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A Benthic Zonation System as a Fundamental Tool for Natural Capital Assessment in a Marine Environment: A Case Study in the Northern Tyrrhenian Sea, Italy

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Abstract: Coastal marine areas are characterized by the highest values of ecosystem services and by multiple uses that are often in conflict with each other. Natural capital analysis is claimed to be a valid tool to support space planning. In the context of the Marine Strategy Framework Directive (MSFD) of the European Union (EU), the EU Joint Research Centre (JRC) Scientific and Policy Report 2014 defines the monitoring of specific descriptors and their possible use, based on an ecosystem-services approach. Mediterranean marine ecosystems are characterized by high biodiversity and the presence of relevant benthic biocenosis that can be used as a tool to support coastal planning, conservation, and monitoring programs. In this study, we considered the Mediterranean benthic biocenosis, as classified by Pérès and Picard, as a working tool and propose a basic spatial unit for the assessment of marine ecosystem services. Focusing on a high-resolution local-scale analysis, this work presents an accurate identification of the different biocenoses for the coastal area of Civitavecchia in the Northern Tyrrhenian Sea, Italy, and ecosystem services, as well as a benefits assessment, of the *Posidonia oceanica* meadows.

Keywords: ecosystem services; natural capital; benthic zonation; *P. oceanica*

1. Introduction

In 2000, United Nations Secretary-General, Kofi Annan, launched the Millennium Ecosystem Assessment (MA) with the general objective of assessing the consequences of changing ecosystems [1]. Over the period of 2001–2005, 1360 experts worked on this assessment with a focus on ecosystem services and their influence on human well-being. Moreover, the MA provides scientific elements to decision-makers for ecosystem conservation and sustainable use. The MA definition of ecosystem services is the following:

> *Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling* [2].

The concept of ecosystem services was introduced in scientific literature in the 1970s and 80s. Initially, this concept considered only the services that nature provides, but over time, it also came to include socio-economic concepts and conservation objectives [3]. Ecosystem benefits evaluation is a process that is strictly connected to the ecosystem approach [4], which has been described as a strategy for the integrated management of land, water, and living resources to promote conservation and sustainable use within the framework of the 1992 Convention on Biological Diversity (CBD) [5]. In recent years, the concept of ecosystem service has become of pivotal importance in assessing biodiversity decline and the implications of ecosystems changes for human kind [6], and various international initiatives have been taken to create an operational concept for research and management, such as the Economics of Ecosystems and Biodiversity (TEEB) and the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) [6,7].

Although all ecosystems are more or less massively influenced by human activities, thus making it difficult to clearly define what a natural capital is (or if there is indeed an existing "natural" part of a capital) [6,8], natural capital assessment is being established as a valid tool to support spatial planning and increase the compatibility among the multiple uses of resources, which are often in conflict with each other.

The coastal area is characterized by multiple physical and ecological conditions that can support multiple uses of natural resources. In this situation, conflicts impacting both human uses and fragile resources often arise among the various interests [9]. Therefore, it is necessary to face the problems affecting coastal systems to minimize the mutual impacts of the conflicting uses. The overall management objective must ensure the sustainable use of all resources. This concept obviously includes the conservation of ecological structures and processes involved in use, aside from their usefulness in human activities.

From an applicative point of view, the analysis of the distribution and abundance of benthic communities can be used as a tool for both coastal planning, conservation, and monitoring programs. In this paper, we considered the benthic biocenosis, as identified by Pérès and Picard for the Mediterranean Sea, as our most important working tool and we proposed it to be the funding unit for the classification of a marine ecosystem.

> *A zonation system has a pragmatic nature, useful in the classification process, that does not need to have a precise confirmation in the reality. Hence a zonation system has to be considered as a working tool, not as an end, or a finality* [10].

In this context, the distribution and abundance of benthic communities is used as a tool to be coupled with the ecosystem services evaluation methods.

The goal is to set an appropriate spatial scale to be used as a funding unit for the application of empirical economic valuation data.

We considered benthic biocenosis, as identified by Pérès and Picard for the Mediterranean Sea, as our base zonation system to apply the "basic value transfer" method for the evaluation of ecosystem services [11]. This work also presents an assessment of the natural capital economic value for *Posidonia oceanica* meadows in the coastal area of Civitavecchia in the Northern Tyrrhenian Sea, Italy.

2. Spatial Distribution of Benthic Biocenosis

2.1. Study Area

The study area (Figure 1) extends along the stretch of the coast, from Punta S. Agostino in the north to Capo Linaro in the south. Civitavecchia Harbor is located in the central zone of the study area and is an important crossroads for cruise and commercial traffic in the Mediterranean Sea [12,13]. The area is characterized by sites of community interest with habitats and species considered as having a high priority by the Habitat Directive 92/43/EEC. In particular, there are meadows of *Posidonia oceanica* and reefs (Annex I—Habitat Directive code * 1120 and * 1170, respectively), as well the species *Pinna nobilis* (Annex IV—Habitat Code Directive 1028) and *Corallium rubrum* (Annex IV—Habitat Code Code * 1001). IT6000005 SCI extends from Punta Sant'Agostino to Punta Mattonara, covering an area of 435 ha, with a total length of about 5 km. SCI IT6000006 is located further south and includes the seabed between Punta del Pecoraro and Capo Linaro, with an area of about 746 ha and a total length of 5 km.

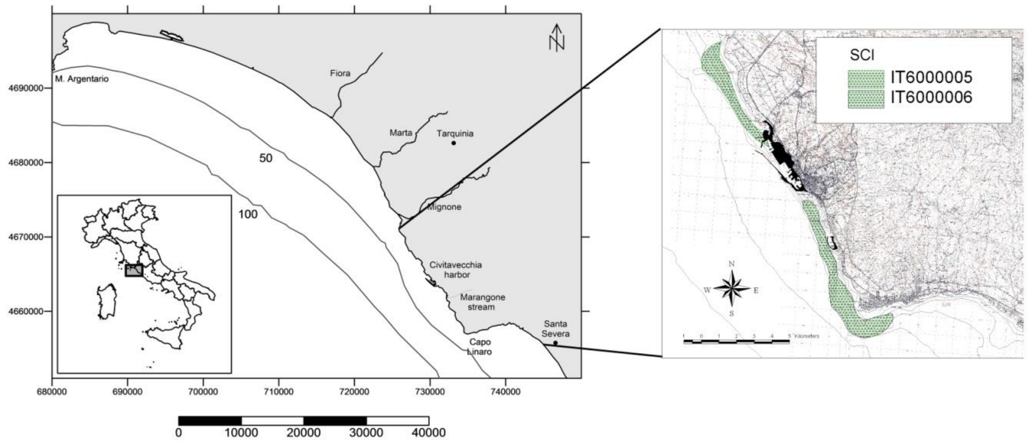

Figure 1. Coastal area of Civitavecchia (with SCIs IT6000005 and IT6000006) in the Northern Tyrrhenian Sea, Italy.

2.2. Benthic Biocenosis Data Acquisition and Processing

A large body of literature on benthic biocenosis has been built for the study area over the years, which mainly comprise environmental impact assessments, related to infrastructure works. Marine ecosystems were assessed by identifying characteristic species, based on the main references for the area and for the Mediterranean Sea in general. Based on this information, species lists were determined for every unit area to define the relative biocenosis. Literature data were integrated with original unpublished data obtained through two sampling campaigns of soft substrate benthic biocenosis, performed in 2013 and 2017, and through assessment campaigns for the characterization of *P. oceanica* meadows, in the study area [14,15]. The aim was to validate the literature information by comparing the characteristic species lists.

2.3. Spatial Assessment Using Benthic Zonation as a Reference Unit

The identification of benefits provided from benthic biocenosis is made spatially explicit through the display of qualitative information on a high-resolution map. The resulting map should support planning efforts for coastal use to assess the need for future management strategies, aimed at preserving the environment by considering the contribution of ecosystem services to human well-being while achieving sustainable development [16].

Figure 2 shows a detailed biocenosis distribution map, based on Pérès and Picard zonation [17], built through a GIS application. The map is based on Map 1:100,000 from the Military Geographic Institute of Italy (IGM) and on previous studies with particular reference to a compendium of several surveys conducted in the decade 1999–2009, in the study area [18]. Literature data are integrated using unpublished results of two sampling campaigns of soft bottom benthic biocoenoses, carried out in 2013 and 2017, and *P. oceanica* characterization surveys [14,15].

The distribution of the biocenosis *P. oceanica* (Herbier de Posidonies, HP), is represented on the basis of the substrates, in order to have a greater level of detail. The harbor structure was reconstructed using information from Google Maps from 2016. Table 1 shows the surface of each biocenosis considered in Figure 2.

Not all of the ecosystems identified within the study area can actually be considered distinct ecological spatial units. Some are mosaics of other ecosystems, while others represent a transition between two successive environments. In both cases, these areas are characterized by a biocenosis. In some cases, they can even feature species that do not appear in the neighboring ecosystems. This is one of the main reasons why an accurate redaction of the characteristic species list in a very heterogeneous zone is a key feature in this process.

The complex variability of existing ecosystems, along with the number of intense and diversified coastal uses, shows the necessity of a spatial description of the feature distribution within the study area. Such a large number of resources and threats can only be understood using instruments that allow a better understanding of the on-going processes. From an operational point of view, the analysis of the distribution and abundance of benthic communities are used as tools for both coastal planning and conservation-and-monitoring programs, as the zonation system has a pragmatic nature [10].

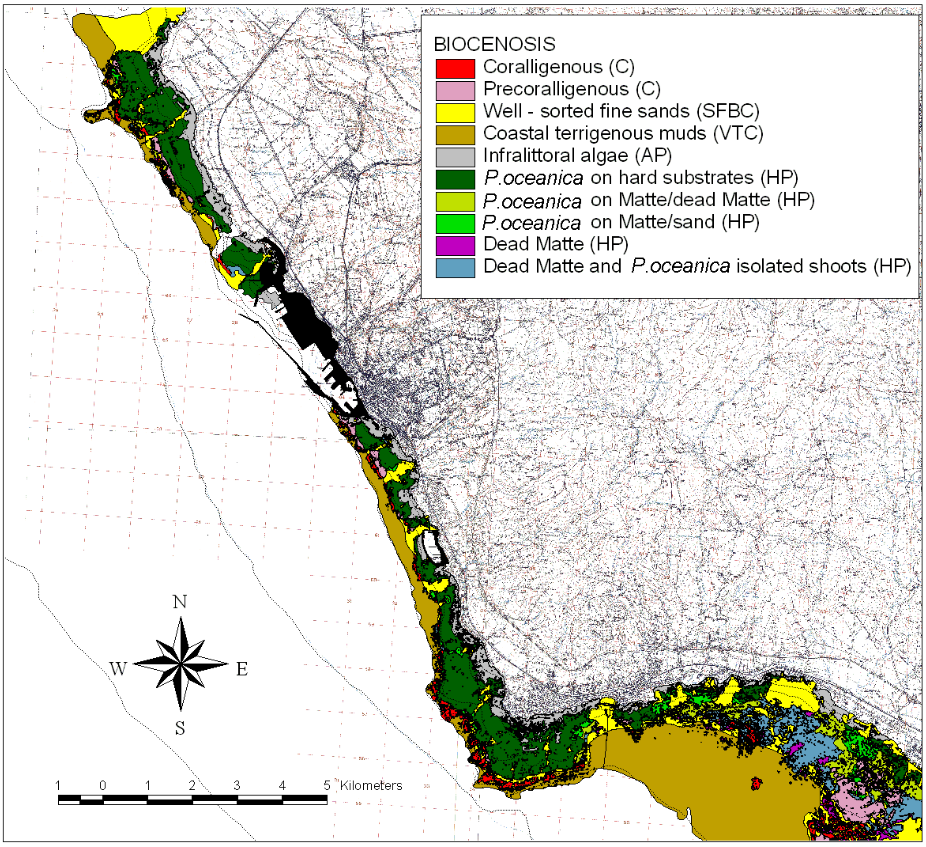

Figure 2. Pérès and Picard biocenosis classification distribution for the study area.

Table 1. Spatial distribution of each biocenosis in Civitavecchia coastal area.

Biocenosis (Pérès and Picard, 1964)	HECTARES
Coastal terrigenous muds (VTC)	2957
Coralligenous (C)	340
Dead Matte (HP)	107
Dead Matte and *P. oceanica* isolated shoots (HP)	568
Infralittoral algae (AP)	888
P. oceanica on hard substrates (HP)	928
P. oceanica on Matte/dead Matte (HP)	360
P. oceanica on Matte/sand (HP)	105
Precoralligenous (hard substrate with mosaic of photophile and sciaphile association) (C)	312
Well—sorted fine sands (SFBC)	1989
TOTAL	8555

Bionomic cartography has for many decades been a primary tool for analysis and knowledge of marine ecosystems [19]. It provides a fundamental contribution to environmental characterization and, therefore, can already be configured as a management tool. Furthermore, the biocenosis is the population unit that allows calculation of the potential quality of habitats and their values [20]. The bionomic approach, in which the tradition of the Mediterranean school has always been at the forefront [21], intended as a biological and ecological indicator for environmental assessment, is increasingly promoted by international organizations, such as UNEP and UNESCO [22,23]. Moreover, the distribution of habitats can be deduced directly from the biocenosis map [24].

This work uses the biocenosis map because it is at a greater level of detail than habitat units and it provides implicit information about the potential presence of marine species (ichthyofauna and macrozoobenthonic species), in a given area.

2.4. Ecosystem Services Assessment and Benefit Provision

According to the Millennium Ecosystem Assessment, "Ecosystem services are the benefits people obtain from ecosystems" [1]. This is probably the most diffuse and general definition of ecosystem services. Throughout the evolution of the conceptual framework, services have often been coupled with goods and been considered together, and this framing has historically obscured the benefits we derive from ecosystems [25–30]. These definitions can actually influence the stakeholders' approaches and their readiness to consider the provision of ecosystem benefits when making decisions [31]. Moreover, when human activities cause the ecological deterioration of a natural system (e.g., land-use change) but do not directly affect human health (e.g., air emissions), concern about the consequences of such activities usually focuses on environmental issues, which often produces only a minor impact in public awareness.

Conceptual frameworks that were recently proposed by different authors were evaluated [11]. Many authors have tried to define ecosystem services in a unique way so far, often leading to uncertainties and misunderstandings [27]. For this reason, it is very important to choose a definition that best fits the requirements of a specific case study and to elaborate upon the most suitable approach. This approach is consistent with the latest developments of the conceptual framework, indicated by Costanza [32], who suggested that a unique definition of ecosystem services and benefits is not even useful, as the definition has to be specifically re-shaped for each valuation case (Table 2). Costanza's definition was used as a theoretical framework for our evaluation.

Table 2. Principal conceptual framework of services and benefits considered in this work.

MEA 2005	Wallace 2007	Boyd & Bazshaf 2007	Fisher & Turner 2008	Costanza 2008
Services are benefits people obtain from ecosystem	Same definition as MEA with a distinction: ecological processes are means while ecosystem services are ends	Ecosystem services are ecological characteristics; services are divided into intermediate and final services; final ecosystem services are components of nature directly enjoyed, consumed, used	Services are not benefits. Services are ecological in nature. Services do not have to be utilized directly. An ecological process can be an intemediate or final service depending on the typology of resulting benefit.	It's impossible to give an unique definition of services because of the complexity of the real world. Some services can be intermediate/final but in any case they all are means to human well-being. Depending on the specific case an original framework has to be set-up

When an evaluation focuses on only a particular area, the process of assessing the effect of an ecosystem on climate or nutrient cycling may become too complex for operational purposes. In our view, the complex relationship between an ecosystem and global equilibrium should be set aside. We nest our conceptual framework within the context promoted by Boyd and Banzhaf [25] and by Fisher and Turner [27,28], in that, benefits are separated from services, which are ecological processes that we do not utilize directly. Only benefits have a direct impact on human well-being that can be quantified in some way.

As described in the previous section, the use of benthic biocenosis allows us to condense the information on funding ecological processes that regulate the biocenotic balance, thus generating a positive value for human communities. We did not underestimate the services but only focused on the benefits of the services, as the ecological processes were already taken into account when we identified the correct benthic biocenosis, through the species list. The intermediate services, final services, and benefits were assessed for the whole study area with reference to benthic community zonation system, and the results are summarized in Table 3. The following benefits and services are considered in the table:

Table 3. Summary of intermediate services, final services, and benefits provision for some of the biocenosis identified in the area.

Biocenosis	Intermediate Services						Final Services									Benefits									
	Ph	Dec	Res	Rem	Fix	Rep	H/R	PO	BC	NR	SF	CR	SRR	HRR	HR	FP	GR	RM	O_2	CO_2	EC	WC	Brm	A/C	RP
Well-sorted fine sands (SFBC)		X	X	X	X					X		X				X				X			X	X	
Coastal terrigenous muds (VTC)		X	X	X	X	X				X	X	X				X				X			X		
P. oceanica meadows (HP)	X	X	X	X	X	X	X		X	X	X	X	X	X		X		X	X	X	X	X	X	X	X
P. oceanica on hard substrate (HP)	X		X			X	X		X			X	X			X			X			X	X		X
P. oceanica (50%) and dead matte (HP)	X	X	X	X	X	X	X		X	X	X	X	X			X			X	X		X	X		X
Dead matte and *P. oceanica* (isolated shoots) (HP)	X	X	X	X	X	X	X			X		X				X			X	X			X		X
Dead matte (HP)		X	X	X	X					X		X								X			X		
Infralittoral algae (AP)	X		X			X						X				X				X				X	X

Ph = photosynthesis, Dec = decomposition, Res = respiration, Rem = remineralization, Fix = fixation, Rep = reproduction; BP = biological production, H/R = habitat/refuge, PO = pollination, NR = nutrient regulation, SF = soil formation, CR = climate regulation, SRR = sedimentation rate regulation, HRR = hydrodynamic regime regulation, HR = hydrogeological regulation, FP = food production, GR = genetic resources provision, RM = raw materials, O_2 = oxygen production, CO_2 = carbon sequestration, EC = erosion control, WC = water cleaning, Brm = bioremediation, A/C = aesthetic/cultural, RP = recreational potential.

The classification of benthic biocenosis is based on the identification of characteristic (and associated/auxiliary) species to deduce a significant amount of information on ecological processes (services), allowing us to identify intermediate and final services and, in the end, the actual benefit for human well-being. Once the classification of benthic biocenosis has been carried out, based on literature and/or original studies, the benefits provided by each spatial unit can be identified through our conceptual framework as reported in Table 3.

3. Ecosystem Benefits from *P. oceanica* Meadows and Their Economic Evaluation in the Northern Tyrrhenian Sea

Studying the ecological conditions and biological communities enables better understanding of the on-going dynamics. The identification of the benthic biocenosis and its related regulating processes allow us to focus on the benefits that the ecosystem provides. To better illustrate the process of benefit identification, an example assessment of *P. oceanica* meadows is presented. *P. oceanica* was chosen because it forms one of the most important marine ecosystems in the Mediterranean Sea. These meadows form a climax community [33] and are a major benefit provider in the study area. The list of ecosystem services for the Civitavecchia presented in Table 3 was further elaborated, according to the coastal area characteristics and data availability, as shown in Table 4.

Table 4. Benefits identified for *P. oceanica* meadows.

Ecosystem Services (Costanza 2008)	This work (Benefits)
Carbon sequestration	Carbon sequestration
Water supply	O_2 Provision
Sediment regulation/erosion control	Erosion control
Waste treatment	Bioremediation
Food production	Food production
Raw materials	Raw materials
Genetic resources	Recreational potential
Recreation potential	Cultural/aesthetic
Cultural/aesthetic	

We used the list of ecosystem services proposed by Costanza [8] for standardization and comparison. We adapted Costanza's list to our case of valuation by splitting what we considered to be services or processes and quantifiable benefits. Although *Posidonia* meadows are considered a priority habitat under the EU Habitat Directive, there are currently no actual management plans to support their conservation in the area. The lack of long-term management has already led to a decrease in the ecological status of the meadows, mainly due to aggressive coastal development and the occurrence of major dredgings for coastal infrastructure during the last decades. Only a few spots could be described as dense meadows, and most of the areas were patchy meadows.

3.1. Ecosystem Benefits Assessment

Data from the literature [14,15,34–36] were used in this work. *P. oceanica* is widely distributed in the study area and can be found in most of the littoral zone on, both, rocky and sandy seabeds. The considered benefits (Table 4) for *P. oceanica* were computed as follows.

3.1.1. Carbon Sequestration

According to Reference [37], 24–44% of the total biomass production of the plant is remineralized or recycled in various ways, 6–50% is exported outside the meadows, and 6–20% is used by herbivorous organisms. The remaining 11–47% can be considered an indirect estimate of short- and long-term carbon flow. The estimate of long-term sequestered carbon through the metabolic and ecological processes in *P. oceanica* is 10–25% of total production [37]. To estimate the value of this benefit, phenological laboratory analyses [14,38], for the *P. oceanica* meadows, in the study area, are used to assess the biomass production. Using this approach, the carbon sequestered in the short term (10%) was determined as 0.3 tons/ha, and that in the long term (25%) was 0.7 tons/ha.

Considering that carbon accounts for 57% of the total biomass [39], we calculated the economic value of a ton of CO_2, using the EU Allowance (EUA) from the Emission Trading Scheme (ETS), the exchange trading system of the EU. The calculation was done using the average value at which the share was exchanged for 12 months (6.24 €/ton). Using the two extreme values for a long-term sequestration (10–25%) for the estimate, we obtained a range of economic value of 1.9–4.8 €/ha per year for the carbon sequestration from *P. oceanica*, in the study area, and the mean value was about 3.4 €/ha per year.

3.1.2. Erosion Prevention

Estimates were made using numerical models to simulate wave propagation in shallow waters through the application of Surface water modelling system (SMS 9.2) which is based on finite element mesh. To study the coastal hydrodynamic field, the contribution of the wind and wave climate was considered using ADCIRC (Advanced Circulation Model) module, taking the POM oceanographic model of the Mediterranean Sea, as input data, in the physiographic unit (M.Argentario—Capo Linaro).

The simulations considered the depth, density, and vegetation coverage of *P. oceanica* meadows and used a bottom friction coefficient deduced in a previous study [40]. *P. oceanica* generally induces a drastic decrease in the heights of waves. As a result, the energy oscillates from 20%, in the cases of a greater depth and a lower coverage, to 30%, in the cases of a lesser depth and a greater coverage. To obtain an estimate of how much the benefit can be worth, in economic terms, we calculated how much it would cost to obtain the same result in energy dissipation through the construction of a submerged barrier, which is commonly used in coastal defence work. In this work, submerged barrier modules of the same dimensions are proposed to be installed in a non-continuous manner to allow a constant exchange of water, as shown in Figure 3.

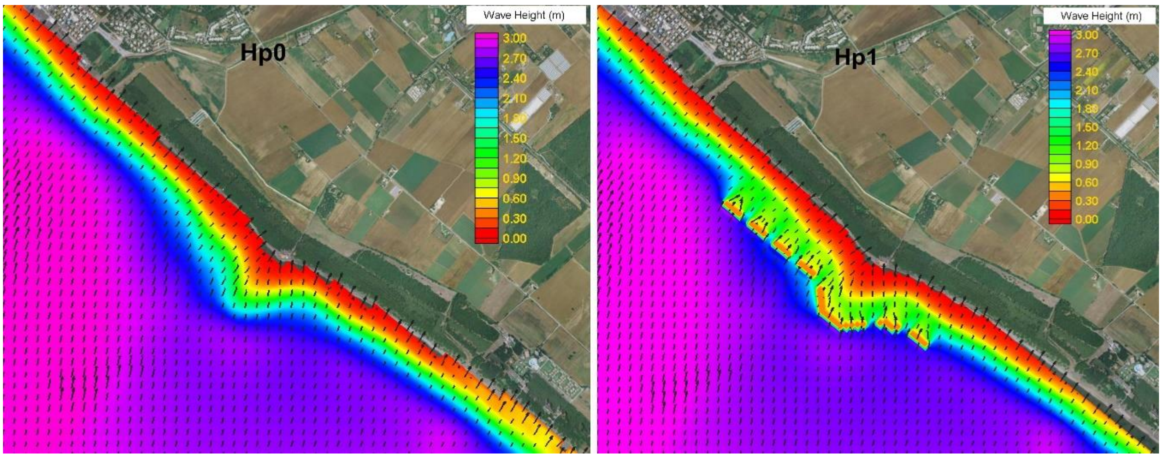

Figure 3. Effect of a barrier on the incident waves assessed through the use of numerical model simulations: Hp 0 wave height (m) without submerged barriers, and Hp 1 wave height with submerged barriers.

The value for this benefit can be estimated using the costs for the realization of a module and normalizing them to obtain energy dissipation comparable to that determined by the meadows of the study area. The cost per meter of a structure that allows an average energy dissipation of 20% is about 1432.08 €. If we compare the cost of dissipation induced by *P. oceanica* (25%), we obtain a value of 1790.1 €/m. This cost is extended to one hectare, assuming a square area of 100 m^2, and the cost is distributed over a period of time for which the structure is guaranteed (about 20 years). The result is €8950.5, which is an estimate of the erosion protection benefit provided by one hectare of *P. oceanica* meadow every year.

3.1.3. Bioremediation

We calculated how much it would cost to process the excess of nutrients that *P. oceanica* is able to absorb with biological methods. In terms of fixation, the rates of absorption of nitrogen and phosphorous used were:

> N = 1.90 mol/m^2/yr, corresponding to 34.2 g/m^2/yr and P = 0.49 mol/m^2/yr, corresponding to 1.52 g/m^2/yr, which, by extracting the value per hectare, resulted in N = 342,000 g/ha/year and P = 15200 g/ha/year.

To obtain this result, the nutrient fixation values of the meadows were compared with nutrient disposal data in the wastewater from plants, identified within the Research Report of the Lombardy Region and ERSAF (Regional Authority for Agriculture and Forestry Services), and by the "Management and reduction of nitrogen of zootechnical origin—Technological and Plant Solutions" [41]. The nutrient absorption levels of *P. oceanica* meadows were obtained from a previous research on the meadows in the study area [42] (Table 5).

Table 5. Summary of the economic value of the benefit in terms of € per hectare per year.

Technique	Economic value €/ha/yr
Nitrogen	
coarse solids separation	337.5
coarse and fine solids separation	985
biological removal	2400
extraction as mineral fertilizer	2250
mean value	*1617.5*
Phosphorous	
coarse solids separation	134.3
coarse and fine solids separation	331
biological removal	208.3
extraction as mineral fertilizer	393.6
mean value	*269.7*
N + P value	*1887.2*

3.1.4. Food Production

We estimated the economic value provided by *P. oceanica* meadows in terms of food production by considering the economic value of commercial species that rely on the ecosystem for at least one phase of their life cycle. We included both characteristic species and regular visitors in this evaluation. In the second case, we considered the species that visits the meadows on an occasional but regular basis, such as nocturnal hunters, and those that usually live in patchy meadow areas were also included [43,44]. Fishery data used in this study were provided by the "Sailors and Shareholders cooperative", which manages the fish auctions in the Civitavecchia area and brings together thirteen of the sixteen fishing boats that make up the fleet of Civitavecchia, which regularly operates in the study area. The calculation presented is shown in proportional to the total of the sixteen boats that make up the fleet. Table 6 shows the two estimates made, based on the average quantity fished for each species, in the years 2012, 2013, and 2014, as well as the average auction price over the three reference years.

From the map of the distribution of the biocoenoses (Figure 2), it was possible to determine the area occupied by *P. oceanica* biocenosis (total 2068 ha). It is necessary to specify that for the species strictly related to *P. oceanica*, we have not considered the area with dead matte and *P. oceanica* isolated shoots, so as to obtain two evaluations—for characteristic species a total benefit of 707 €/ha/yr (total area 1393 ha), and for regular visitors a total benefit of 558 €/ha/yr (total HP areas). The total benefit assessment for the food production of *P. oceanica* was 1265 €/ha/yr.

Table 6. Economic benefit assessment of food production for *P. oceanica*. The species strictly related to the presence of *P. oceanica* meadow are shown in bold.

Species	Q (tons)	R (euros)
Engraulis encrasicolus	**6.37**	**18,763**
Alloteuthis media	2.93	33,587
Mugil cephalus	0.49	1215
Epinephelus marginatus	0.14	2612
Dentex dentex	**1.72**	**17,204**
Scyliorhinus canicula	2.49	8970
Conger conger	0.59	566
Uranoscopus scaber	0.82	4123
Eledone moschata	**40.11**	**200,663**
Sparus aurata	**5.23**	**54,892**
Pagellus erythrinus	**1.01**	**5733**
Squilla mantis	12.93	60,065
Zeus faber	0.86	13,357
Octopus vulgaris	**36.45**	**250,311**
Raja clavata	3.62	12,089
Seriola dumerili	0.47	3975
Psetta maxima	0.29	7502
Diplodus sargus	**1.54**	**10,101**
Sardina pilchardus	0.08	30
Scorpaena porcus	**1.59**	**15,853**
Sepia officinalis	**4.55**	**53,197**
Soleas vulgaris	1.06	17,914
Dicentrarchus labrax	0.13	2952
Trachurus trachurus	0.73	524
Mullus barbatus	**23.57**	**107,724**
Paracentrotus lividus	**25**	**250,000**
16 Fishing boats: all species	174.77	1,153,922
16 fishing boats: species strictly related to *P. oceanica*	**147.14**	**984,441**

3.1.5. O_2 Supply

Oxygen production in coastal areas is a fundamental ecosystem service. It favors the maintenance of productive ecological conditions and limits the onset of anoxic areas, with direct consequences for human health. The estimates of organic production used to evaluate the sequestration of carbon dioxide can also be used, in this context, to evaluate the benefit of oxygen production. Duarte et al. (2010) [45] found that the net production of oxygen, after respiration in the metabolic cycles of *P. oceanica*, corresponds to 0.25 mmol per gram of dry weight of the biomass produced.

Using the available data for the *P. oceanica* meadows for the study area [14,15,38,42], it was possible to assess the economic value of O_2 production, using the cost of industrial methods of making oxygen [46]. The cost of the industrial production of 1 kg of O_2 was 0.05 €, and the total O_2 production from *P. oceanica*, in the study area, was about 10143 Kg/ha/yr. Thus, the economic value of O_2 supply was about 507 €/ha.

It was possible to carry out a provisional economic evaluation, per hectare, in consideration of the benefits and value of use provided by the meadows of *P. oceanica* in the coastal context of Civitavecchia (Table 7). The value of carbon sequestration was evaluated as 4.8 €/hectare year, and the value of oxygen production was estimated at around 507 €/hectare year. The value of food production amounted to about 1265 €/hectare year, and the value of bioremediation amounted to around 1887 €/hectare. The value of protection from coastal erosion was estimated at around 8950 €/hectare year. Therefore, the total value of the benefits analyzed added up to 12,614 € per hectare, per year. In no case should these estimates be considered as an approximation of the real total value of the ecosystem services provided by *P. oceanica*, as this evaluation did not include all the benefits listed above, nor the inherent values, which are impossible to estimate, currently.

Table 7. Annual economic benefit per hectare for *P. oceanica* in the coastal area of Civitavecchia.

Benefits	Euros ha/yr
Carbon sequestration	4.8
Erosion prevention	8950
Bioremediation	1887
Food production	1265
O_2 supply	507
Total benefit	12,614

4. Conclusions

In this work, the benthic biocenosis, as identified by Pérès and Picard for the Mediterranean Sea, is proposed as a working tool for the application of a monetary evaluation of coastal biocenosis with focus on the benefits of *P. oceanica*, in the coastal area of Civitavecchia, Northern Tyrrhenian Sea, Italy. After years of discussions about the most appropriate definition of ecosystem services, Costanza et al. [32] proposed an adaptative framework approach for each case study. Building on this definition, this work presented a characteristic framework for the assessment of benefits of *P. oceanica* meadows, in the study area. *P. oceanica* meadows are one of the fundamental components for the equilibrium and richness of the Mediterranean coastal area and represent a very complex and well-structured biocenosis characterized by high biological variability of the associated plant and animal communities. Thus *P. oceanica* could be considered the ideal test field for the application of the principles of economic evaluation of ecosystem services.

The result of the economic evaluation of *P. oceanica*, in the coastal area of Civitavecchia (12,614 €), was in line with other studies that had applied a similar methodology [8,46]. This work represents the first example of application of the benthic biocenosis as a tool for the economic evaluation of the associated benefits and the first study applied to the coastal area of the Northern Tyrrhenian, in Italy.

The classification of benthic biocenosis shows huge potential in the evaluation of ecosystem services as it provides key ecological information for specific areas, starting from the identification of characteristic and secondary species.

This work aimed to provide a case study on the use of a spatial approach in the evaluation of the economic value of marine coastal ecosystems, as well as a baseline measure of some of the benefits provided by *P. oceanica* biocenosis to support further studies. Furthermore, we consider our economic estimates to be particularly accurate because they are based on ecological data that are scientifically sound and highly representative of the study area.

Although the monetary evaluation of ecosystem benefits still presents some conceptual and application problems, it is nevertheless a guide for decision making, sustainable management, and resources allocation [47].

The management of biological resources is of fundamental importance in anthropized contexts, such as the coastal area of Civitavecchia, in which the economic and commercial needs cohabit with a high impact on local coastal ecosystems.

The economic evaluation of the benefits provided by the *P. oceanica* meadows, and in general of all the biocenosis, could be an important element for their conservation and a useful support for decision makers who are often too tied to qualitative damage assessments instead of a cost-benefit analysis.

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References

1. Millennium Ecosystem Assessment. Overview of the Milliennium Ecosystem Assessment. Available online: http://www.millenniumassessment.org/en/About.html (accessed on 15 October 2018).
2. Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being: Synthesis*; Island Press: Washington, DC, USA, 2005; ISBN 1-59726-040-1. Available online: http://www.millenniumassessment.org/en/Reports.html (accessed on 15 October 2018).
3. Daily, G.C. *Nature's Services: Societal Dependence on Natural Ecosystems*; Island Press: Washington, DC, USA, 1997.
4. Shepherd, G. *The Ecosystem Approach: Five Steps to Implementation*; Ecosystem Management Series No.3; IUCN/Atar Roto Presse SA: Vernier, Switzerland, 2004.
5. United Nations Environmental Program (UNEP). *Convention on Biological Diversity*; 1760 UNTS 79, 31 ILM 818; United Nations: New York, NY, USA, 1992.
6. Robinson, D.A.; Hockley, N.; Cooper, D.; Emmet, B.A.; Keith, A.M.; Lebron, I.; Reynolds, B.; Tipping, E.; Tye, A.M.; Watts, C.W.; et al. Natural Capital and Ecosystem Services, Developing an Appropriate Soils Framework as a basis for Valuation. *Soil Biol. Biochem.* **2013**, *57*, 1023–1033. [CrossRef]
7. Marris, E. UN body will assess ecosystems and biodiversity. *Nature* **2010**, *465*, 859. [CrossRef] [PubMed]
8. Costanza, R.; d'Arge, R.; de Groot, R.S.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.; Paruelo, J.; et al. The value of the world's ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [CrossRef]
9. Marcelli, M.; Peviani, M.; Piermattei, V.; Carli, F.; Bonamano, S. Sea-use map of Italy: Gis supporting marine energy siting. In Proceedings of the European Seminar "Offshore Wind and Other Marine Renewable Energies in Mediterranean and European Seas", Brindisi, Italy, 21—23 May 2009.
10. Boudouresque, C.F.; Fresi, E. Modelli di zonazione del benthos fitale del Mediterraneo. *Boll. Pesca Piscic Idrobiol.* **1976**, *31*, 129–143.
11. Costanza, R.; de Groot, R.; Braat, L.; Kubiszewski, I.; Fioramonti, L.; Sutton, P.; Farber, S.; Grasso, G. Twenty years of ecosystem services: How far have we come and how far do we still need to go? *Ecosyst. Serv.* **2017**, *28*, 1–16. [CrossRef]
12. Scanu, S.; Soetebier, S.; Piazzolla, D.; Tiralongo, F.; Mancini, E.; Romano, N.; Marcelli, M. Concentrations of As, Cd, Cr, Ni, and Pb in the echinoid Paracentrotus lividus on the coast of Civitavecchia, Northern Tyrrhenian Sea, Italy. *Reg. Stud. Mar. Sci.* **2015**, *1*, 7–17. [CrossRef]
13. Cafaro, V.; Piazzolla, D.; Melchiorri, C.; Burgio, C.; Fersini, G.; Conversano, F.; Piermattei, V.; Marcelli, M. Underwater noise assessment outside harbor areas: The case of Port of Civitavecchia, northern Tyrrhenian Sea, Italy. *Mar. Pollut. Bull.* **2018**, *133*, 865–871. [CrossRef] [PubMed]
14. Borfecchia, F.; Micheli, C.; Carli, F.M.; De Martis, S.C.; Gnisci, V.; Piermattei, V.; Belmonte, A.; De Cecco, L.; Martini, S.; Marcelli, M. Mapping spatial patterns of Posidonia oceanica meadows by means of daedalus ATM airborne sensor in the coastal area of Civitavecchia (Central Tyrrhenian Sea, Italy). *Remote Sens.* **2013**, *5*, 4877–4899. [CrossRef]
15. Gnisci, V.; Bonamano, S.; Micheli, C.; De Martis, S.C.; Piermattei, V.; Marcelli, M. Effect of dredging activities on the health status of Posidonia oceanica meadows along the north Latium coast (Tyrrhenian Sea). *PeerJ PrePrints* **2015**. [CrossRef]
16. Beaumont, N.J.; Austen, M.C.; Atkins, J.P.; Burdon, D.; Degraer, S.; Dentinho, T.P.; Derous, S.; Holm, P.; Horton, T.; van Ierland, E.; et al. Identification, definition and quantification of goods and services provided by marine biodiversity: Implications for the ecosystem approach. *Mar. Pollut. Bull.* **2007**, *54*, 253–265. [CrossRef] [PubMed]
17. Pérès, J.M.; Picard, J. *Nouveau Manuel de Bionomie Benthique de la Mer Méditerranée*; Station Marine d'Endoume: Marseille, France, 1964.
18. Agnesi, S.; Proietti, R.; La Valle, P.; Paganelli, D.; Nicoletti, L. Distribuzione delle biocenosi bentoniche. In *Cartografia Tematica dei Fondali Marini Laziali*; ISPRA: Roma, Italy, 2012.
19. Bianchi, C.N.; Ardizzone, G.D.; Belluscio, A.; Colantoni, P.; Diviacco, G.; Morri, C.; Tunesi, L. La cartografia del benthos. *Biol. Mar. Mediterr.* **2003**, *10*, 367–394.

20. Bellan-Santini, D.; Bellan, G.; Bitar, G.; Harmelin, J.G.; Pergent, G. *Handbook for Interpreting Types of Marine Habitat for the Selection of Sites to Be Included in the National Inventories of Natural Sites of Conservation Interest*; UNEP-MAP-RAC/SPA: Tunis, Tunisia, 2002.
21. Bianchi, C.N.; Morri, C. L'approccio bionomico per la caratterizzazione e la zonazione dell'ambiente marino costiero: Una rassegna introduttiva. *Atti Assoc. Ital. Oceanol. Limnol.* **2001**, *14*, 401–434.
22. UNEP/MAP/MED POL. *Guidelines for the Development of Ecological Status and Stress Reduction Indicators for the Mediterranean Region*; MAP Technical Reports Series No. 154; UNEP/MAP: Athens, Greece, 2004.
23. Magni, P.; Hyland, J.; Manzella, G.; Rumohr, H.; Viaroli, P.; Zenetos, A. *Indicators of Stress in the Marine Benthos*; IOC Workshop Report No. 195; IMC Special Publication; UNESCO: Paris, France, 2005.
24. Bianchi, C.N. From bionomic mapping to territorial cartography, or from knowledge to management of marine protected areas. *Biol. Mar. Mediterr.* **2007**, *14*, 22–51.
25. Boyd, J.; Banzhaf, S. What are ecosystem services? The need for standardized environmental accounting units. *Ecol. Econ.* **2007**, *63*, 616–626. [CrossRef]
26. Farber, S.C.; Costanza, R.; Wilson, M.A. Economic and ecological concepts for valuing ecosystem services. *Ecol. Econ.* **2002**, *41*, 375–392. [CrossRef]
27. Fisher, B.; Turner, R.K.; Morling, P. Defining and classifying ecosystem services for decision making. *Ecol. Econ.* **2009**, *68*, 643–653. [CrossRef]
28. Fisher, B.; Turner, R.K. Ecosystem services: Classification for valuation. *Boil. Conserv.* **2008**, *141*, 1167–1169. [CrossRef]
29. Wallace, K.J. Classification of ecosystem services: Problems and solutions. *Boil. Conserv.* **2007**, *139*, 235–246. [CrossRef]
30. Daily, G.C.; Polasky, S.; Goldstein, J.; Kareiva, P.M.; Mooney, H.A.; Pejchar, L.; Ricketts, T.H.; Salzman, J.; Shallenberger, R. Ecosystem services in decision making: Time to deliver. *Front. Ecol. Environ.* **2009**, *7*, 21–28. [CrossRef]
31. Fu, B.J.; Su, C.H.; Wei, Y.P.; Willett, I.R.; Lu, Y.H.; Liu, G.H. Double counting in ecosystem services valuation: Causes and countermeasures. *Ecol. Res.* **2011**, *26*, 1–14. [CrossRef]
32. Costanza, R. Ecosystem services: Multiple classification systems are needed. *Boil. Conserv.* **2008**, *141*, 350–352. [CrossRef]
33. Moreno, D.; Aguilera, P.A.; Castro, H. Assessment of the conservation status of seagrass (*Posidonia oceanica*) meadows: Implications for monitoring strategy and the decision-making process. *Boil. Conserv.* **2001**, *102*, 325–332. [CrossRef]
34. Meinesz, A.; Boudouresque, C.F.; Falconetti, C.; Astier, J.M.; Bay, D.; Blanc, J.J.; Bourcier, M.; Cinelli, F.; Cirik, S.; Cristiani, G.; et al. Normalisation des symboles pour la représentation et la cartographie des biocénoses benthiques littorales de Méditerranée. *Ann. Inst. Océanogr.* **1983**, *59*, 155–172.
35. Duarte, C.M. Allometric scaling of seagrass form and productivity. *Mar. Ecol. Prog. Ser.* **1991**, *77*, 284–300. [CrossRef]
36. Directive, H. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. *Off. J. Euro. Union* **1992**, *206*, 7–50.
37. Mateo, M.A.; Serrano, O. The carbon sink associated to Posidonia oceanica. In *Mediterranean Seagrasses: Resilience and Contribution to the Attenuation of Climate Change*; IUCN Mediterranee: Malaga, Spain, 2011.
38. Micheli, C.; D'Esposito, D.; Belmonte, A.; Peirano, A.; Valiante, L.M.; Procaccini, G. Genetic diversity and structure in two protected Posidonia oceanica meadows. *Mar. Environ. Res.* **2015**. [CrossRef] [PubMed]
39. Ott, J.A. Growth and production in *Posidonia oceanica* (L.) Delile. *Mar. Ecol.* **1980**, *1*, 47–64. [CrossRef]
40. Infantes, E.; Orfila, A.; Simarro, G.; Terrados, J.; Luhar, M.; Nepf, H. Effect of a seagrass (*Posidonia oceanica*) meadow on wave propagation. *Mar. Ecol. Prog. Ser.* **2012**, *456*, 63–72. [CrossRef]
41. Provolo, G.; Riva, E.; Serù, S. *Gestione e Riduzione Dell'azoto di Origine Zootecnica—Soluzioni Tecnologiche ed Impiantistiche*; Quaderno di Ricerca della Regione Lombardia; ERSAF: Regione Lombardia, Italy, 2008.
42. De Martiis, S.C. Primary Production study on *Posidonia oceanica* (L.) Delile (1813) in the Northern Latium. Ph.D. Thesis, Tuscia University, Viterbo, Italy, 2016.
43. Kalogirou, S.; Corsini-Foka, M.; Sioulas, A.; Wennhage, H.; Pihl, L. Diversity, structure and function of fish assemblages associated with *Posidonia oceanica* beds in an area of the eastern Mediterranean Sea and the role of non-indigenous species. *J. Fish Boil.* **2010**, *77*, 2338–2357. [CrossRef] [PubMed]

44. Del Pilar Ruso, Y.; Bayle-Sempere, J.T. Diel and Vertical movements of preflexion fish larvae assemblages associated with *Posidonia oceanica* beds. *Sci. Mar.* **2006**, *70*, 399–406. [CrossRef]
45. Duarte, C.M.; Marbà, N.; Gacia, E.; Fourqueran, J.W.; Beggins, J.; Barròn, C.; Apostolaki, T. Seagrass community metabolism: Assessing the carbon sink capacity of seagrass meadows. *Glob. Biogeochem. Cycles* **2010**, *24*, GB4032. [CrossRef]
46. Li, J.; Ren, Z.; Zhou, Z. Ecosystem services and their values: A case study in the Qinba mountains of China. *Ecol. Res.* **2006**, *21*, 597–604. [CrossRef]
47. De Groot, R.; Brander, L.; van der Ploeg, S.; Costanza, R.; Bernard, F.; Braat, L.; Christie, M.; Crossman, N.; Ghermandi, A.; Hein, L.; et al. Global estimates of the value of ecosystems and their services in monetary units. *Ecosyst. Serv.* **2012**, *1*, 50–61. [CrossRef]