Progress in Oceanography 156 (2017) 221–239

Contents lists available at ScienceDirect

Progress in Oceanography

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

Dynamics of particulate organic matter composition in coastal systems: A spatio-temporal study at multi-systems scale

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ARTICLE INFO

Article history:
Received 19 September 2016
Received in revised form 16 December 2016
Accepted 4 March 2017
Available online 9 March 2017

Keywords:
Particulate organic matter
Coastal systems
C and N stable isotopes
C:N ratio
Mixing model

ABSTRACT

In coastal systems, the multiplicity of sources fueling the pool of particulate organic matter (POM) leads to divergent estimations of POM composition. Eleven systems (two littoral systems, eight embayments and semi-enclosed systems and one estuary) distributed along the three maritime façades of France were studied for two to eight years in order to quantify the relative contribution of organic matter sources to the surface-water POM pool in coastal systems. This study was based on carbon and nitrogen elemental and isotopic ratios, used for running mixing models.

The POM of the estuary is dominated by terrestrial material (93% on average), whereas the POM of the other systems is dominated by phytoplankton (84% on average). Nevertheless, for the latter systems, the POM composition varies in space, with (1) systems where POM is highly composed of phytoplankton (≥93%), (2) systems characterized by a non-negligible contribution of benthic (8–19%) and/or river (7–19%) POM sources, and (3) the Mediterranean systems characterized by the contribution of diazotroph

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http://dx.doi.org/10.1016/j.pocean.2017.03.001
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Meta-analysis
France

organisms (ca. 14%). A continent-to-ocean gradient of river and/or benthic POM contribution is observed. Finally, time series reveal (1) seasonal variations of POM composition, (2) differences in seasonality between systems, and (3) an inshore-offshore gradient of seasonality within each system that were sampled at several stations.

Spatial and seasonal patterns of POM composition are mainly due to local to regional processes such as hydrodynamics and sedimentary hydrodynamic (e.g. resuspension processes, changes in river flows, wind patterns influencing along-shore currents) but also due to the geomorphology of the systems (depth of the water column, distance to the shore). Future studies investigating the link between these forcings and POM composition would help to better understand the dynamics of POM composition in coastal systems.

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1. Introduction

As they are positioned at the interface between ocean and continent, coastal systems experience inputs of dissolved and particulate matter from both reservoirs. It results that these systems are highly productive and are key areas for global biogeochemical cycles (Bauer et al., 2013; Regnier et al., 2013; Smith and Hollibaugh, 1993). More specifically, the multiple origin of particulate organic matter (POM) strongly influence ecosystem functioning since POM is largely considered as a mainstay of the coastal trophic network (e.g. Malet et al., 2008). Coastal POM is also exported offshore (Sanchez-Vidal et al., 2009) or buried in sediment (Duarte and Cebrián, 1996) and contributes to enhance remineralization in the water column and to fuel deep sea ecosystems (Azam et al., 1983; Karl et al., 1988; Wakeham and Lee, 1989). Acquiring a better knowledge about POM composition in coastal systems remains a key concern to understand biogeochemical interactions between continental and oceanic realms and to have a better insight of ecosystem functioning.

The pool of coastal POM is composed of a mixture of autochthonous POM and allochthonous POM (Berto et al., 2013; Dubois et al., 2012; Tesi et al., 2007). Autochthonous POM is considered as originating from *in situ* pelagic and benthic primary producers. Many studies reported that phytoplankton dominates coastal POM (e.g. Cresson et al., 2012; Tesi et al., 2007). In addition, due to the shallow depth of coastal systems, the benthic compartment has a significant influence on coastal POM composition (e.g. Malet et al., 2008). Benthic organic matter includes various sources such as macrophytes (i.e. macroalgae, spermatophytes), microphytobenthos or even sediment detritus. Allochthonous POM is organic matter originating from the continent. It is mainly carried by rivers but also by run-off or by artificial outlets. Sources of continental POM are usually considered as river POM, which is a mixture of freshwater phytoplankton and terrestrial POM (e.g. litter, soils), and sometimes anthropogenic inputs such as POM originating from treated/untreated sewage effluents (Berto et al., 2013; Cresson et al., 2012; Liénart et al., 2016). This multiplicity of sources makes difficult the understanding of the relative influence of each source to the coastal POM pool. Also, depending on its composition, POM is more or less labile (Etcheber et al., 2007) and thus more or less bioavailable and subject to processing.

To assess and quantify the POM composition (i.e. the contribution of each source to the pool of POM), a large panel of tools is available. A first approach for characterizing coastal POM consists in measuring particulate organic carbon (POC) and chlorophyll *a* (Chl *a*) concentrations. Classically, POC:Chl *a* ratio is used to discriminate living phytoplankton (POC:Chl $a \approx 40–140\ g\ g^{-1}$) or phytoplankton-dominated POM (POC:Chl $a < 200\ g\ g^{-1}$) from other material (POC:Chl $a > 200\ g\ g^{-1}$) (Savoye et al. (2003) and references therein). Among available tools, C and N elemental and isotopic ratios have been widely used to investigate the relative contribution of each source to the coastal POM thanks to their distinct elemental and isotopic signatures. Roughly, C:N ratio discriminates phytoplankton ($C:N \approx 6–10\ mol\ mol^{-1}$) from terrestrial material ($C:N > 12\ mol\ mol^{-1}$) whereas $\delta^{13}C$ values generally discriminates continental ($\delta^{13}C < -26‰$) from marine ($\delta^{13}C > -24‰$) POM in temperate systems (Savoye et al. (2003) and references therein). No 'universal' values exist for nitrogen isotope ratio ($\delta^{15}N$) and a strong variability of values is observed depending on the systems (Middelburg and Herman, 2007). Nevertheless, C:N ratios, $\delta^{13}C$ and $\delta^{15}N$ values are largely used in combination to characterize and even quantify POM composition in coastal systems (e.g. Berto et al., 2013; Liénart et al., 2016). Relative contribution of each source to the POM pool is usually estimated using mixing models, which are a system of mass balance equations based on the above parameters (Parnell et al., 2010; Phillips and Gregg, 2003).

Studies comparing POM characteristics and/or composition at multi-systems scale are scarce and were only performed in estuarine or river systems and in a limited period of time (Middelburg and Herman, 2007; Pradhan et al., 2014; Higueras et al., 2014). The present study was performed in a wide diversity of systems (e.g. open bay, gulf, semi-enclosed systems, lagoon, estuary) and of environmental gradients, and at multi-annual time scale, using an original dataset (17 time series of ca. bi-monthly sampling for 2–8 years). It aims at (1) determining POM composition in eleven coastal systems distributed along the three coastlines of France and (2) characterizing its spatial and temporal variabilities at both local and multi-systems scale. Specifically, we hypothesize that phytoplankton dominate POM in marine systems (coastal systems out of estuaries), the contribution of other sources increases depending on the proximity to the latest (e.g. higher contribution of river POM when closer to river mouth) and POM composition vary seasonally (e.g. higher contribution of river and or benthic sources in winter). Beyond this qualitative view, the study aims at quantitatively state the extent of the spatial and temporal variability of POM composition in a large diversity of coastal systems.

2. Material and methods

2.1. Studied systems

Seventeen stations from eleven systems distributed along the French coastline (42–51°N, 4–7°E; Fig. 1) were studied. Four systems are located along the English Channel: the south eastern littoral of the English Channel (stations Côte and Large near Wimereux), the Bay of Seine (station of Luc/mer), the Normano-Breton Gulf (station of Bizeux near Dinard in the ria of the Rance River) and the western littoral of the English Channel (stations Estacade and Astan near Roscoff). One system is located in the Iroise Sea, at the interface between the English Channel and the Atlantic Ocean: the marine end of the Bay of Brest (station Portzic).

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