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Assessing natural capital value in the network of Italian marine protected areas: a comparative approach

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Abstract. Marine and coastal natural capital stocks provide a bundle of ecosystem services vital for human well-being. The biophysical and economic assessment of the value of natural capital stocks is much needed for achieving nature conservation goals, while ensuring the sustainable exploitation of marine resources. Marine Protected Areas (MPAs) are increasingly being established worldwide to protect and conserve natural capital stocks from anthropogenic threats. In this study, a biophysical and trophodynamic model based on the emergy accounting method was used to assess the value of natural capital for a set of Italian MPAs. In particular, the assessment focused on four main macro-habitats: 1) sciaphilic hard bottom (SHB), 2) photophilic hard bottom (PHB), 3) soft bottom (SB), and 4) *Posidonia oceanica* seagrass beds (PSB). The emergy method allowed the assessment of natural capital stocks in terms of direct and indirect solar energy flows invested by nature for their generation. The SHB habitat showed the highest emergy density value in most of the investigated MPAs, confirming the high convergence of input resource flows in the formation of this habitat. When considering extensive indicators, the contribution of the PSB habitat to the total value of natural capital was higher than other habitats in most MPAs. In addition, to facilitate the understanding of the results in socio-economic contexts, the biophysical values of natural capital stocks were converted into monetary units. The total value of natural capital in the investigated MPAs ranged from about 8 to 1163 M€. In conclusion, assessing the value of natural capital can support local managers and policy makers in charge for achieving nature conservation targets while ensuring the sustainable exploitation of natural resources.

Key words: environmental accounting; natural capital; marine ecosystems; marine protected areas.

1. Introduction

In the last decades, there has been growing awareness on the vital support natural ecosystems provide to human well-being both in scientific and policy contexts (Buonocore et al., 2018; Chan et al., 2016; Häyhä and Franzese, 2014; Pauna et al., 2018). The concepts of "natural capital" and "ecosystem services" are conceived to explore the interactions between natural ecosystems and human well-being. They are also meant to allow for a better understanding of when, where and to what extent humans may benefit from ecosystems, influence ecosystems and loose ecosystem functions and services with overexploitation of natural resources (van Dijk et al., 2018).

Marine and coastal ecosystems are recognized as among the most productive ecosystems in the world (UNEP, 2006; Hattam et al., 2015). Healthy, resilient, and diverse marine ecosystems are capable of generating and maintaining natural capital stocks while providing a bundle of ecosystem services vital for human economic development and well-being (Armoškaitė et al., 2020; Cattaneo-Vietti et al., 2016; Cavanagh et al., 2016; Vihervaara et al., 2019).

Marine ecosystems are exposed to several anthropogenic pressures among which, pollution, overfishing, the introduction of invasive species, and acidification (Halpern et al., 2008; Pauna et al., 2019). The cumulative impact of human activities on marine ecosystems often leads to ecosystem degradation and biodiversity loss, also affecting their capacity to provide benefits to humans (Halpern et al., 2019).

Marine Protected Areas (MPAs) are important tools to protect and conserve natural capital stocks from different anthropogenic threats on marine ecosystems (Maestro et al., 2019; Rasheed et al., 2020). MPAs are characterized by interlinked social, economic, and ecological dynamics and represent complex conservation and management tools for achieving sustainability goals. Several studies show that MPAs contribute to biodiversity protection while ensuring the sustainable exploitation of marine resources (Halpern, 2003; OECD, 2017).

When effective management measures are in place, MPAs are able to meet the multitude of objectives they are designed for. Although an increasing number of MPAs has been established worldwide, efforts are still required for the evaluation and understanding of their effectiveness (UNEP-WCMC and IUCN, 2019). Therefore, novel multi-criteria frameworks are much needed for assessing MPAs effectiveness and management performance, providing useful information to local managers and policy makers in charge of achieving local and large-scale sustainability goals (Rasheed, 2020).

Accounting for natural capital and ecosystem services value is the basis for the effective management of natural resources (Barbier, 2014; Yu et al., 2019). Over the past decade, there have been increasing research efforts to assess natural capital value and related ecosystem services in marine ecosystems, also exploring how these values can be embedded into decision making (Christie et al., 2015; Franzese et al., 2008, 2015; Schumann and Mahon, 2015; TEEB, 2010).

Recent studies provided an assessment of the biophysical value of natural capital in MPAs. In particular, Vassallo et al. (2017) developed a biophysical and trophodynamic model based on emergy accounting to assess the value of natural capital in MPAs. Franzese et al. (2017), Picone et al. (2017), Paoli et al. (2018), and Buonocore et al. (2019, 2020) assessed the biophysical value of natural capital in selected Mediterranean MPAs. Berrios et al. (2017) used emergy accounting to provide an evaluation of natural capital and ecosystem services of benthic marine ecosystems in Chile, also exploring their contributions to the well-being of regional economy.

In 2014, following the EU Biodiversity Strategy to 2020 guidelines, the Italian Ministry of the Environment and Protection of Land and Sea financed a 4-years research programme entitled "Environmental Accounting in Italian Marine Protected Areas" and based on the implementation of an environmental accounting system for all the twenty-nine Italian MPAs. The purpose of the project was to carry out a biophysical and economic assessment of natural capital stocks and ecosystem services flows (Franzese et al., 2015). The project also aimed at the spatial representation of both the ecological and economic value of natural capital to support marine spatial planning and the sustainable management of biological resources.

In this study, we present a synthesis of the results of this national project dealing with natural capital assessment for selected Italian MPAs.

2. Materials and methods

2.1 The network of Italian marine protected areas

The network of Italian MPAs includes 29 sites protecting about 228,000 ha of sea and 700 km of coastline (Fig. 1). All the Italian MPAs include three subareas with different levels of protection and accessibility, namely Zone A, Zone B, and Zone C. In Zone A (no-take/no-access zone) the maximum level of protection is enforced (e.g., tourist access is not allowed, while diving is only authorized for research purposes); in Zone B (general protection zone) more activities are allowed (e.g., swimming, authorized professional and recreational fishing); lastly, Zone C (partial protection zone) allows the highest degree of human activities.

Important socio-ecological and cultural features characterize these sites. Noteworthy is the presence of the endemic Mediterranean seagrass *Posidonia oceanica* and Coralligenous bioconstructions, both representing priority habitats protected under the European Directive 92/43/EEC (Habitat Directive). Besides their ecological importance, these habitats also represent main tourist attractions enhancing recreational activities such as boating and diving.

Figure 1. Network of Italian Marine Protected Areas.

2.2 The environmental accounting model

In this study, a biophysical and trophodynamic environmental accounting model (Vassallo et al., 2017) was applied to assess the value of natural capital stocks in a set of Italian MPAs.

In particular, all the habitats included within the boundaries of the MPAs were clustered into four main macro-habitats: 1) soft bottom (SB), 2) *Posidonia oceanica* seagrass beds (PSB), 3) sciaphilic hard bottom (SHB) (coralligenous bioconstruction), and 4) photophilic hard bottom (PHB). The area of the four macro-habitats for the set of investigated MPAs is reported in Table 1.

Table 1. Areas of the investigated Italian MPAs and related macro-habitats.

MPA	SHB (ha)	PHB (ha)	SB (ha)	PSB (ha)	Total (ha)
Isole Ventotene e S. Stefano	100	16	2297	433	2850
Punta Campanella	137	19	1250	143	1550
Costa degli Infreschi e della Masseta	27	35	2144	150	2360
S. Maria di Castellabate	427	147	3501	2857	6930
Capo Rizzuto	808	2512	11224	442	15000
Isole Tremiti	251	119	938	16	1320
Isole Egadi	553	5265	12434	36452	53992
Regno di Nettuno	181	177	4085	1839	6282
Isole Pelagie	2	314	2904	628	3849

Ad hoc sampling campaigns were performed to collect data on macrobenthic communities and necto-benthic fishes of each macro-habitat. All identified species were clustered in the following main taxonomic groups: Algae, Annelida, Ascidiacea, Bryozoa, Crustacea, Fishes, Porifera, Echinodermata, Mollusca, and Sipuncula.

The matrixes of the biomass density calculated for the main taxonomic groups were the basis for the environmental accounting model implemented through the following main steps:

1. Identification of the boundaries (spatial and temporal) of the MPAs and their main macro-habitats;
2. Modelling of the MPAs by means of a system diagram drawn according to a standardized energy systems language (Odum, 1996);
3. Biomass inventory of the main taxonomic groups identified in the macro-habitats of the MPAs;
4. Trophodynamic analysis, providing an estimate of the primary productivity used to support the benthic trophic chain within the study areas;
5. Calculation of the main matter and energy flows supporting the generation of natural capital in the different macro-habitats of the MPAs, and conversion of these flows into solar emergy units (Odum, 1996);

6. Calculation of the total emergy value of natural capital stocks for the macro-habitats and the whole MPAs.

In addition, to complement the biophysical assessment with an economic perspective, the emergy values of natural capital were converted into non-market monetary units by using the Emergy-to-Money Ratio (EMR) indicator (www.emergy-nead.com).

2.3 The Emergy accounting method

Emergy is an environmental accounting method measuring the cumulative environmental support to a process (Odum, 1988, 1996). The method aims at evaluating the environmental performance of a system on the global scale of the biosphere, taking into account free environmental inputs (e.g., solar radiation, wind, rain, and geothermal flow), human-driven material and energy flows, and the indirect environmental support embodied in human labor and services (Brown and Ulgiati, 2004; Brown et al., 2016a,b; Franzese et al., 2009, 2014). According to this method, inputs 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 in sej (solar equivalent joules). The solar emergy required to generate one unit of product or service is referred to as Unit Emergy Value (UEV, sej J^{-1}, sej g^{-1}). Mass, energy, labor, and money inputs to the investigated system are converted into emergy units by using appropriate UEVs, and then summed to calculate the total emergy support.

The UEVs used in this study (Table 2) were updated to the $1.20 \cdot 10^{25}$ sej yr^{-1} biosphere emergy baseline calculated by Brown et al. (2016a,b).

Table 2. UEVs used in this study.

INPUT	UEV (sej unit^{-1})	References
Solar radiation (J)	1.00	By definition
Rain (J)	2.31E+04	Odum, 1996
Wind (J)	1.90E+03	Odum, 1996
Geothermal flow (J)	1.58E+04	Brown and Ulgiati, 2010
Tides (J)	5.68E+04	Brown and Ulgiati, 2010
Currents (J)	3.00E+04	Odum, 1996
Runoff (J)	5.22E+04	Odum, 1996
C (g)	8.07E+07	Campbell et al., 2014
N (g)	5.84E+09	Odum, 1996
P (g)	8.07E+07	Odum, 1996

3. Results

Figure 2 shows the systems diagram modelling the investigated MPAs and drawn according to a standardized energy systems language (Odum, 1994; 1996). The systems diagram highlights: a) the main external driving forces supporting the generation of natural capital stocks, b) the producers, consumers, and main storages of the marine ecosystem, and c) the interactions among components.

This symbolic model is useful to implement the quantitative assessment of mass and energy flows, and stocks included within the boundaries of the investigated MPAs.

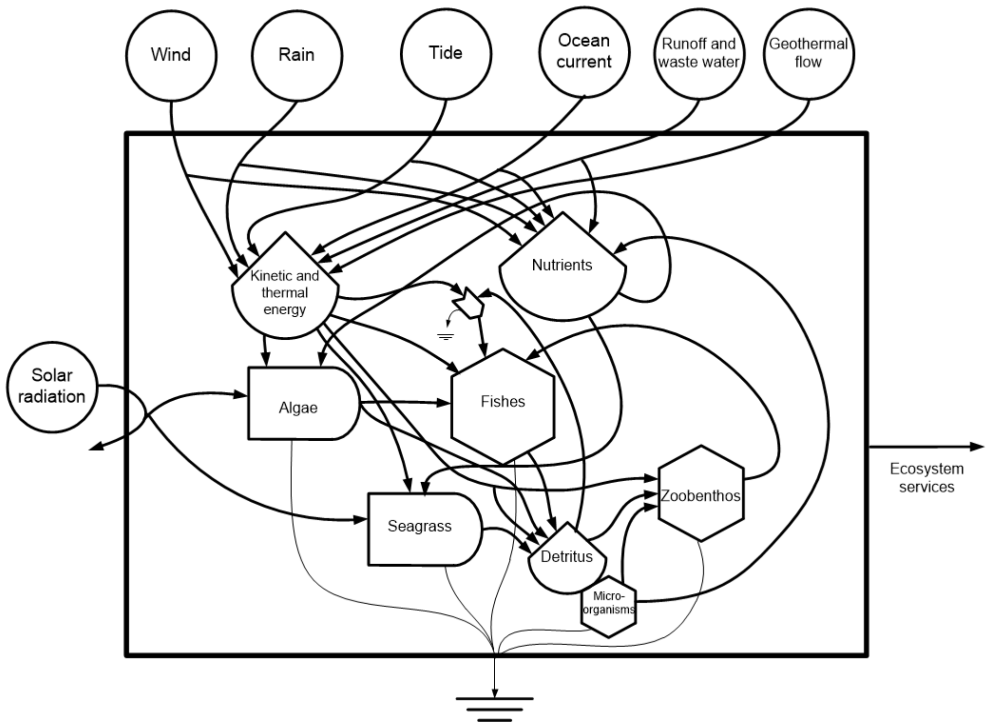

Figure 2. Systems diagram of the investigated MPAs (Franzese et al., 2017).

Table 3 shows the emergy cost supported for the generation of natural capital stocks in each macro-habitat of the MPAs. The emergy costs refer to the evaluation of natural flows and nutrients flows that supported the formation of both autotrophic and heterotrophic natural capital stocks in each of the four investigated macro-habitats. The values ranged from $7.79 \cdot 10^{16}$ sej for the PSB habitat of the "Isole Tremiti" MPA to $8.62 \cdot 10^{20}$ sej for the PSB habitat of the "Isole Egadi" MPA. These values are extensive measures depending on the area of the MPAs and their relative macro-habitats. Instead, the emergy density values (Table 4) account for the emergy flows concentrated per unit area, representing an intensive measure of the emergy support to each macro-habitat.

The emergy density value ranged from $9.15 \cdot 10^{11}$ to $4.94 \cdot 10^{12}$ sej m^{-2} for the SHB habitat, from $7.43 \cdot 10^{11}$ to $2.50 \cdot 10^{12}$ sej m^{-2} for the PHB habitat, from $1.03 \cdot 10^{11}$ to $8.67 \cdot 10^{11}$sej m^{-2} for the SB habitat, and from $4.87 \cdot 10^{11}$ to $2.37 \cdot 10^{12}$sej m^{-2} for the PSB habitat (Table 4).

Table 3. Emergy values of natural capital in the four macro-habitats for selected Italian MPAs.

MPA	SHB (sej)	PHB (sej)	SB (sej)	PSB (sej)	Total (sej)
Isole Ventotene e S. Stefano	2.85E+18	1.20E+17	2.36E+18	2.60E+18	7.92E+18
Punta Campanella	6.79E+18	4.16E+17	2.72E+18	1.58E+18	1.15E+19
Costa degli Infreschi e della Masseta	2.51E+17	4.44E+17	6.27E+18	1.83E+18	8.79E+18
S. Maria di Castellabate	1.12E+19	2.88E+18	8.75E+18	2.87E+19	5.15E+19
Capo Rizzuto	1.21E+19	5.61E+19	1.21E+19	4.07E+18	8.44E+19
Isole Tremiti	3.74E+18	2.71E+18	4.37E+18	7.79E+16	1.09E+19
Isole Egadi	1.46E+19	1.32E+20	1.08E+20	8.62E+20	1.12E+21
Regno di Nettuno	4.92E+18	4.34E+18	1.14E+19	2.32E+19	4.39E+19
Isole Pelagie	8.16E+16	3.30E+18	4.01E+18	1.23E+19	1.97E+19

Table 4. Emergy density values of natural capital for selected Italian MPAs.

MPA	SHB (sej/m^2)	PHB (sej/m^2)	SB (sej/m^2)	PSB (sej/m^2)
Isole Ventotene e S. Stefano	2.85E+12	7.43E+11	1.03E+11	6.00E+11
Punta Campanella	4.94E+12	2.22E+12	2.18E+11	1.10E+12
Costa degli Infreschi e della Masseta	9.15E+11	1.27E+12	2.92E+11	1.22E+12
S. Maria di Castellabate	2.61E+12	1.96E+12	2.50E+11	1.00E+12
Capo Rizzuto	1.50E+12	2.23E+12	1.08E+11	9.20E+11
Isole Tremiti	1.49E+12	2.28E+12	4.66E+11	4.87E+11
Isole Egadi	2.65E+12	2.50E+12	8.67E+11	2.37E+12
Regno di Nettuno	2.72E+12	2.45E+12	2.79E+11	1.26E+12
Isole Pelagie	3.43E+12	1.05E+12	1.38E+11	1.96E+12

Table 5 shows the economic value of natural capital calculated for the set of investigated MPAs. The total value of natural capital (i.e., the sum of the values of the four macro-habitats) ranged from about 8 to 1163 M€.

Table 5. Economic values of natural capital stocks for selected Italian MPAs.

MPA	SHB (€)	PHB (€)	SB (€)	PSB (€)	Total (€)
Isole Ventotene e S. Stefano	2.97E+06	1.25E+05	2.46E+06	2.70E+06	8.25E+06
Punta Campanella	7.08E+06	4.34E+05	2.84E+06	1.64E+06	1.20E+07
Costa degli Infreschi e della Masseta	2.61E+05	4.62E+05	6.53E+06	1.91E+06	9.16E+06
S. Maria di Castellabate	1.16E+07	3.00E+06	9.12E+06	2.99E+07	5.36E+07
Capo Rizzuto	1.27E+07	5.84E+07	1.26E+07	4.24E+06	8.79E+07
Isole Tremiti	3.90E+06	2.82E+06	4.55E+06	8.11E+04	1.14E+07
Isole Egadi	1.53E+07	1.37E+08	1.12E+08	8.98E+08	1.16E+09
Regno di Nettuno	5.13E+06	4.52E+06	1.19E+07	2.42E+07	4.57E+07
Isole Pelagie	8.50E+04	3.44E+06	4.18E+06	1.28E+07	2.05E+07

4. Discussion

Accounting for the biophysical and economic value of natural capital stocks is the basis for the sustainable management of natural resources, especially in the case of MPAs meant to protect biological diversity while ensuring sustainable human activities.

In this study, the value of natural capital stocks in selected Italian MPAs was assessed through the lens of the biophysical perspective of the emergy accounting method.

The emergy density value of the SHB habitat (coralligenous bioconstructions) resulted higher than all other habitats for most of the investigated MPAs. The high emergy cost calculated for the SHB habitat is due to the high convergence of natural input flows for its generation, confirming the importance of coralligenous habitats in coastal marine ecosystems (Ferrigno et al., 2017; Appolloni et al., 2020a).

When considering extensive indicators, the contribution of the SHB habitat to the total value of natural capital was higher than other habitats in the case of “Punta Campanella” and “Isole di Ventotene e Santo Stefano” MPAs (Figure 3). Instead, the PSB habitat showed higher value compared to other habitats for four investigated MPAs (Figure 3). In particular, the contribution of the PSB habitat to the total value of natural capital was very high in the case of the “Isole Pelagie” (62%) and “Isole Egadi” (77%) MPAs.

These outcomes highlight the importance of protecting *P. oceanica* seagrass beds representing one of the most important habitat formers in the Mediterranean Sea whose primary production generates significant biomass stocks associated with high biodiversity (Appolloni et al., 2020b; de Virgilio et al., 2020).

Only in the case of “Capo Rizzuto” MPA, the PHB habitat showed the highest contribution to the total natural capital value (Figure 3). In fact, although this habitat covers about 17% of the total MPA area, its emergy density value was higher than all the other habitats (Table 4). This peculiar feature highlights that the SHB habitat deserves particular attention in the conservation planning of the MPA of “Capo Rizzuto”.

In the case of “Costa degli Infreschi e della Masseta” and “Isole Tremiti” MPAs the SB habitat showed the highest contribution to the total natural capital value. This was mainly due to the area covered by this habitat accounting for about 51% and 71% of the total MPAs area, respectively.

In addition, the conversion of the emergy values into non-market monetary units provided a complementary perspective to the biophysical assessment. Nonetheless, it is noteworthy that results expressed in monetary equivalent still represent the environmental cost for natural capital stocks generation but, at the same time, allow for an easier understanding of the outcomes of the study in socio-economic contexts.

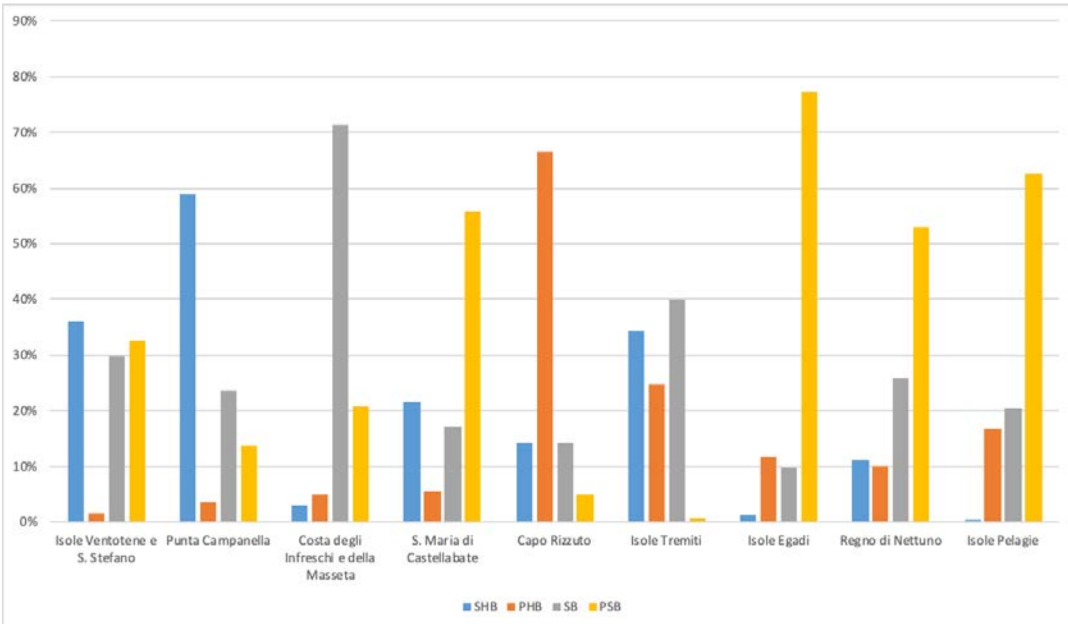

Figure 3. Contribution of the four macro-habitats to the total value of natural capital in the investigated Italian MPAs.

The assessment of natural capital value in the Italian MPAs was based on the implementation of a standardized protocol developed in the framework of the Italian national project. The standardization of the sampling techniques and the development of an *ad hoc* environmental accounting model allowed the comparison of the results obtained for the different MPAs.

Nonetheless, the complexity and openness of marine ecosystems along with the limited data and resources availability forced to adopt several simplifications in the development of the environmental accounting model. For instance, the main focus was on benthic macro-habitats while the pelagic domain was not investigated. Moreover, while multiple samplings were performed to estimate the biomass data, the clustering of the benthic habitats into macro-habitats may simplify the habitat heterogeneity within MPAs. Nevertheless, in future studies the accounting model could be modified and adapted to assess the natural capital value of specific habitats that are peculiar in some Italian MPAs, such as vermetid reefs and other bioconstructions (Donnarumma et al., 2018; Ingrosso et al., 2018).

5. Conclusions

In this study, a biophysical and trophodynamic model based on the Emergy accounting method was used to assess the value of natural capital stocks in a set of Italian MPAs.

The value of natural capital was calculated for each macro-habitat and for the whole MPAs in both biophysical and economic terms. While the biophysical value reflects the ecological dynamics in the MPAs, the economic value is useful to better communicate the outcomes of the biophysical assessment in socio-economic contexts. Therefore, assessing the biophysical and economic value of natural capital can support local managers and policy makers in charge for achieving nature conservation targets while ensuring the sustainable exploitation of natural resources.

The outcomes of this study may be updated in the future on the base of new and comprehensive biomass dataset and bionomic maps.

Finally, according to the goals of the national project, the accounting of natural capital value will be integrated with an ecological-economic assessment of the bundle of ecosystem services underpinned by MPAs.

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