfall in the area (Tomaselli et al., 2009, Fig. 2A). The rainfall of the sampling years is reported in Fig. 2B. Irregular flooding may occur during autumn with increased continental inputs in the sea, as observed by the Regional Agency for the Protection of the Environment (ARPA-Liguria, www.arpal.gov.it) for late 2012.

Seven stations along three transects (A, B and C) were sampled (Fig. 1), covering the main part of the continental shelf in the Gulf of Tigullio, with special focus on the Entella R. outflow. Station A1 was, in fact, placed in front of the river mouth at a 20 m depth (shallow station), stations A2, B2 and C2 were located at 53 ± 2 m (mid-depth stations), stations A3, B3 and C3 were located at 84 ± 5 m (deep stations).

At each station sediment samples were collected using a Van Veen grab. Four replicates were sieved with a 0.5 mm mesh, on board of our research vessel, in order to retrieve the macrofaunal organisms. The replicates for organism classification were then treated with formalin (10% final concentration), while the subsamples for isotopic measurements were kept frozen until sorting and analysis.

One replicate was sampled for the sediment texture analysis and three replicates were sampled for the OM and stable isotope analyses using PVC corers. The cores were cut into two sections: 0–2 cm and 2–10 cm, on board.

Seawater and freshwater were sampled for the determination of the $\delta^{13}C$ signal of the particulate OM. In particular, seawater was collected at approximately an 80-m depth during the sampling and during the month preceding each sampling (June and July 2012, January and February 2013) at an offshore station (95 m depth) placed next to station C3 (Fig. 1). Freshwater was collected at approximately 1.5 km upstream from the Entella R. mouth during the sampling campaigns. Immediately after collection the samples were transported to the laboratory (within 3 h), where they were filtered on pre-combusted (450 °C for 4 h) Whatman GFF filters (glass fiber). The filters were stored at −20 °C until analysis.

2.3. Sample preparation and analysis

The sediment texture analysis was performed within 2 months of the sampling, following Buchanan and Kain (1971). The sediments were sieved after H_2O_2 treatment and drying (60 °C, 48 h). We considered two dimensional fractions: silt-clay (<0.063 mm), and sand (>0.063 mm).