Estuarine, Coastal and Shelf Science 163 (2015) 54–63

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Benthic fluxes, net ecosystem metabolism and seafood harvest: Completing the organic carbon balance in the Ría de Vigo (NW Spain)

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ARTICLE INFO

Article history:
Received 20 January 2015
Accepted 18 May 2015
Available online 27 May 2015

Keywords:
benthic fluxes
primary production
respiration
carbon budget
coastal upwelling
net ecosystem metabolism
mussel harvest
wild catch fisheries

ABSTRACT

Simultaneous direct measurements of primary production, pelagic and benthic respiration and vertical fluxes allowed, for the first time, the evaluation of the carbon metabolism in the Ría de Vigo (NW Spain) on seasonal and annual scales. With this aim, a total of 16 oceanographic cruises covering the main oceanographic conditions were carried out between April 2004 and January 2005. In addition, a 2D carbon budget, including extraction from mussel culture and fisheries activities, is proposed. The pelagic system was net autotrophic during the spring and summer periods and autotrophic or almost in balance during autumn and winter. Vertical fluxes of organic carbon were higher than net community production (NCP) during autumn and winter periods, probably due to resuspension processes and inputs of organic matter from continental runoff. Benthic mineralization is an important process in the Ría de Vigo, which gains significance during autumn and winter when benthic respiration accounts for 40% and 45% of the total respiration, respectively. The Ría de Vigo is net autotrophic on annual basis (317 ± 113 g C m^{-2} yr^{-1}) even though the benthic metabolism reduces the NCP by 23%. Total annual carbon seafood harvest amounted 3% of the net ecosystem metabolism and it is dominated by mussel culture (89%). However, based on mean energy transfer efficiency between trophic levels of 10%, it is estimated that mussel culture and reported fish catches require up to 38% of the NCP. The organic carbon produced *in situ* at the Ría de Vigo and available for export to the adjacent shelf or to be buried in the sediment represents ¼ of the gross primary production and it is favoured during summer upwelling.

1. Introduction

Coastal zones contribute disproportionately large amounts of production and respiration in relation to their areas covered over the global ocean (Wollast, 1998). In these regions, production (P) and respiration (R) processes are magnified due to the influence of hydrodynamic events, such as upwelling and continental inputs, combined with the proximity of the sediment remineralizing environment (Zeldis, 2004). To provide a better understanding of the functioning of these biogeochemically active regions, studies of ecosystem metabolism are necessary. Net ecosystem metabolism (NEM) represents the balance between primary production and total respiration in an ecosystem and can be measured as the summation of anabolic and catabolic rates of all the organisms in the system (Kemp et al., 1997), where catabolic rates represent the sum of the respiratory processes (Testa et al., 2012). The term net community production (NCP) is often used when just the microbial pelagic community metabolism is being measured (Staehr et al., 2012). The balance between net autotrophy and heterotrophy will depend on the nature of exogenous inputs (Caffrey et al., 1998) and so, coastal systems receiving high inorganic nutrient inputs tend to be net autotrophic (P > R) while those ones with high organic inputs tend to be net heterotrophic (R > P). Measurements of ecosystem metabolism indicate the trophic status of the ecosystem (Odum, 1956) as well as to give an idea of how the system processes nutrients and organic matter (Smith and Hollibaugh, 1997). This information is essential to nourish food web models and to partition biogeochemical processes among the different aerobic and anaerobic pathways (Hopkinson et al., 1999). Among the different methods used to calculate NEM, direct rate measurements allow partitioning of production and respiration processes into shares of different habitats (Testa et al., 2012), i.e.

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http://dx.doi.org/10.1016/j.ecss.2015.05.038
0272-7714/

they have the advantage of estimating the relative contribution to total ecosystem metabolism by pelagic and benthic components (Staehr et al., 2012).

Several factors can regulate the trophic status in a coastal system such as inputs of inorganic nutrients, exchange rate with the adjacent seaward region and loading rates of organic carbon. Organic matter produced by phytoplankton not respired in the water column may be transferred to higher trophic levels, transported offshore, exported vertically towards the sediment and mineralized or buried in the sediment. High *in situ* primary production in many coastal systems provides the substrate of autochtonous organic matter that contributes to secondary production either directly or indirectly (Hyndes et al., 2014) and is then, available to higher trophic levels such as predators and scavengers. Therefore, primary production is an important factor on the production of marine fishes as it supports food to fisheries harvest (Pauly and Christensen, 1995; Kemp et al., 1997). Harvest and migration of marine organisms may represent potentially significant losses in the organic carbon budget of a coastal ecosystem (Houde and Rutherford, 1993) and so, overharvesting of marine organisms reduces the abundance of consumers and so it reduces the carbon transfer towards higher trophic levels (Hyndes et al., 2014).

The Galician Rías Baixas (NW Iberian Peninsula; Fig. 1) comprise four V-shaped coastal inlets located in the unique coastal upwelling system of Europe. In this region, the upwelling of subsurface cold and nutrient rich Eastern North Atlantic Central Water (ENACW) promotes high phytoplankton abundance able to support the highest mussel production (*Mytilus galloprovincialis* Lamark) in Europe. This activity renders a total estimated production of 243×10^6 kg yr^{-1} (Figueiras et al., 2002). The Ría de Vigo sustains 474 suspended mussel rafts and provides approx. 15% of the total mussel production of the Rías Baixas. Studies dealing with the biogeochemical fluxes and net budgets of organic carbon in the Rías Baixas have been mainly derived from stationary box models of inorganic nutrients (Prego, 1994, 1993), which then developed to non-stationary box models (Álvarez-Salgado et al., 1996; Rosón et al., 1999; Gilcoto et al., 2001; Dale and Prego, 2002). Later on, Piedracoba et al. (2008) included direct measurements of vertical fluxes and water column production/respiration experiments incubated at laboratory. These studies have inferred that mineralization of the organic matter in the sediments of the rías must have a major importance in the net ecosystem metabolism, but up to date none of them have measured *in situ* benthic measurements.

The first goal of this manuscript is to explore the importance of benthic respiration in the Ría de Vigo and to evaluate in what extent it determined the trophic status of the ecosystem. With this aim, benthic respiration was analysed in relation to *in situ* and simultaneously measured primary production, pelagic respiration rates (Arbones et al., 2008) and vertical export of particles (Zúñiga et al., 2011) during four seasonal campaigns carried out in the framework of the FLUVBE project (Coupling of benthic and pelagic fluxes in the Ría de Vigo). Bringing together all these measurements, the main objective of the manuscript was to determine the Net Ecosystem Metabolism in the Ría de Vigo on seasonal and annual basis. From here, an annual carbon budget including potential carbon inputs from continental sources and losses from the system in the form of mussel harvest, wild catch fisheries and shellfishing has been built. In this way, this manuscript presents an integrative view of the ecosystem carbon trade off, increasing our general knowledge of coastal system responses to different combination of environmental changes (Hobbie, 2000; Carpenter et al., 2009; Rhoten et al., 2009; Kemp and Boynton, 2012).

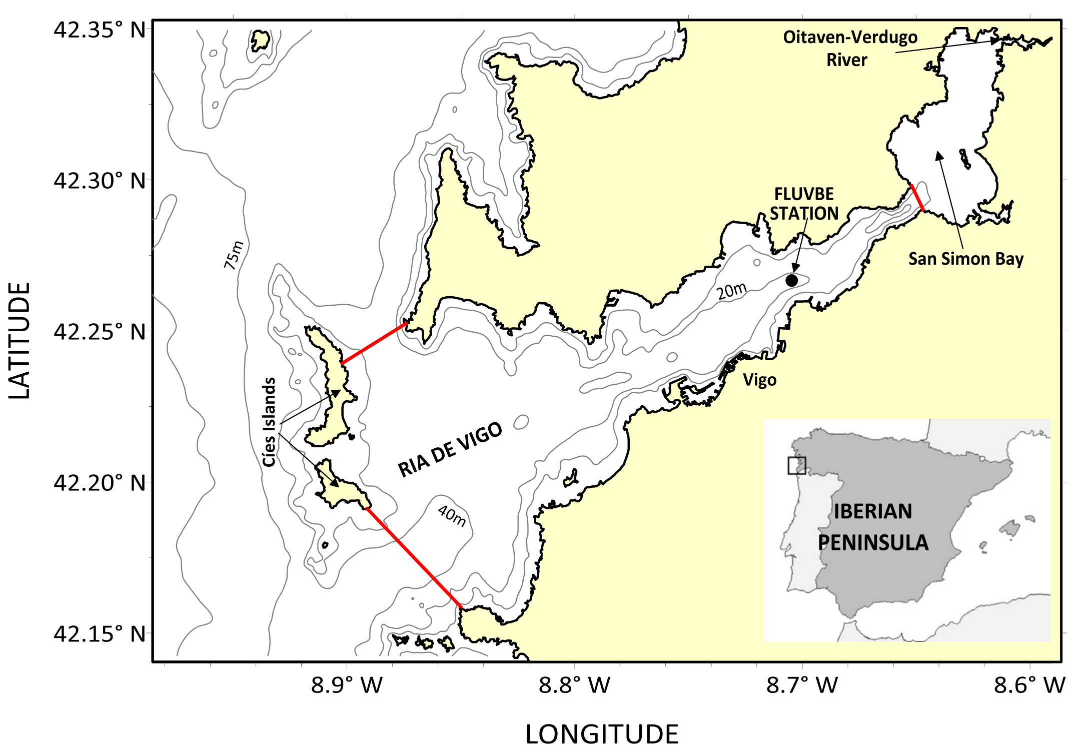

Fig. 1. Map of the Ría de Vigo, showing the location of the sampling station FLUVBE and boundary limits (solid lines) used for the calculations of carbon budget.