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Assessing the value of natural capital in marine protected areas: A biophysical and trophodynamic environmental accounting model

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ABSTRACT

Changes imposed to nature by human activities and related impacts on all environmental matrices have become a critical issue. Gradually, humans began to perceive and face the magnitude of the impact of human economy on natural ecosystems and the implications for human well-being. From this perception, the concepts of natural capital and ecosystem services arose, highlighting the relationships between natural and human economy while boosting environmental conservation and management. In this framework, the definition and application of metrics and models capable of accounting for natural capital value are much needed. This is even more important when a protection regime is established (such as in the case of marine protected areas) to evaluate the efficacy of undertaken conservation measures. In this study, a biophysical and trophodynamic environmental accounting model was developed to assess the value of natural capital in marine protected areas. The model of natural capital assessment is articulated in three main steps: 1) trophodynamic analysis, providing an estimate of the primary productivity used to support the benthic trophic web within the study area, 2) biophysical accounting, providing an estimate of the biophysical value of natural capital by means of emergy accounting, and 3) monetary conversion, expressing the biophysical value of natural capital into monetary units. This conversion does not change the biophysical feature of the assessment, but instead it has the merit of allowing an easier understanding and effective communication of the ecological value of natural capital in socio-economic contexts.

1. Introduction

Over the past few decades, efforts were done to address the topic of the link between healthy natural ecosystems and human well-being. The lack of understanding about the societal dependence upon natural ecosystems generated several environmental issues, among which chemical pollution, eutrophication, biodiversity loss, water crisis, and climate change (Folke et al., 2010; Rockström et al., 2009a,b; MEA, 2005).

Gradually, humans began to perceive (and face) the magnitude of the impact of human economy on natural ecosystems and the implications for human well-being. From this perception, the concept of Ecosystem Services (ES) arose, highlighting the relationships between natural and human economy. Although the ES approach was initially focusing on an economic perspective regarding ecosystems in terms of stock-flows supplying human economy, the increased awareness on the importance of ecosystem goods and services led to the development of environmental conservation and management schemes based on the principle of sustainable development (de Groot et al., 2010; Folke et al., 2011; Hein, 2011; Hein et al., 2015).

There are several possible definitions used to describe the concept of ES (MEA, 2005; Häyhä and Franzese, 2014; Paoli et al., 2016). Most commonly, ES are defined as the benefits people obtain from ecosystems (Diaz et al., 2015). In this context, Costanza and Daly (1992) elaborated the concepts of natural capital in relation to human and manufactured capital. Natural capital can be defined as the stock of natural resources generating valuable flows of different types of ecosystem goods and services. Human capital comprises individuals' capacities for work while manufactured capital encompasses material goods generated through economic activity and technological change (UNU-IHDP and UNEP, 2012). Under the perspective of "strong sustainability", natural capital is irreplaceable

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with manufactured capital and a balanced interaction between these types of capital generates the basis for human well-being. The sustainable exploitation of natural capital stocks is vital as it ensures a continuous provision of ES over time (de Groot et al., 2002, 2012).

The European Union, with a dedicated action under the EU Biodiversity Strategy to 2020 (COM/2011/0244), calls Member States to map and assess the state of ecosystems and their services to estimate their economic value while promoting the integration of such values into national accounting systems by 2020. It is therefore urgent to define and apply metrics and assessment frameworks capable of assessing and valuing natural capital stocks and ES flows (UN et al., 2014).

The biophysical and economic assessment of natural capital is particularly useful in those areas where a protection regime is established (such as in the case of marine protected areas) to assess the efficacy of undertaken conservation strategies.

The assessment of natural capital in ecological and monetary terms requires scientifically sound environmental accounting methods providing results easily interpretable by policy makers and other stakeholders. The neoclassical economic approach to natural capital assessment is based on an instrumental and anthropocentric perspective and typically values ecosystems, their functions and services generating benefits to humans. Indeed, conventional economic approaches are based on users' preferences and on a utilitarian perspective according to which an entity has economic value if people consider it desirable and are willing to pay for it. Under this view, natural resources are regarded as instruments devoted to human satisfaction.

The perspective of neoclassical economics is then based on an instrumental value arising from the subjective preferences of individuals, and often caused the undervaluation and unsustainable use of many ecosystem goods and services due to their lack of a market price.

A number of authors estimated the value of natural capital and ES using economic valutation methods (e.g, Costanza et al., 1997, 2014; Dasgupta, 2008; Farber et al., 2002; Farley and Costanza, 2010; Hein et al., 2016; Nikodinoska et al., 2015; Pearce, 1993; Patterson, 2002). These studies highlighted the importance of natural resources in support of human economy. Yet, economic valuation techniques are affected by limitations, among which the fact that money-based valuations only reflect values to the present human society, disregarding other species and future generations (Mellino et al., 2015).

Other authors recognized the existence of non-anthropocentric measures of value and developed biophysical evaluation methods providing a complementary approach to the economic assessment of natural resources (Jørgensen, 2010; Müller, 2005; Müller and Burkhard, 2012; Odum, 1988, 1996; Wackernagel et al., 1999). In particular, Odum (1996) introduced a measure of natural value named "emergy" that has been widely used to evaluate goods and services sustaining the biosphere including the economy of humans (Brown et al., 2016; Brown and Ulgiati, 1999; Franzese et al., 2014; Geng et al., 2013).

The emergy method is a "donor-side" approach that can provide a biophysical measure of value of natural capital and ES by assessing their cost of production in terms of biophysical flows used to support their generation (Ulgiati et al., 2011). According to the emergy accounting method, the more work of biosphere is embodied in generating natural resources and ES, the greater is their value (Odum, 1988, 1996).

The outcomes of an emergy assessment can be converted into currency equivalents using an emergy-to-money ratio to better convey the importance of natural capital and ES to policy makers and other stakeholders. This conversion does not change the "donor-side" feature of emergy accounting, but provides results in monetary equivalent values still representing the biosphere's investment, thus helping to bridge the gap between biophysical and economic assessments.

In this study, a biophysical and trophodynamic environmental accounting model was developed to assess the value of natural capital in Marine Protected Areas (MPA hereinafter).

2. The emergy accounting method

Emergy Accounting (Odum 1988, 1996) is an environmental accounting method aimed at assessing the environmental performance and sustainability of processes and systems on the global scale of biosphere, taking into account free environmental inputs (e.g., solar radiation, wind, rain, and geothermal flows), human-driven flows as well as the indirect environmental support embodied in human labor and services (Brown and Ulgiati, 2004a).

In this method, all inputs supporting a system are accounted for in terms of their solar emergy, defined as the total amount of solar available energy (exergy) directly or indirectly required to make a given product or support a given flow, and measured as solar equivalent Joules (sej) (Odum, 1996). The amount of emergy required to generate one unit of each input is referred to as Unit Emergy Value (UEV) or emergy intensity (sej J^{-1}, sej g^{-1}, sej €$^{-1}$). UEVs represent a measure of the environmental support provided to a system: the higher the UEV of a product the greater the environmental cost to produce it (Brown and Ulgiati, 1997; Franzese et al., 2009). Raw data on mass, energy, labour, and money input flows are converted into emergy units, and then summed into a total amount of emergy used by the investigated system. When the system under investigation generates more than one output flow the following rules of the emergy algebra apply:

1. If the system generates only one output, all independent emergy input flows are assigned to the system's output.
2. When a flow splits (originating flows sharing the same physical-chemical characteristics), the total emergy splits accordingly, based on the available energy flowing through each pathway. In this case, the two splits have the same UEV.
3. When two or more co-products (i.e. product items showing different physical-chemical characteristics, but which can only be produced jointly) are generated in a process, the total source-emergy is assigned to each of them. This is because each of them cannot be produced without investing the whole emergy amount. In this case, the two co-products have the same emergy value but different UEV.
4. Since emergy cannot be counted twice within a system, emergy in feedbacks should not be double counted, and co-products, when reunited, cannot be summed but only the emergy of the largest co-product flow is accounted for.

The Emergy to Money Ratio (EMR) is used to convert the biophysical flows into emergy-based "currency equivalents" (Lou and Ulgiati, 2013). This indicator is calculated as the ratio between the total emergy supporting a nation and its gross domestic product in the same year (Brown and Ulgiati, 2004b). This indicator represents the average amount of emergy needed to generate one unit of money in the national economy (Odum, 1996). Emergy accounting has been widely applied to explore the interplay of natural ecosystem and human activities (Brown and Ulgiati, 2011; Buonocore et al., 2014; Franzese et al., 2013, 2014; Nikodinoska et al., 2017; Turcato et al., 2015; Vassallo et al., 2009). A fuller explanation of the concepts, principles and applications regarding the emergy accounting method can be found in Odum (1988, 1996), Brown and Ulgiati (2004a,b).