



Natural capital and environmental flows assessment in marine protected areas: The case study of Liguria region (NW Mediterranean Sea)



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ARTICLE INFO

Article history:

Received 24 March 2017
Received in revised form 26 October 2017
Accepted 26 October 2017

Keywords:

Trophic network
Emergy
MPA balance
MPA management
Portofino
Cinque Terre
Natural capital

ABSTRACT

A methodology based on emergy analysis for the calculation of the biophysical value of the stocked biomass (natural capital) was applied to the Marine Protected Areas (MPAs) of Portofino (PF) and Cinque Terre (CT). The resources exploited, on a yearly base, to maintain the natural capital itself alive (environmental flows) were accounted too. Emergy analysis is an accounting method useful to identify and convert in a single unit of measure all resources feeding a system. This allows the implementation of a system overall assessment and then the conversion of the obtained value in money terms. The studied MPAs are located in the northwestern part of Italy, are both tourism oriented and subdivided in zones with different protection degree. The habitats occupying both the MPAs bottoms have been identified together with the biomass stored on their surface, identifying units named FBHA (fishes and benthos habitat assemblage). The calculation of biomass stocked in the benthic organisms and in the fishes associated to each FBHA represents the basis for the assessment of MPA natural capital value and of environmental flows. From these values, the trophic network of each habitat was modeled allowing calculating the inputs to emergy analysis.

The value of PF natural capital, expressed as resources employed through space and time to store the existing biomass, is equal to over 10 million Euros while the CT natural capital amounts to over 30 million.

The high value habitats, where biomass is concentrated and stored, represent *hot spots* that are restricted in a limited surface and that can be maintained only if the resources they need are provided by adjacent lower value habitats. Through the applied methodology, a balance is performed to understand if an MPA is self-sufficient or dependent on external areas. Therefore, if an MPA is correctly planned, as CT is, the wider low value areas are able to provide resources to the deficit FBHAs and even to export resources to other systems. In this case, the MPA lies in a surplus condition. On the contrary, the MPA is not able to maintain itself and depends on external systems not subjected to protection and then potentially posed at risk.

If information about natural capital, flows and balance is synthesized in a Geographical Information System, it represents an effective tool to MPAs managers to measure the efficacy of protection established.

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1. Introduction

Coastal marine ecosystems are high-valuable systems providing services and benefits such as high productivity (Beaumont et al., 2007; Moberg and Folke, 1999; Townsend et al., 2011), commercial and not commercial fisheries (Muntadas et al., 2015) and sink and stabilization of sediments (Duarte et al., 2005; Ohde and Van Woesik, 1999; Orth et al., 2006). However, the intense

urban, industrial and tourist development in coastal areas, coupled with a scarce sensitivity about the link between ecosystem health and human well-being is threatening marine ecosystems worldwide (UNEP, 2006). The consequences of anthropogenic impacts on marine ecosystems are proved by the dramatic extent loss of habitats such as mangroves, coral reefs and seagrass meadows (Ferreira et al., 2017; Fortes, 1988; Ilman et al., 2016; Montefalcone et al., 2015; Parravicini et al., 2013; Pauly et al., 1998; Short and Wyllie-Echeverria, 1996; Waycott et al., 2009).

In this background, the marine protected areas (MPAs) have become one of the most important marine ecosystem management and conservation strategies (Campbell and Hewitt, 2006) aiming to

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halt or reverse the ecosystem's degradation, conserving the biodiversity and maintaining or enhancing living resources (NRC, 2001; Pita et al., 2011). MPAs' proper design together with the monitoring of the achievement of conservation goals are crucial to effectively protect the ecosystems and to generate benefits which can positively impact on local and regional economies (Angulo-Valdes and Hatcher, 2010; Badalamenti et al., 2000; Boncoeur et al., 2002; Hoskin et al., 2011; Sanchirico et al., 2002).

To avoid the so called "paper parks" (Lindenmayer and Likens, 2010) it is urgent to provide management tools able to assess the MPAs efficacy. The capacity of ecosystems to produce benefits lays on the maintenance of the natural capital, defined as the stock of natural resources supporting ecosystem goods and services (Costanza and Daly, 1992). Therefore, any kind of effective ecosystem management will lay on a correct natural capital evaluation (de Groot et al., 2002, 2012).

In this context, the emergy accounting (Odum, 1996) represents a fundamental tool to synthesize the ecological complexity and to ascribe a value to the natural capital, as it quantifies the work of biosphere in terms of direct and indirect solar energy embodied in generating natural resources. Accordingly, emergy provides a measure of natural capital value in terms of biophysical resources consumption required to support the generation, the extraction and the fruition of goods and services (Franzese et al., 2015; Paoli et al., 2016a). Recently emergy as tool for natural capital and ecosystem services valuation has been applied in specific study cases (Campbell and Hewitt, 2006; Campbell and Brown, 2012; Vassallo et al., 2013; Berrios et al., 2017; Franzese et al., 2017).

The evaluation of MPAs' natural capital requires taking into account that a MPA contains a variety of habitats providing different types and amounts of ecosystem services, subjected to different pressures and responding differently to the stresses. This habitats' heterogeneity makes fundamental to know the location of each habitat to assess adequate conservation targets and manage human pressures. Consequently, the seabed habitat mapping has become an effective tool, not only to implement MPAs decisions, but also to synthesize spatial information essential for the monitoring and further management of the MPAs (Cogan et al., 2009; Ehler and Douvère, 2009).

This research, therefore, aims at:

- estimating the value of the natural capital within two different MPAs;
- estimating the value of environmental annual flows that maintain natural capital;
- highlighting differences in terms of value among different habitats and the associated biocenosis that compose MPAs;
- providing an MPA management tool based on biophysical measures and monetary evaluation of natural stocks and fluxes.

2. Materials and methods

2.1. Study area

The methodology described by Vassallo et al. (2017) was applied to the Portofino MPA and the Cinque Terre MPA (Liguria Region, NW Italy, respectively PF and CT hereinafter) (Fig. 1). The PF MPA was established in 1999 and occupies a total surface of 363 ha while the CT MPA was instituted in 1997 and occupies a surface of 4865 ha. PF is distant 69 km from CT.

The PF MPA's borders include the totality of Portofino municipality coast and a fraction of Santa Margherita Ligure coast and Camogli coast (Fig. 1). CT MPA involves the coast of four municipalities including five villages that from east to west are: Riomaggiore, Manarola (part of Riomaggiore municipality), Corniglia (part of

Vernazza municipality), Vernazza, Monterosso al Mare and partly Levanto (Fig. 1).

Both MPAs are tourism oriented areas, widely recognized for their high natural value, worldwide known for their emerged and submerged landscape, as well as for the rich biodiversity they host with endemisms and endangered species. The MPAs contain areas protected within the framework of the so-called "Habitats" Directive (HSD: 92/43/EEC, EEC, 1992) (SCI IT1332674: Fondali monte di Portofino, IT1344270 Fondali Punta Mesco – Riomaggiore). The Habitat Directive is a European Community legislative instrument in the field of nature conservation that establishes a common framework for the conservation of wild animal and plant species and natural habitats of Community importance; both MPAs include the endemic *Posidonia oceanica* habitat and the biogenic formation named coralligenous designated as Mediterranean priority habitats by the Directive. Moreover, since 2005 the PF MPA, created within a national Ministry decree in 1999, is a SPAMI (Specially Protected Area of Mediterranean Interest) according to the decision of the RAC/SPA (Regional Activity Centre for Specially Protected Areas) Office (<http://www.rac-spa.org>, UNEP, 2005). Within the MPAs many activities such as diving, fishing and recreational boating are regulated (Cattaneo-Vietti et al., 2015) with different protection levels, from more severe in the A zone to less severe in the C zone (Table 1). Since in PF the C zone is physically split in two subareas separated by the A and the B zones, the C east (CE) and the C west (CW) zones have been considered within this study.

Analogously in CT the A and the B zones are separated in the eastern and the western part (hereinafter named AE and AW and BE and BW respectively). Despite the protection regimes, tourism oriented activities are very common and pressure on local environment can be very high. In PF the recreational boating reaches the maximum in August with about 200 units per days and the diving activities count more than 30,000 annual dives (Venturini et al., 2016). In CT, the recreational boating pressure can reach maximum values in August, equal to over 80 units per days and over 2700 annual dives (Conidi, 2010). The pressure from bathing users is exerted only in some segments of the MPAs since a large part of the MPAs coastline is occupied by rocky and steep tracts not accessible. In PF the available surface for bathing users is equal to 9162 m², frequented by a precautionary estimate of over 100,000 users per summer. The CT's available space for bathing users is around 42,800 m², mainly located in Monterosso (93%) and frequented by a raw and precautionary estimate of around 500,000 users per summer.

2.2. Methodology

2.2.1. The emergy accounting method

Emergy is an environmental accounting method based on thermodynamics introduced in the '80s by Howard Odum. Emergy is a technique of quantitative analysis converting the amounts of resources with and without an economic value, services and commodities in a sole common unit (Brown and Herendeen, 1996). This makes emergy a very versatile technique that can be applied to both natural and human-dominated ecosystems. In particular, the free environmental inputs (e.g., solar radiation, wind, rain, and geothermal flows) to a system are taken into account as well as the human-driven flows. All inputs are accounted together with indirect environmental support embodied in human labour and services (Brown and Ulgiati, 2004).

The emergy theory is defined by two key concepts: the solar emergy and the solar transformity. The solar emergy is defined by the quantity of solar energy required, directly or not, to provide a given flow or storage of energy or matter (Odum, 1996). The emergy is expressed in solar emergy Joule (sej) and it is usually calculated on an annual scale. The solar transformity measures the input of emergy per unit output and it is calculated as the ratio of the

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