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Estimating the value of carbon sequestration ecosystem services in the Mediterranean Sea: An ecological economics approach

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ABSTRACT

Ocean and marine ecosystems provide a range of valuable services to humans, including benefits such as carbon sequestration, whose economic value are as yet poorly understood. This paper presents a novel contribution to the valuation of carbon sequestration services in marine ecosystems with an application to the Mediterranean Sea. We combine a state-of-the-art biogeochemical model with various estimates of the social cost of carbon emissions to provide a spatially explicit characterization of the current flow of values that are attributable to the various sequestration processes, including the biological component. Using conservative estimates of the social cost of carbon, we evaluate the carbon sequestration value flows over the entire basin to range between 127 and 1722 million €/year. Values per unit area range from −135 to 1000 €/km^2 year, with the exclusive economic zone of some countries acting as net carbon sources. Whereas the contribution of physical processes can be either positive or negative, also depending on the properties of incoming Atlantic water, the contribution of biological processes to the marine "blue carbon" sequestration is always positive, and found to range between 100 to 1500 million €/year for the whole basin.

1. Introduction

Marine systems are known to play a crucial role in the global carbon cycle by absorbing an important quota of anthropogenic carbon dioxide (CO_2) from the atmosphere. The world's oceans are estimated to absorb up 2 ± 0.8 billion tons of carbon annually, corresponding to about 25 percent of the total anthropogenic emissions to the atmosphere every year (Sarmiento et al., 1998; Sarmiento and Wofsy, 1999) and about 48 percent of the total fossil-fuel and cement-manufacturing emissions in the period from 1800 to 1994 (Sabine et al., 2004a). The temporary storage of large quantities of CO_2 in the various components of marine systems provides an important service in regulating atmospheric CO_2 concentration since it prevents the absorbed CO_2 from immediately contributing to the greenhouse effect thus slowing climate change (Sabine et al., 2004b).

The relevance of sinks and reservoirs of ocean and marine ecosystems for climate change mitigation is acknowledged by the United Nations Framework Convention on Climate Change (UNFCCC, 1992), which in Art. 4.1(d) calls for all Parties to promote and cooperate in their conservation and enhancement, as appropriate and along with biomass, forests and other terrestrial and coastal ecosystems. Over the past decade, there has been a substantial progress in the development of mechanisms for financing the restoration, conservation and sustainable management of forest and, more recently, coastal carbon sinks. The Reduced Emissions from Deforestation and Forest Degradation (REDD+) mechanism has provided a widely accepted international policy foundation for ecosystem-based management, which has been proposed as a blueprint for the management of coastal "blue carbon" sinks, including mangroves, seagrass beds, salt marshes and kelp forests (Crooks et al., 2011; Nellemann et al., 2009). The

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development of reliable carbon accounting methodologies that rely on scientific measures and sound biogeochemical modeling of carbon fluxes has proved crucial for both REDD+ and blue carbon initiatives (Crooks et al., 2011; Tamelander et al., 2010). Against this background, the contribution of the marine biota to blue carbon sequestration remains poorly understood (Reid et al., 2009). Policy development aimed at characterizing the potential of marine-based mitigation strategies is lacking (Tamelander et al., 2010). According to all available estimates, however, the uptake of CO_2 by marine organisms is not negligible. Although phytoplankton constitutes merely 0.2 percent of the photosynthetically active biomass on Earth, marine photosynthesis accounts for about 50 percent of the world's total primary productivity (Falkowski et al., 1998; Beardall and Raven, 2004). Furthermore, even if it is estimated that only 0.1 percent of the organic carbon fixed by phytoplankton at or near the sea-air interface attains long-term storage in the seafloor sediments, about 30 percent of the biologically fixed carbon sinks into deep waters and only reemerges in upwelling regions after traveling large distances and over time scales of decades or longer (Sabine et al., 2004b).

From a welfare perspective, the regulating service of carbon sequestration by marine and coastal systems generates positive welfare impacts that are felt globally in the form of nature-based mitigation of climate change. Because of its public good nature, however, the current markets and respective price signals fail to capture these benefits to society. In other words, the current market prices, in their wide range of market goods and services, fail to embed the contribution that marine and coastal systems have in terms of carbon sequestration. The absence of information in the existing market prices with respect to the benefits generated by these systems may be incorrectly interpreted as indicating that the value of this ecosystem service is zero. Since many decisions, in both the private and public sectors, are based on market information, this information failure may fuel inefficient decision-making with respect to the management of marine and coastal ecosystems. In this context, the present paper provides an attempt to estimate empirically the benefits of marine systems in terms of carbon sequestration services. We followed an integrated, ecological-economic, spatially explicit approach with an application to the Mediterranean Sea.

The paper is structured as follows. Section 2 provides the details of a two-step biogeochemical/economic methodology for a comprehensive and spatially explicit valuation of carbon sequestration flows in the Mediterranean Sea. In Section 3, the proposed methodology is applied to the biogeochemical and economic assessment of the carbon sequestration service under present conditions. Section 4 discusses the policy implications of our findings for the management of carbon sinks in the Mediterranean Sea, with particular reference to blue carbon sinks.

2. An integrated model of marine carbon sequestration services

2.1. Setting the scene

This section describes the method consisting of an integrated biogeochemical-economic assessment of the carbon sequestration services in marine ecosystems, including their contribution to human welfare—see Fig. 1. In this setting, a high-resolution biogeochemical model is applied to provide a sound natural science characterization of the net CO_2 fluxes at the air-sea interface. A key aspect of the analysis, in view of the management implications of the study, involves the ability to separately account for the contribution of abiotic (physical and dissolution pumps) and biotic processes (biological pump) in terms of carbon sequestration services. Then we proceed with an economic valuation exercise of these services. Among the different methods that have been used to assign a value to carbon sequestration, one may count the analysis of prices in regulatory and voluntary carbon markets, the analysis of marginal abatement and marginal damage costs, and stated preference techniques (DECC, 2009; Jerath et al., 2012). Furthermore, we apply this integrated model with a spatially explicit approach and apply it to Mediterranean basin, directly allocating blue carbon tags to the Mediterranean countries and their Exclusive Economic Zones (EEZs).

2.2. The biogeochemical model

The biogeochemical model is a state-of-the-art 3D coupled transport-biogeochemical model purposely developed and validated for describing plankton productivity and carbon biogeochemical cycle in the Mediterranean Sea (Lazzari et al., 2012). Here it is used to assess the CO_2 fluxes at the air-ocean interface under present climate conditions. The ocean general circulation model is based on the Ocean PArallelize system (OPA, Madec et al., 1999). For these specific simulations, the transport is computed with a horizontal resolution of 1/8 of degree (which corresponds to about 12 km) and with a vertical z-coordinate discretization that is coarser in the bottom layers and increases in resolution at the surface layers, where plankton activity occurs: in total there are 43 levels with a grid spacing ranging from 3 to 350 m (MED16 OGCM model, Béranger et al., 2005). The biogeochemical dynamics are simulated using the Biogeochemical Flux Model (BFM, Vichi et al., 2007; Lazzari et al., 2012); a model in which chlorophyll and carbon dynamics are based on the parameterization of chlorophyll synthesis proposed by Geider et al. (1997) and on a Plankton Functional Type (PTF) representation of the planktonic food web that includes nine plankton pools, subdivided in photosynthetic producers (phytoplankton), consumers (zooplankton), and decomposer (bacteria). These broad functional classifications are further

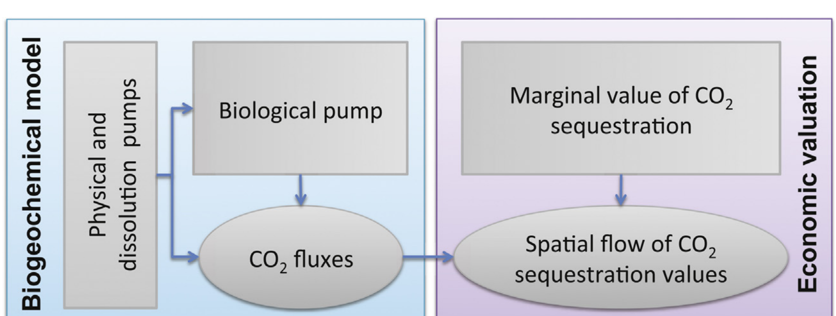

Fig. 1. Scheme of the hybrid ecosystem economic approach to valuation of carbon sequestration.