The value of the seagrass Posidonia oceanica: A natural capital assessment

Article *in* Marine Pollution Bulletin · August 2013

DOI: 10.1016/j.marpolbul.2013.07.044 · Source: PubMed

6 authors, including:

Paolo Vassallo
Università degli Studi di Genova
69 PUBLICATIONS 522 CITATIONS

Alessio Rovere
MARUM Center for Marine Environmental Sci…
110 PUBLICATIONS 667 CITATIONS

Monica Montefalcone
Università degli Studi di Genova
96 PUBLICATIONS 1,278 CITATIONS

Carlo Nike Bianchi
Università degli Studi di Genova
373 PUBLICATIONS 6,793 CITATIONS

Marine Pollution Bulletin xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

The value of the seagrass *Posidonia oceanica*: A natural capital assessment

Paolo Vassallo [a], Chiara Paoli [a,*], Alessio Rovere [b], Monica Montefalcone [a], Carla Morri [a], Carlo Nike Bianchi [a]

[a] DISTAV, Dipartimento di Scienze della Terra, dell'Ambiente e della Vita, Genoa University, Italy
[b] Lamont Doherty Earth Observatory, Columbia University, NY, USA

ARTICLE INFO

Keywords:
Emergy analysis
Ecosystem services
Posidonia oceanica
Seagrass
Mediterranean Sea
Ligurian Sea

ABSTRACT

Making nature's value visible to humans is a key issue for the XXI century and it is crucial to identify and measure natural capital to incorporate benefits or costs of changes in ecosystem services into policy. Emergy analysis, a method able to analyze the overall functioning of a system, was applied to reckon the value of main ecosystem services provided by *Posidonia oceanica*, a fragile and precious Mediterranean seagrass ecosystem. Estimates, based on calculation of resources employed by nature, resulted in a value of 172 € m^{-2} a^{-1}. Sediment retained by meadow is most relevant input, composing almost the whole *P. oceanica* value. Remarks about economic losses arising from meadow regression have been made through a time-comparison of meadow maps. Suggested procedure represents an operative tool to provide a synthetic monetary measure of ecosystem services to be employed when comparing natural capital to human and financial capitals in a substitutability perspective.

1. Introduction

Making nature's value visible to humans is a key issue for the XXI century (de Groot et al., 2012; MA, 2005; TEEB, 2010). Conservation, protection and valuation of natural capital are gaining increasing importance: recently, many efforts were directed to investigate the links between ecosystems and human wellbeing.

During the last decades, politician and common people started to perceive that present economic development is subjected to limits imposed by nature, that natural environment suffers strains and damages and that the economic growth can no longer be equated to an increase of welfare (Harsanyi, 1996; Leipert and Pulselli, 2008). The Millennium Ecosystem Assessment (MA, 2005) concluded that human activities have degraded the ability of earth's ecosystems to provide these services. Ecosystem services are the direct and indirect contributions of ecosystems to human wellbeing (Boyd and Banzhaf, 2007; Braat and de Groot, 2012; TEEB, 2010). They arise from natural capital stocks including land, air, water, sea, fossil fuels, biodiversity and ecosystems (Ayres, 1996; Berkes and Folke, 1994; Cleveland, 1994; Costanza and Daly, 1992; Costanza et al., 1997; Coulthard et al., 2011; Daly, 1994; Dasgupta, 1994; Ehrlich, 1994; Jannson and Jansson, 1994; Jansson et al., 1994).

Turner (1993) argued about the substitutability theory, debating if manufactured capital, made by goods and services from economy, can substitute natural capital: if the different types of capital are not perfectly substitutable welfare can be irreparably decreased by our choices (Ekins et al., 2003). As a consequence, to address policies, it is crucial to identify and measure natural capital. Since most economists and managers aim solely at economic growth (Pulselli et al., 2012) the measure of natural capital must be both ecologic and economic. In such a way it can be comparable with other ones and its value easily inserted in decisional process. In particular, incorporating the benefits or costs associated with changes in ecosystem services into policy analysis requires quantifying the value of changes in natural capital stock (Johnston and Russell, 2011). A range of methods have been suggested at this purpose (Bateman et al., 2011; Boyd and Banzhaf, 2007; Boyd and Krupnick, 2009; Brown et al., 2007; Chee, 2004; Fisher et al., 2008, 2009; Freeman, 2003; Hanley and Barbier, 2009; Holland et al., 2010; Kontogianni et al., 2010; Wallace, 2007), nonetheless "despite the proliferation of interest in ecosystem services there have been relatively few attempts to define the concept clearly to make it operational" (Fisher et al., 2008; Johnston and Russell, 2011).

Authors, performing this study and aiming at solve this issue, applied a method named emergy analysis, able to evaluate the convergence of matter and energy from several inputs to a (eco)system on a common basis: the equivalent solar energy required to maintain a process.

* Coresponding author. Tel.: +39 0103538069; fax: +39 0103538140.
E-mail address: chiara.paoli@unige.it (C. Paoli).

0025-326X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpolbul.2013.07.044

Solar energy is used up, directly and indirectly, in transformations chains happening in the biosphere: this energy expressed in solar emergy Joules (seJ), is a measure of the work done to provide a flow or a service and of the investment made by nature in term of natural capital in space and time (Odum, 1996, 2000; Odum and Odum, 2000a; Pulselli et al., 2011).

The link between emergy and ecosystem services evaluation has been recently deepened in theory by Pulselli et al. (2011). Ecosystem services traditional approach is an anthropocentric, user side approach, based on the subjective preferences. On the contrary, emergy is a donor side approach, valuing ecosystem services as the amount of resources invested by nature to satisfy human needs, independently from the presence of users and from the value they ascribe to a service (Pulselli et al., 2011). The adoption of this approach is fundamental since, even if an ecosystem service is not perceived by humans or scarcely evaluated by market, it can be essential for the existence of an ecosystem.

Emergy has been applied to a pilot study case in order to provide a basis for a practical evaluation of ecosystem services provided by seagrass meadows.

The endemic *Posidonia oceanica* (L.) Delile is the most abundant seagrass in the Mediterranean Sea, where it forms extensive meadows from the surface down to 40 m depth (Boudouresque et al., 2006). The species is included in the Red List of marine threatened species of the Mediterranean (Boudouresque et al., 1990) and meadows are defined as priority natural habitats by the Annex I of the EC Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (EEC, 1992), which lists the natural habitats whose conservation requires the designation of special areas of conservation, identified as Sites of Community Interests (SCIs).

Meadows of *P. oceanica* occur in coastal areas, which are often subjected to intense human activities that inevitably affect their distribution, either directly by physical damages to the meadow (Meinesz et al., 1991) or indirectly through the impact on the quality of waters and sediments (Duarte, 2002). An alarming decline of the *P. oceanica* meadows has been reported in the Mediterranean Sea and mainly in the north-western side of the basin (Ardizzone et al., 2006; Boudouresque et al., 2009; Montefalcone et al., 2007a, 2010), where many meadows have already been lost during last decades (Bianchi and Morri, 2000; Leriche et al., 2006; Marbà et al., 1996; Montefalcone et al., 2007b).

Here a practical study case is proposed aiming at: (1) providing a valuation of ecosystem services based on an objective measure of ecological functioning (donor side approach) rather than subjective preferences of users (user side approach) obtaining benefits from ecosystem exploitation, (2) providing a tool to include costs deriving from the depletion of natural capital in policies and decisional processes. At this purpose main ecosystem services provided by *P. oceanica* were identified and their emergy and economic value computed; the obtained economic value per unit area has been applied to the meadow located in the Marine Protected Area ''Isola di Bergeggi'' (Ligurian Sea, NW Mediterranean), in order to quantify the economic loss associated to *P. oceanica* regression.

2. Materials and methods

2.1. Study area

The Marine Protected Area (hereafter MPA) ''Isola di Bergeggi'' has been created in 2007 (Law 394/91; D.M. 07/05/07); it is located in the Savona county (Liguria, NW Italy) and includes the seabed located around the island, recognized of particular interest both from a geological and biological point of view and occupies a surface of 260 ha, being one of the smallest Italian MPA (Fig. 1). The area is embedded within a human-dominated landscape (Parravicini et al., 2011), characterized by a twofold scenario of economic exploitation: westbound the area borders with a tourist centre, eastbound with a container port. The coastline of Bergeggi municipality is jagged with karst caves, cliffs of dolomitic limestones, pocket beaches and, together with the island, is part of Bergeggi Regional Nature Reserve since 1985 (Rovere et al., 2010a,b, 2011).

The MPA is bordered by two large beaches, one of which has been created during several nourishments between 1969 and 1971 (Ferrari et al., 2013; Fierro et al., 1975). The island of Bergeggi is composed of calcareous rocks; it occupies a surface equal to 364 m^2 with a coastline of almost 260 m with steep rocks on the eastern part and a slowly degrading gradient in the western part. Around Bergeggi Island, the bathymetric gradients together with the geological nature of the latter, favour the settlement of several biological associations (Bianchi et al., 2007).

2.2. Ecosystem services identification and quantification

Main services played by *P. oceanica* meadows have been here identified applying a not anthropocentric donor side perspective. In other words also ecological function having benefits only on ecosystem itself where considered rather than those having direct advantages to humans.

Even if these functions are not completely perceived by society and economy, they imply indirect benefits, even economic, for coastal areas (e.g. fisheries, tourism). Several definitions, descriptions, and classifications of ecosystem services have been suggested through the last decades (Costanza et al., 1997; de Groot et al., 2002; Ewel et al., 1998; Hein et al., 2006; Holmlund and Hammer, 1999; MA, 2005; Moberg and Folke, 1999; Pimentel et al., 1997). The more recent, synthetic and adopted classification is that proposed by the Millennium Ecosystem Assessment (MA, 2005) and by Hein et al. (2006); here services provided by seagrasses are listed as: nursery areas for fish and invertebrates, high production, oxygenation of coastal waters and source of food for many species of coastal and marine organisms, sediments trapping and shoreline defense.

Other authors also report oxygenation of coastal waters and carbon sink role due to slow decomposition rate of lignified rhizomes and roots within the reef structure (or ''matte'') developed by *P. oceanica* (Boudouresque et al., 2006; Díaz-Almela and Duarte, 2008; Gacia et al., 2002; Pergent et al., 2012; UNEP MAP, 2010).

On the basis of these references the main ecosystem services were here identified as: sediment retention and hydrodynamics attenuation, oxygen release, nursery role and primary production. Every ecosystem service requires inputs to *P. oceanica* system to be obtained and maintained.

Identified services are listed together with their main inputs in Table 1.

The total amount of inputs required represents an estimate of the investment made by natural system to provide ecosystem services.

Sediment retention and hydrodynamics attenuation is maintained by means of the quantity of sedimentary material entering *P. oceanica*. The quantity of this material was evaluated by reckoning the amount of sediment retained because of meadow presence. This calculation represents an underestimate since, to guarantee the amount retained, a greater amount is expected to be entered in the system (and partly removed by re-suspension).

As a consequence a balance between primary deposition, as well as resuspension, inside and outside the meadow was realized: inside the meadow a greater quantity of material is deposited while a lower quantity is resuspended and the comparison allows accounting for shore protection service.

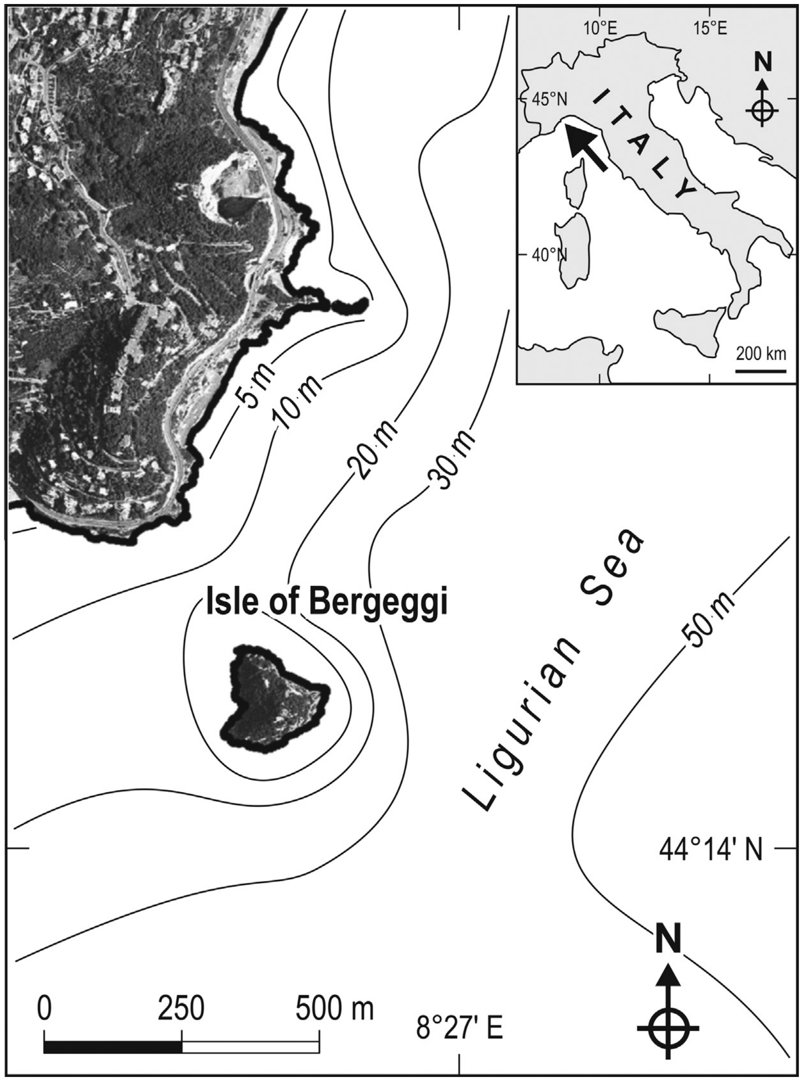

Fig. 1. Study area, Bergeggi marine protected area and its location.

Table 1
Ecosystem services indentified and associated inputs.

Ecosystem service	Inputs required
Nursery role	Carbon dioxide for photosynthetic activity and nutrients fixed at the basis of trophic chain
Sediment retention and hydrodynamics attenuation	Sediment entering the meadow
Primary production	Sunlight Carbon dioxide for photosynthetic activity and nutrients fixed
Oxygen release	Sunlight Carbon dioxide for photosynthetic activity

Oxygen is released by meadow through photosynthetic activity together with carbon fixation.

Oxygen release service is then maintained by sunlight hitting meadow surface and by consumed CO_2.

Estimates of required CO_2 were indirectly obtained from data of *P. oceanica* primary productivity found in previous studies (Alcoverro et al., 1998; Boudouresque et al., 2006; Libes, 1984; Ott, 1980; Pergent et al., 1994, 1997). This CO_2 amount, together with nutrients, is also invested to generate organic matter through primary productivity. The quantity of nutrients fixed (nitrogen and phosphorus) was obtained from carbon data, adopting Redfield et al. (1963) ratio.

Juvenile fishes' biomass was evaluated from visual census data obtained by Francour (1997). The effort required to ecosystem to support this biomass has been computed (here considered as the cost of the nursery role service), according to Pauly and Christensen approach (1995), based on a mean energy transfer efficiency between trophic levels of 10%.

Detailed calculation procedures are reported in Appendix A.

2.3. Emergy fundamentals

Emergy is a thermodynamic based methodology introduced during the 1980s by Howard Odum and it is a technique of quantitative analysis that standardizes the values of non-monied and monied resources, services and commodities in a sole unit (Brown and Herendeen, 1996). This makes emergy a very versatile technique that can be applied to whatever natural or human system or to a mix of two and allows measuring the work of the environment and economy on a common basis (Odum and Odum, 2000b). Emergy theory is defined by two key concepts: solar emergy itself and solar transformity. Solar emergy is identified by the quantity of solar energy required, directly or not, to provide a given flow or storage of energy or matter (Odum, 1996). Emergy is expressed in solar emergy Joule (seJ) and is usually calculated on an annual scale. Transformity measures the input of emergy per unit output and it is calculated as the ratio of the emergy necessary to produce a flow or a storage to the actual energy of that flow or storage (Ulgiati and Brown, 2002). Transformity is expressed in solar emergy Joule per Joule of output flow (seJ J^{-1}). For certain products or flows easily quantifiable in units of mass or money a conversion value expressed in seJ g^{-1} or seJ $€^{-1}$ can be used (Paoli et al., 2008a,b). These coefficients are respectively named specific emergy and emergy per unit money; transformity, specific emergy and emergy per unit money can be gathered under the locution Unit Emergy Value (UEV hereinafter, Paoli et al., 2013).

Methodology first step consists in the drawing of a diagram where the analyzed system is represented as a box. The box contains main components and is surrounded by all inputs that support the system, all located on left and upper boundaries. Outputs are located outside right boundary while heat losses are represented below.

An emergy table is built based on the depicted diagram: first column contains all inputs to the system, second column the corresponding unit of measure, third one UEV while, in the fourth, emergy values obtained as multiplication of each input flows and the respective UEV.

Sum of emergy values provides an estimate of total resources amount required by the system.

Finally when an emergy amount is ascribed to each product the latter step consists in the calculation of the corresponding monetary value. This is made calculating the ratio between emergy content of each product and a specific emergy index named Emergy Money Ratio (EMR).

The ratio of gross domestic product (GDP) to total emergy supporting a certain country or a specific geographical area yields the Emergy Money Ratio, which describes the purchasing power, in emergy units, of standardized currency (Cohen et al., 2006). It is expressed in seJ $currency^{-1}$ (seJ $€^{-1}$ in our case) and it values how much emergy corresponds, on average, to one unit of money produced by the local economy (Odum, 1996).

Conversion of emergy to currency is accomplished by dividing emergy values by the EMR related to the economy within which the evaluation is being conducted (Odum, 1996).

Emergy has been already applied to ecosystems even if its employment to ecosystem services and functions valuation issue has been approached mainly in theory (Brown and Ulgiati, 1999; Odum and Odum, 2000a; Pulselli et al., 2011). Case studies are rare and pioneering (Bardi, 2002), most of all if marine systems are concerned.

2.4. Ecosystem services monetary valuation

Conventional methods for ecosystem services evaluation are based on users' preferences and on a merely utilitarian approach. In this sense an entity has economic value only if people consider it desirable and are willing to pay for it; natural resources are usually regarded as instruments devoted to human satisfaction. Economy lays on consumer sovereignty principle, on the base on which welfare can be achieved if allocation of resources is chosen so as to satisfy to the maximum extent possible the wants of individuals (Common, 1997; Tisdell, 1991;). But preferences are mutable, particularly over longer timeframes that, on the contrary, are important because they represent the temporal scale of ecosystem dynamics. Preferences modify under the influence of education, advertising, cultural assumptions and specific social and environmental contexts (Farber et al., 2002; Norton et al., 1998), and are often determined by changes in outcomes relative to a person's reference level (Tversky and Kahneman, 1991).

Moreover a paradox lies in the fact that, for many years, humans were only able to perceive the value of final manmade or natural products, all generated by the exploitation of natural resources, considered as free.

Since the value of ecosystem goods and services should be precautionary preserved to assure the maintenance of a certain well-being level for us and future generations, economy principles, as formerly described, cannot be applied to environmental products (Carson and Bergstrom, 2003; Niccolucci et al., 2007).

Economy is not able to ascribe to ecological services a value independent by human appreciation of nature's work. As a consequence when performing their valuation techniques based on ecological accounting principles must be introduced. Emergy is able to attribute a cost to resources that do not own a market value and to put them at the same level of items valued by economy and to provide an objective valuation based on the effort made by nature to supply energy and material flows that allows the provisioning of services (Vassallo et al., 2009). Inputs having different unit of measure are standardized to solar emergy Joules as previously described. Different items can be compared and the total amount of resources required by the system can be reckoned.

In the specific case, input flows that maintain a square meter of *P. oceanica* system have been identified and calculated. From that calculation a money value of the ecosystem services provided by a unit area of *P. oceanica* meadow was obtained.

The link between ecosystem services and emergy has been deepened in theory by Pulselli et al. (2011), according to which emergy flow and ecosystem service values can be independent from each other just because ecosystem works independently of the economic fruition of it made by humans. Therefore, a direct quantitative relation between the two does not seem appropriate.

However, an indirect use of the relation between emergy and ecosystem service evaluation is possible by putting into relation the two entities. Campbell (2000) proposed a global emergy budget, required to maintain the entire biosphere, equal to 9.26E+24 seJ a^{-1}. Costanza et al. (1997) found that the global value of services yearly provided by terrestrial ecosystems ranges between 1.82 and 6.15E+13 € a^{-1}. Dividing the world ecosystem service value by the emergy flow to the biosphere, we obtained the amount of money that is, in average, produced by one seJ of solar emergy that can be considered as an estimate of the ability of the biosphere in providing a kind of economic wealth for humans.

This ratio has been named Environmental Emergy Money Ratio (EnEMR hereinafter). In fact if Emergy Money Ratio, in its classical definition links emergy to economy, the EnEMR is able to establish a link between environment and economy through emergy. EnEMR has a value between 5.09E+11 seJ $€^{-1}$ and 1.51E+11 seJ $€^{-1}$ depending on the minimum and maximum values calculated by Costanza et al. (1997). In this study authors precautionary employed the highest value.

The monetary value of a natural good or services can be calculated by dividing its emergy content by EnEMR. At this purpose cartographies of the *P. oceanica* meadows inside the MPA of Bergeggi were produced in 1990 and 2006 (Table 2). To allow for a quick comparison, the 2006 map, originally at a larger scale (1:10,000), was redrawn and reduced to the same nominal scale of 1990 one (1:25,000). A reduced scale should also minimize differences in positioning accuracy and those due to observer effect (Montefalcone et al., 2013). The two cartographies were digitized with the GIS software ArcGis®.

On each map the extension of *P. oceanica* meadow was identified.

Table 2
Characteristics of the maps of *Posidonia oceanica* used in this study. SSS = Side Scan Sonar; ROV = Remotely Operated Vehicle.

Year	1990	2006
Acquisition method	Mainly SSS and ROV;	Mainly SSS and aerial photography;
	SCUBA dives	ROV, SCUBA dives
Positioning system	Loran C	DGPS
Scale	1:25,000	1:10,000
References	Snamprogetti (private engineering company) (Bianchi and Peirano (1995)	Liguria Regional Authority Diviacco and Coppo (2006) and MPA monitoring programs Rovere et al. (2010a)

3. Results and discussion

3.1. System diagram

First result is represented by the diagram depicting the *P. oceanica* system and main services it provides (Fig. 2); these services are nursery role, sediment retention and hydrodynamics attenuation, primary production and oxygen release.

Services are maintained as previously described by sun, nitrogen, phosphorus, carbon dioxide and sediment, that are the main inputs to the system.

From these services some outputs arise: fish biomass from nursery role, shore protection from sediment retention and hydrodynamics attenuation, water oxygenation from oxygen release, plant biomass from primary production. Plant biomass and oxygen are both generated by photosynthesis. Fish biomass and sediment retained arise from different internal process and generated separately.

It is demonstrated that a 10 m depth meadow can generate till 14 l of oxygen per day; this considerable production is due to both leaves and epiphytes biomasses, especially in shallow waters (Alcoverro et al., 1998; Bay, 1978).

The primary production of *P. oceanica* meadows is similar or greater than other highly productive environments, both terrestrial (e.g. temperate or tropical forests) or marine (e.g. upwelling areas, mangroves, coral reefs) and generates a vegetable biomass that is at the base of marine trophic networks that allows habitat existence and organization (Fergusson et al., 1980). Nursery role is widely recognized being well-known that a great variety of species lives on or are protected by *P. oceanica* leaves, or in the sediment where *P. oceanica* stands (Bell and Harmelin-Vivien, 1982; Boudouresque and Meinesz, 1982; Bellan-Santini et al., 1986, 1994; Francour, 1990; Boudouresque, 2004). In particular, seagrass meadows provide shelter and food for various fish communities, which can include a high proportion of resident species but also juveniles of commercially important species (Bell and Pollard, 1989; Connolly, 1994; Harmelin-Vivien, 1982; Heck and Thoman, 1984; Robertson, 1980).

An important service of *P. oceanica* ecosystem is sediment retention and hydrodynamics attenuation, leading to an effective protection from shoreline erosion. In literature, several authors have addressed how the presence of a meadow can affect sedimentological features (De Falco et al., 2008; Gacia et al., 1999) or wave energy (Basterretxea et al., 2004; Infantes et al., 2009; Vacchi et al., 2010). In particular, the meadow damps the swell and forms an obstacle to the movement of sediments on the bottom (Brunel and Sabatier, 2009) and plays an active role in the sedimentary balance of the beach both supplying biogenic sand and/or trapping sediments in eventual offshore migrations (Basterretxea et al., 2004). The reduction of the hydrodynamic forces represented by waves and bottom currents has been tested in laboratory (Boudouresque et al., 2006 reporting unpublished data from ICI–DELFT) and in situ (Duarte, 2004; Gambi et al., 1989; Gacia and Duarte, 2001; Jeudy de Grissac and Boudouresque, 1985): the results showed that the hydrodynamic forces are reduced from 10% to 75% under the leaves (Gacia et al., 1999; Gambi et al., 1989), and of 20% few centimeters above the meadow (Gacia and Duarte, 2001). This attenuation reduces littoral erosion, and examples of coastal regression due to the loss of marine Magnoliophytes have been reported in literature (Larkum and West, 1990; Pasqualini et al., 1999; Pergent and Kempf, 1993). Moreover, the presence of a *P. oceanica* meadow in the coastal zone produces deposits on the shore, called banquettes of dead leaves able to reduce the wave effect on shoreline.

3.2. Ecosystem services valuation

From diagram in Fig. 2 an emergy table has been drawn (Table 3).

Formulas and coefficients employed to obtain values in Table 3 are reported in Appendix A.

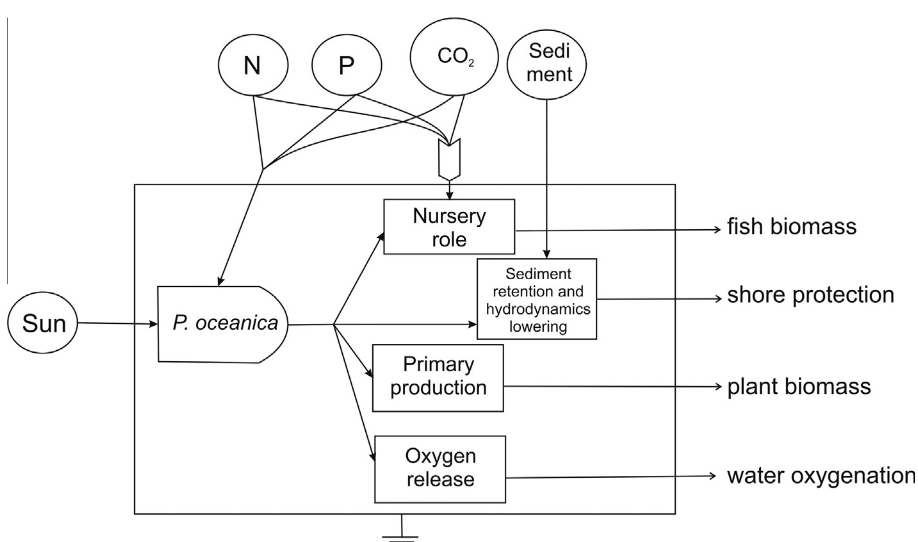

Fig. 2. System diagram of *P. oceanica* services.

Table 3
Emergy valuation of *Posidonia oceanica* ecosystem services, see Appendix for full details about items' quantity calculation. a: Odum (1996); b: Campbell et al. (2013); c: Odum (1992).

Inputs			Unit of measure	UEV		Emergy
Item		Quantity			Ref.	seJ m^{-2} a^{-1}
Sun	Primary production	5.11E+09	J m^{-2} a^{-1}	1	a	5.11E+09
Carbon dioxide	Primary production	3.02E+03	g m^{-2} a^{-1}	1.47E+08	b	4.45E+11
	Fishes	7.34E+01	g m^{-2} a^{-1}	1.47E+08		1.08E+10
Nitrogen	Primary production	2.28E+01	g m^{-2} a^{-1}	2.82E+09		6.43E+10
	Fishes	1.18E+00	g m^{-2} a^{-1}	2.82E+09		3.34E+09
Phosphorous	Primary production	2.19E+00	g m^{-2} a^{-1}	3.15E+10		6.89E+10
	Fishes	1.09E−01	g m^{-2} a^{-1}	3.15E+10		3.43E+09
Sediment		5.19E+04	g m^{-2} a^{-1}	1.68E+09	c	8.70E+13
Total						8.76E+13

The emergy budget of ecosystem services provided by *P. oceanica* is almost completely composed by sediment retained by meadow that contributes up to the 99% of the total emergy required and of the ecosystem services value.

This great emergy share is due both to a remarkable UEV and to a huge quantity of sediment retained.

Transformity and UEV, can be interpreted as quality indicators: energy flows of the universe are organized in an energy transformation hierarchy connecting each kind of energy to the next (Odum, 1988, 1996; Odum and Pinkerton, 1955; Odum and Odum, 2003). A hierarchy is a design in which many units of one kind are required to support a few of another. According to the second law of thermodynamic, all energy transformation works to convert many Joules of available energy of one kind to a few Joules of another kind of energy. Since moving through these hierarchies energy (or matter) flow decreases in quantity, each energy transformations series is an energy hierarchy. The energy amount decreases from a hierarchic level to the upper one and it is coupled with a fitting transformity increase (more energy for less units). This means that hierarchically higher energy flows are more concentrated, have more effect per unit, are more flexible in their uses, and in these senses are higher quality.

Sediment is a not renewable resource generated by complex geological and tectonic processes, happening in centuries or even millennia, which work and concentrate them; in emergy terms it results in a considerable UEV value.

As a consequence, even if sediment UEV is not the greatest among those considered, when applied to the huge quantity of sediment retained, gives almost the total of final emergy of *P. oceanica* ecosystem services.

The ratio among emergy of ecosystem services and the EnEMR from Pulselli et al. (2011) gives the monetary value of a square meter of *P. oceanica* meadow that equals to 172.2 € a^{-1}.

The value has been compared with evaluations made by de Groot et al. (2012) and Costanza et al. (1997). They both realized an estimate of global services applying classical methods for ecosystem services valuation and they realized a synthesis and an overview of all publications regarding about this issue. Result is a valuation of respectively 10 and 16 biomes among which coastal ones are comprised and presented in Table 4.

All calculation related to coastal biomes are, in both publications, sensibly lower than the *P. oceanica* system value here calculated. This shows that, probably, economy underestimates how much is nature worth: the *P. oceanica* value is almost a hundred

Table 4
Values (in € m^{-2} a^{-1}) of marine biomes from de Groot et al. (2012) and Costanza et al. (1997).

	€ m^{-2} a^{-1}	
	de Groot et al. (2012)	Costanza et al. (1997)
Coral reefs	274.88	0.65
Coastal systems	22.56	NA
Coastal wetlands	151.26	NA
Seagrasses	Not available	2.03
Shelf	Not available	0.17

of times greater than the maximum among those calculated by de Groot et al. (2012) and Costanza et al. (1997).

The greater value among considered biomes is, anyway, the one ascribed to seagrasses, confirming that economy is partially aware of the remarkable role played by this ecosystem.

At local level a couple of pioneer researches specifically devoted to *P. oceanica* ecosystem services value have been conducted by Blasi (2009) and Blasi and Cavalletti (2010).

The value of *P. oceanica* services estimated by Blasi is sensibly greater, figuring up to over 2240 € m^{-2} a^{-1}, while the value associated with the effort performed by the ecosystem to maintain other coastal ecosystem counts to nearly 0.8 € m^{-2}.

Estimates presented by Blasi, nonetheless, do not allow for further remarks since detailed calculations are not presented.

The economic value of *P. oceanica* meadows located in the Bergeggi MPA in two different years has been calculated according to different meadow extensions estimated for 1990 and 2006, i.e. 26 ha and 14 ha respectively (Fig. 3 and Table 5). Bergeggi meadow monetary value decreased from 45 millions of € in 1990 to 24 millions of € in 2006. If a linear decrease of the extension in the period of fifteen years is considered, a loss of approximately 174 millions of € of natural capital can be estimated. This estimate has been calculated according to the following algorithm:

$$\sum_{a=1990}^{2006} (\text{Extension}_a - \text{Extension}_1) * \text{value per unit area}$$

considering that the yearly natural capital loss sums up to the amount of services not provided by meadow because of the lack of *P. oceanica* disappeared from 1990.

These amounts probably still represent an underestimate of *P. oceanica* real value but they can be considered a reference in order to make further evaluations.

First they can be employed to raise awareness about the weight of ecosystem services and damages humans provoke to them. Lack of awareness and of accurate information result in actions that, although unintentionally, harm coastal ecosystems; moreover the absence of strong signals about the value of ecosystem services (and connected benefits) encourages short-term wild exploitation (Van Beukering and Cesar, 2004; Fujita et al., 2013).

Furthermore, calculated money amounts could be employed by institutions to develop actions addressed to *P. oceanica* protection such as boosting of scientific research, mitigation procedures or restoration interventions.

The choice of the intervention to which devote the amount can be a delicate issue to managers and decision makers. Costs of restoration interventions in Europe are reported to be lower than the calculated value of *P. oceanica* ecosystem services, ranging from 4 € m^{-2} to 142 € m^{-2} with an average value of 56 € m^{-2} (Perillo et al., 2009). Recent *P. oceanica* restoration experiences in Italy had a cost of 175 to 300 € m^{-2} for the reimplantation of 32 seedlings m^{-2} (L. Piazzi, pers. comm.). Note, however, that healthy meadows have a shoot density of one order of magnitude higher (Boudouresque et al., 2006). Nonetheless the success of intervention should be taken into account when performing this

Please cite this article in press as: Vassallo, P., et al. The value of the seagrass *Posidonia oceanica*: A natural capital assessment. Mar. Pollut. Bull. (2013), http://dx.doi.org/10.1016/j.marpolbul.2013.07.044

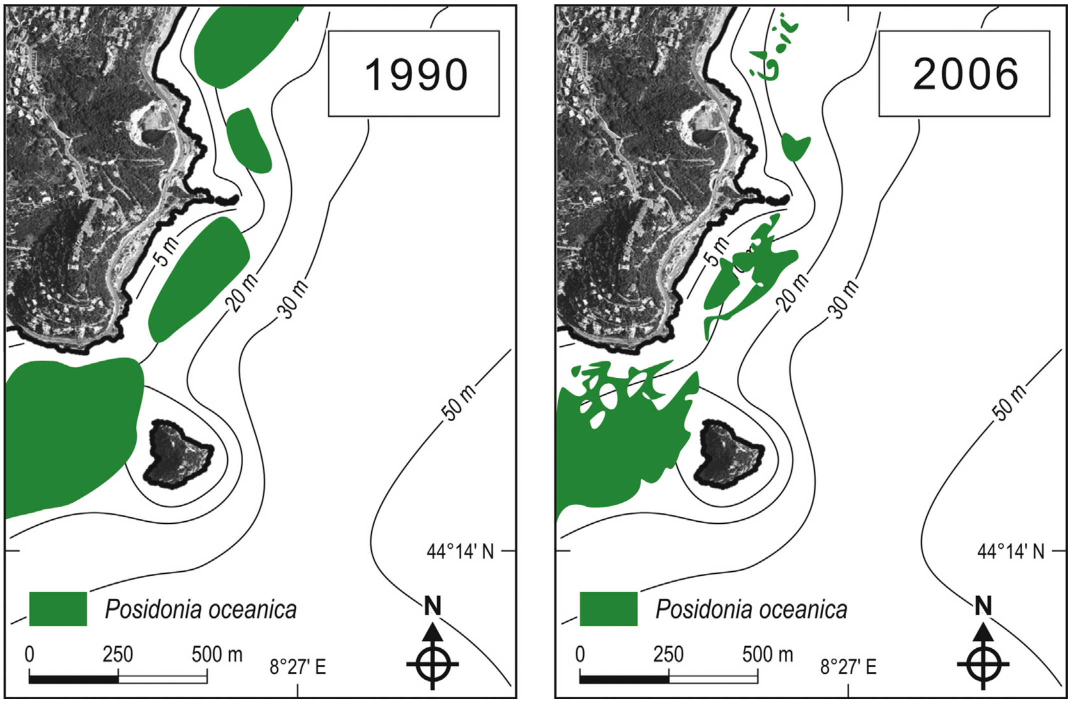

Fig. 3. Graphical comparison of the 1990 and 2006 cartographies.

Table 5
Economic value of ecosystem functions calculated for the different years of mapping.

Year	Living *P. oceanica* extent (m^2)	Economy value (€ a^{-1})
1990	2.60E+05	4.48E+07
2006	1.40E+05	2.41E+07

kind of appraisals. Since the 1960s, various restoration and mitigation projects using different seagrass species have been attempted worldwide with varying degrees of success (Fonseca, 1992). As far as restoration is considered, considerable progress have been made in recent years since a greater attention has been devoted to factors affecting restoration success such as site selection, choice and development of new methodologies appropriate to site conditions, seagrass spreading and coverage rates improvement, high labor and time costs reduction and bioturbation prevention.

A survival of 70% after three years is reported by Paling et al. (2001) with reference to a very large-scale program in Western Australia where *Posidonia* spp. and *Amphibolis griffithii* were mechanically transplanted (Lewis et al., 2006; Paling et al., 2001).

Anyway *P. oceanica* is a slow-growing species, its recoveries are slow and the recovered areas remain vulnerable (Gobert et al., 2006; Gonzalez-Correa et al., 2005; Marbà et al., 1996).

P. oceanica has an extremely low growing rate that it is not conducive to a rapid re-colonization of dead matte: sexual reproduction is exceptional and horizontal growth of rhizome edges from a contiguous bed is very slow (Meinesz et al., 1991). If still exist a potentiality of natural recovery in a meadow showing few and small dead matte areas, a large-scale regression of *P. oceanica* meadows may require centuries and must therefore be considered almost irreversible on human-life time scales (Montefalcone et al., 2007b).

Some large-scale mitigations of *P. oceanica* take place in Spain, with quite poor results (Sànchez-Lizaso et al., 2006). Recovery of *P. oceanica* seems to be possible to realize mostly at a local scale, particularly considering some further wide ranging remarks: (1) seagrasses modify the environment they colonize and once they have disappeared, conditions may have become unsuitable to host them such that only large-scale efforts can avoid negative outcomes related to erosion and turbidity (Bouma et al., 2005; van der Heide et al., 2006); for example in the Mediterranean Sea, the wide and strong regression of the seagrass *P. oceanica* had lead to significant changes in the community within the meadow ecosystem, a phenomenon recognized as phase shift (Montefalcone et al., 2007a); (2) the disappearing of the original meadow can be due to eutrophication processes that may have altered irreparably the environment.

Moreover when resilience of native ecosystems is strongly reduced, natural recovery is not to be expected in most cases over a human-life timescale because they are shifted to an alternative stable state. Recovery of degraded ecosystems has been shown to be more efficient in marine protected areas where all kinds of human activities are prohibited or limited (Guidetti, 2006; Montefalcone et al., 2011). This poses severe uncertainty about success of projects realized in coastal areas subjected to high human pressure, as the greatest part are.

Finally Fonseca (2006) demonstrated that almost the 60% of restoration intervention cost is devoted to monitoring activities proving that a great effort is required to bring these recovery activities to completion.

4. Conclusions

Emergy analysis, a methodology able to analyze the overall functioning of a system or a process has been applied to estimate the value of main ecosystem services provided by *P. oceanica* meadows, a fragile Mediterranean ecosystem widely recognized as an high value habitat (Boudouresque et al., 2006).

Principal aims were: (1) to provide a valuation of ecosystem services based on an objective measure of ecological functioning (donor side approach) rather than subjective preferences of users (user side approach) obtaining benefits from ecosystem exploitation, (2) to provide a tool to include costs deriving from the depletion of natural capital in policies and decisional processes.

Please cite this article in press as: Vassallo, P., et al. The value of the seagrass *Posidonia oceanica*: A natural capital assessment. Mar. Pollut. Bull. (2013), http://dx.doi.org/10.1016/j.marpolbul.2013.07.044

Estimates, based on calculation of resources employed by nature to provide considered services, leaded to an economic value of *P. oceanica* equal to 172 € m^{-2} a^{-1}.

The value of ecosystem services provided by *P. oceanica* is almost completely associated with sediment retained by the meadow and is notably greater (nearly 2 orders of magnitude) of that proposed by Costanza et al. (1997) for seagrasses in general.

The suggested procedure, even if preliminary, represents an effective and operative tool to provide a synthetic monetary measure of ecosystem services value to be employed when natural capital must be compared human and financial capitals in a substitutability perspective (Bianchi et al., 2012).

It become evident from results that preservation actions and research activities addressed to system conservation and damages limitation (or even avoidance) are to be preferred in a precautionary approach: appraisals have been made about the high intrinsic value owned by *P. oceanica*, the high cost of restoration and mitigation procedures as well as the uncertainty about their success, the great investment devoted to monitoring after intervention and the fact that research about ecosystem services evaluation is still in progress.

Such evaluations should be always taken into account in decisional process as, for example, when evaluating whether a recovery intervention should be applied or protective measures fostered, carefully evaluating costs to incur in or to avoid.

Acknowledgements

Part of this study benefited of the results of an investigation initially fostered by the 'Isola di Bergeggi' MPA. Stefano Coppo and Giovanni Diviacco (Regione Liguria) provided cartographic data and other information. Finally, Luigi Piazzi (CIBM, Leghorn, Italy) gave advice on reimplantation costs for *Posidonia oceanica*.

Appendix A.

See Tables A.1 and A.2.

Table A.1
Detailed calculations for emergy analysis.

	Item	Formula		Factors and input data	Reference
1	Sun	Annual solar radiation per unit area		5.11E+09 J/ m^2 ∗ year	http://clisun.casaccia.enea.it/pagine/TabelleRadiazione.htm
2	Carbon dioxide	Primary production = Carbon fixed + associated oxygen	Carbon fixed	Average value from references	Pergent et al. (1994, 1997), Ott (1980), Boudouresque et al. (2006), Alcoverro et al. (1998), Libes (1984)
			Associated oxygen = carbon fixed ∗ 36/12		
		Fishes = carbon fixed through primary production at the base of trophic chain maintaining juvenile fishes + associated oxygen	Carbon = ∑(yearly juveniles biomass per species in carbon grams)$^{(\text{trophic level-1})}$ Associated oxygen = carbon fixed ∗ 36/12	Trophic level = see Table A.2	Pauly and Christensen (1995), Francour (1997)
3	Nitrogen	Carbon fixed ∗ 7/41			Redfield et al. (1963)
4	Phosporus	Nitrogen fixed/7			Redfield et al. (1963)
5	Sediment	Quantity of sediment retained = (Primary deposition inside the meadow − primary deposition outside the meadow) + (Resuspension outside the meadow − resuspension inside the meadow)	Primary deposition inside the meadow = 4190 g DMm^{-2} a^{-1}		Gacia and Duarte (2001)
			Primary deposition outside the meadow = 4070 g DMm^{-2} a^{-1} Resuspension outside the meadow = 76146 g DMm^{-2} a^{-1} Resuspension inside the meadow = 24360 g DMm^{-2} a^{-1}		

Table A.2
Trophic level of considered species from Stergiou and Karpouzik (2002).

Coris julis	3.41
Labrus spp	3.31
Symphodus cinereus	3.23
S. mediterraneus	3.16
S. melanocercus	3.25
S. ocellatus	3.24
S. roissali	3.24
S. rostrauts	3.37
S. tinca	3.20
Diplodus annularis	3.40
Sarpa salpa	2.00
Spondyliosoma cantharus	3.29
Serranus cabrilla	3.71
S. scriba	3.79

References

Alcoverro, T., Manzanera, M., Romero, J., 1998. Seasonal and age-dependent variability of *Posidonia oceanica* (L.) Delile photosynthetic parameters. Journal of Experimental Marine Biology and Ecology 230, 1–13.
Ardizzone, G., Belluscio, A., Maiorano, L., 2006. Long-term change in the structure of a *Posidonia oceanica* landscape and its reference for a monitoring plan. Marine Ecology Progress Series 27, 299–309.
Ayres, R.U., 1996. Statistical measures of unsustainability. Ecological Economics 16, 239–255.
Bardi, E., 2002. Emergy Evaluation of Ecosystems: a Basis for Mitigation Policy. A thesis presented to the graduate school of the University of Florida in partial fullfillment of the requirements for the degree of master of science.
Basterretxea, G., Orfila, A., Jordi, A., Casas, B., Lynett, P., Liu, P., Duarte, C., Tintoré, J., 2004. Seasonal dynamics of a microtidal pocket beach with *Posidonia oceanica* seabeds (Mallorca, Spain). Journal of Coastal Research 20, 1155–1164.
Bateman, I.J., Mace, G.M., Fezzi, C., Atkinson, G., Turner, K., 2011. Economic analysis for ecosystem service assessments. Environmental and Resource Economics 48, 177–218.
Bay, D., 1978. Etude in situ de la production primaire d'un herbier de Posidonies (*Posidonia oceanica* (L.) Delile) de la baie de Calvi-Corse. Progr. Rép. Stn. Océanogr. Stareso, Univ. Liège, Belg., 18: 6 p non num. + 1-251.
Bell, J.D., Harmelin-Vivien, M.L., 1982. Fish fauna of French Mediterranean *Posidonia oceanica* seagrass meadows. 1. Community structure. Téthys 10, 337–347.
Bell, J.D., Pollard, D.A., 1989. Ecology of Fish Assemblages and Fisheries Associated with Seagrasses, Biology of Seagrasses: a Treatise on the Biology of Seagrasses with Special Reference to the Australian Region. Elsevier, Amsterdam.
Bellan-Santini, D., Arnoux, A., Willsie, A., 1986. Distribution comparée des crustacés amphipodes de la "matte" d'herbier de Posidonies mort et vivant. Rapport Procès-verbaux des Réunions de la Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée 30, 8.

Bellan-Santini, D., Lacaze, J.C., Poizat, C., 1994. Les biocénoses marines et littorales de Méditerranée, synthèse, menaces et perspectives. Muséum National d'Histoire Naturelle publ., Paris.
Berkes, F., Folke, C., 1994. Investing in Cultural Capital for Sustainable Use of Natural Capital. In: Jansson, Ann Mari et al. (Eds.), Investing in Natural Capital. Island Press, Washington.
Bianchi, C., Morri, C., 2000. Marine biodiversity of the mediterranean sea: situation, problems and prospects for future research. Marine Pollution Bulletin 40, 367–376.
Bianchi, C.N., Morri, C., Parravicini, V., Rovere, A., 2007. Realizzazione di cartografia tematica sull'ambiente marino costiero di Bergeggi ed elaborazione di un piano di monitoraggio. Relazione finale nell'ambito del contratto di ricerca tra il Dipartimento per lo Studio del Territorio e delle sue Risorse dell'Università degli Studi di Genova ed il Comune di Bergeggi.
Bianchi, C.N., Parravicini, V., Montefalcone, M., Rovere, A., Morri, C., 2012. The challenge of managing marine biodiversity: a practical toolkit for a cartographic, territorial approach. Diversity 4, 419–452.
Bianchi C.N., Peirano A., 1995 - Atlante delle fanerogame marine della liguria. Posidonia oceanica e Cymodocea nodosa. ENEA, Centro Ricerche Ambiente Marino, La Spezia: 1-146.
Blasi, F., 2009. The economic value of the *Posidonia oceanica* meadows. Biologia Marina Mediterranea 16, 130–131.
Blasi, F., Cavalletti, B., 2010. A discount rate for the *Posidonia oceanica* meadows (in Italian). Biologia Marina Mediterranea 17, 316–317.
Boudouresque, C.F., 2004. Marine biodiversity in the Mediterranean: status of species, populations and communities. Travaux Scientifiques du Parc National de Port-Cros 20, 97–146.
Boudouresque, C.F., Meinesz, A., 1982. Découverte de l'herbier de Posidonie. Parc National de Port-Cros Cahiers 4, 1–80.
Boudouresque, C.F., Ballesteros, E., Ben Maiz, N., Boisset, F., Bouladier, E., Cinelli, F., Cirik, S., Cormaci, M., Jeudy de Grissac, A., Laborel, J., Lanfranco, E., Lundberg, B., Mayhoub, H., Meinesz, A., Panayotidis, P., Semroud, R., Sinnassamy, J. M., Span, A., Vuigner, G., 1990. Livre Rouge "Gérard Vuigner" des végétaux, peuplements et paysages marins menacées de Méditerranée. UNEP/IUCN/GIS Posidonie. MAP Technical Report Series No. 43, Athens.
Boudouresque, C.F., Bernard, G., Bonhomme, P., Charbonnel, E., Diviacco, G., Meinesz, A., Pergent, G., Pergent-Martini, C., Ruitton, S., Tunesi, L., 2006. Préservation et conservation des herbiers à *Posidonia oceanica*. Ramoge pub., Monaco.
Boudouresque, C.F., Bernard, G., Pergent, G., Shili, A., Verlaque, M., 2009. Regression of Mediterranean seagrasses caused by natural processes and anthropogenic disturbances and stress: a critical review. Botanica Marina 52, 395–418.
Bouma, T.J., de Vries, M.B., Low, E., Kusters, L., Herman, P.M.J., Tanczos, I.C., Temmerman, S., Hesselink, A., Meire, P., van Regenmortel, S., 2005. Flow hydrodynamics on a mudflat and in salt marsh vegetation: identifying general relationships for habitat characterisations. Hydrobiologia 540, 259–274.
Boyd, J., Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics 63, 616–626.
Boyd, J., Krupnick, A., 2009. The Definition and Choice of Environmental Commodities for Nonmarket Valuation. RFF DP 09-35 Resources for the Future, Washington, DC.
Braat, L.C., de Groot, R., 2012. The ecosystem services agenda: bridging the worlds of natural science and economics, conservation and development, and public and private policy. Ecosystem Services 1, 4–15.
Brown, M.T., Herendeen, R.A., 1996. Embodied energy analysis and EMERGY analysis: a comparative view. Ecological Economics 19, 219–235.
Brown, M.T., Ulgiati, S., 1999. Emergy evaluation of the biosphere and natural capital. Ambio 28, 486–493.
Brown, T.C., Bergstrom, J.C., Loomis, J.B., 2007. Defining, valuing and providing ecosystem goods and services. Natural Resources Journal 47, 329–376.
Brunel, C., Sabatier, F., 2009. Potential influence of sea-level rise in controlling shoreline position on the French Mediterranean Coast. Geomorphology 107, 47–57.
Campbell, D.E., 2000. Emergy synthesis of natural capital and environmental services of the united states forest service system. In: Brown, M., Sweeney, S. (Eds.), Emergy Synthesis 5. The Center for Environmental Policy. University of Florida, Gainesville, USA, pp. 65–86.
Campbell, D.E., Lu, H., Lin, B., 2013. Emergy evaluations of the global biogeochemical cycles of six biologically active elements and two compounds. Ecological Modelling. <http://dx.doi.org/10.1016/j.ecolmodel.2013.01.013>.
Carson, R.M., Bergstrom, J.C., 2003. A review of ecosystem valuation techniques. University of Georgia, Department of Agricultural and Applied Economics, Faculty Series 03-03.
Chee, Y.E., 2004. An ecological perspective on the valuation of ecosystem services. Biological Conservation 120, 549–565.
Cleveland, C.J., 1994. Re-allocating work between human and natural capital in agriculture: examples from India and the united states. In: Jansson, Ann Mari et al. (Eds.), Investing in Natural Capital. Island Press, Washington.
Cohen, M.J., Brown, M.T., Shepherd, K.D., 2006. Estimating the environmental costs of soil erosion at multiple scales in Kenya using emergy synthesis. Agriculture, Ecosystems & Environment 114, 249–269.
Common, M.S., 1997. Roles for ecology in ecological economics and sustainable development. In: Klomp, N., Lunt, I. (Eds.), Frontiers in Ecology. Elsevier Science Ltd., Oxford, UK, pp. 323–334.
Connolly, R.M., 1994. The role of seagrass as preferred habitat for juvenile Sillaginodes punctata (CUV. and VAL.) (Sillaginidae, Pisces): habitat selection or feeding? Journal of Experimental Marine Biology and Ecology 180, 39–47.
Costanza, R., Daly, H.E., 1992. Natural capital and sustainable development. Conservation Biology 6, 37–46.
Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.
Coulthard, S., Johnson, D., McGregor, J.A., 2011. Poverty, sustainability and human wellbeing: a social wellbeing approach to the global fisheries crisis. Global Environmental Change 21, 453–463.
Daly, H.E., 1994. Operationalizing sustainable development by investing in natural capital. In: Jansson, Ann Mari et al. (Eds.), Investing in Natural Capital. Island Press, Washington.
Dasgupta, P., 1994. Saving and fertility: ethical issues. Philosophy & Public Affairs 23, 99–127.
De Falco, G., Baroli, M., Cucco, A., Simeone, S., 2008. Intrabasinal conditions promoting the development of a biogenic carbonate sedimentary facies associated with the seagrass *Posidonia oceanica*. Continental Shelf Research 28, 797–812.
de Groot, R.S., Wilson, M.A., Boumans, R.M., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41, 393–408.
de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P., van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosystem Services 1, 50–61.
Díaz-Almela, E., Duarte, C.M., 2008. Management of Natura 2000 habitats. 1120 ∗Posidonia beds (*Posidonion oceanicae*). European Commission.
Diviacco, G., Coppo, S., 2006. Atlante degli habitat marini della Liguria. Regione Liguria, Catalogo dei beni naturali 6, Genova.
Duarte, C.M., 2002. The future of seagrass meadows. Environmental Conservation 29, 192–206.
Duarte, C.M., 2004. Las praderas de Fanerógamas marinas. El papel de las praderas en la dinámica costera. In: Luque, A.A., Templado, J. (Eds.), Praderas y bosques marinos de Andalucía. Consejería de Medio Ambiente, Junta de Andalucía publ., Sevilla, pp. 81–85.
EEC. 1992. Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Communities. Law 206 of 22 July 1992.
Ehrlich, P.R., 1994. Ecological economics and the carrying capacity of earth. In: Jansson, Ann Mari et al. (Eds.), Investing in Natural Capital. Island Press, Washington.
Ekins, P., Simon, S., Deutsch, L., Folke, C., de Groot, R., 2003. A framework for the practical application of the concepts of critical natural capital and strong sustainability. Ecological Economics 44, 165–185.
Ewel, K.C., Twilley, R.R., Ong, J.E., 1998. Different kinds of mangrove forest provide different goods and services. Global Ecology and Biogeography Letters 7, 83–94.
Farber, S.C., Costanza, R., Wilson, M.A., 2002. Economic and ecological concepts for valuing ecosystem services. Ecological Economics 41, 375–392.
Fergusson, R.L., Thayer, G.W., Rice, T.R., 1980. Marine primary producers. In: Vernberg, F.J., Vernberg, W.B. (Eds.), Functional Adaptations of Marine Organisms. Academic Press publ., Amsterdam, pp. 9–69.
Ferrari, M., Cabella, R., Berriolo, G., Montefalcone, M., 2013. Gravel sediment bypass between contiguous littoral cells in the NW Mediterranean Sea. Journal of Coastal Research, <http://dx.doi.org/10.2112/JCOASTRES-D-12-00241.1>.
Fierro, G., Imperiale, G., Montano, F., Piacentino, G., 1975. Caratteristiche sedimentologiche delle spiagge del finalese e loro evoluzione. Atti della Società italiana di scienze naturali. Museo civico di storia naturale di Milano 115, 118–156.
Fisher, B., Turner, K., Zylstra, M., Brouwer, R., de Groot, R., Farber, S., Ferraro, P., Green, R., Hadley, D., Harlow, J., Jefferiss, P., Kirkby, C., Morling, P., Mowatt, S., Naidoo, R., Paavola, J., Strassburg, B., Yu, D., Balmford, A., 2008. Ecosystem services and economic theory: integration for policy relevant research. Ecological Applications 18, 2050–2067.
Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. Ecological Economics 68, 643–653.
Fonseca, M.S., 1992. Restoring seagrass systems in the United States. In: Thayer, G.W. (Ed.), Restoring the Nation's Marine Environment. College Park, Maryland Sea Grant College, pp. 79–110.
Fonseca, M., 2006. Wrap-up of seagrass restoration: success, failure and lessons about the costs of both. In: Treat, S.F., Lewis III R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 169–175.
Francour, P., 1990. Dynamique de l'écosystème à *Posidonia oceanica* dans le Parc national de Port-Cros. Analyse des compartiments "matte", litière, faune vagile, échinodermes et poissons. Thèse Doct. Océanol., Univ. Paris VI, Fr.: 1–373.
Francour, P., 1997. Fish Assemblages of *Posidonia oceanica* beds at Port-Cros (France, NW Mediterranean): assessment of composition and long-term fluctuations by visual census. Marine Ecology Progress Series 18, 157–173.
Freeman III, A.M., 2003. The Measurement of Environmental and Resource Values: Theory and Methods. Resources for the Future, Washington, DC.

Fujita, R., Lynham, J., Micheli, F., Feinberg, P.G., Bourillón, L., Sáenz-Arroyo, A., Markham, A.C., 2013. Ecomarkets for conservation and sustainable development in the coastal zone. Biological Reviews of the Cambridge Philosophical Society 88, 273–286.

Gacia, E., Duarte, C.M., 2001. Sediment retention by a Mediterranean *Posidonia oceanica* meadow: the balance between deposition and resuspension. Estuarine, Coastal and Shelf Science 52, 505–514.

Gacia, E., Granata, T.C., Duarte, C.M., 1999. An approach to measurement of particle flux and sediment retention within seagrass (*Posidonia oceanica*) meadows. Aquatic Botany 65, 255–268.

Gacia, E., Duarte, C.M., Middelburg, J.J., 2002. Carbon and nutrient deposition in a Mediterranean seagrass (*Posidonia oceanica*) meadow. Limnology and Oceanography 47, 23–32.

Gambi, M.C., Buia, M.C., Casola, E., Scardi, M., 1989. Estimates of water movement in *Posidonia oceanica* beds: a first approach. In: Boudouresque, C.F., Meinesz, A., Fresi, E., Gravez, V. (Eds.), International Workshop on Posidonia beds. GIS Posidonie publ. 2, Marseille, pp. 101–112.

Gobert, S., Cambridge, M.L., Velimirov, B., Pergent, G., Lepoint, G., Bouquegneau, J.M., Dauby, P., Pergent-Martini, C., Walker, D.I., 2006. Biology of posidonia. In: Larkum, A.W.D., Orth, R.J., Duarte, C.M. (Eds.), Seagrasses: Biology, Ecology and Conservation. Springer,, ordrecht, pp. 387–408.

Gonzalez-Correa, J.M., Bayle, J.T., Sanchez-Lizasa, J.L., Valle, C., Sanchez-Jerez, P., Ruiz, J.M., 2005. Recovery of deep *Posidonia oceanica* meadows degraded by trawling. Journal of Experimental Marine Biology and Ecology 320, 65–76.

Guidetti, P., 2006. Marine reserves reestablish lost predatory interactions and cause community changes in rocky reefs. Ecological Applications 16, 963–976.

Hanley, N., Barbier, E.B., 2009. Pricing Nature: Cost Benefit Analysis and Environmental Policy. Edward Elgar Cheltenham, UK.

Harmelin-Vivien, M.L., 1982. Ichtyofaune des herbiers de posidonies du Parc national de Portâ€“Cros. I. Composition et variations spatio-temporelles. Travaux Scientifiques du Parc National de Port-Cros 8, 69–92.

Harsanyi, J.C., 1996. Utilities, preferences, and substantive goods. Social Choice and Welfare 14, 129–145.

Heck, K.L., Thoman, T.A., 1984. The nursery role of seagrass meadows in the upper and lower reaches of the Chesapeake Bay. Estuaries and Coasts 7, 70–92.

Hein, L., Van Koppen, K., de Groot, R.S., van Ierland, E.C., 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecological Economics 57, 209–228.

Holland, D.S., Sanchirico, J., Johnston, R.J., Joglekar, D., 2010. Economic Analysis for Ecosystem Based Management: Applications to Marine and Coastal Environments. RFF Press, Washington, DC.

Holmlund, C.M., Hammer, M., 1999. Ecosystem services generated by fish populations. Ecological Economics 29, 253–268.

Infantes, E., Terrados, J., Orfila, A., Canellas, B., Álvarez–Ellacuria, A., 2009. Wave energy and the upper depth limit distribution of *Posidonia oceanica*. Botanica Marina 52, 419–427.

Jannson, A., Jansson, B., 1994. Ecosystem properties as a basis for sustainability. In: Jansson, Ann Mari et al. (Eds.), Investing in Natural Capital. Island Press, Washington.

Jansson, A.M., Hammer, M., Folke, C., Costanza, R., 1994. Investing in Natural Capital: The Ecological Economics Approach to Sustainability. Island Press, Washington, DC, 504p.

Jeudy De Grissac, A., Boudouresque, C.F., 1985. Rôle des herbiers de Phanérogames marines dans les mouvements de sédiments côtiers: les herbiers à *Posidonia oceanica*. Colloque franco–japonais d'Océanographie 1, 143–151.

Johnston, R.J., Russell, M., 2011. An operational structure for clarity in ecosystem service values. Ecological Economics 70, 2243–2249.

Kontogianni, A., Luck, G.W., Skourtos, M., 2010. Valuing ecosystem services on the basis of service-providing units: a potential approach to address the 'endpoint problem' and improve stated preference methods. Ecological Economics 69, 1479–1487.

Larkum, A.W.D., West, R.J., 1990. Long-term changes of seagrass meadows in Botany Bay, Australia. Aquatic Botany 37, 55–70.

Leipert, C., Pulselli, F.M., 2008. The origins of research on defensive expenditures: a dialogue with Christian Leipert. International Journal of Design & Nature and Ecodynamics 3 (2), 150–161.

Leriche, A., Pasqualini, V., Boudouresque, C.F., Bernard, G., Bonhomme, P., Clabaut, P., Denis, J., 2006. Spatial, temporal and structural variations of a *Posidonia oceanica* seagrass meadow facing human activities. Aquatic Botany 84, 287–293.

Lewis III R.R., Marshall, M.J., Bloom, S.A., Hodgson, A.B., Flynn, L.L., 2006. Evaluation of the success of seagrass mitigation at Port Manatee, Tampa Bay, Florida. In: Treat, S.F., Lewis III R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 19–40.

Libes, M., 1984. Production primaire d'un herbier à *Posidonia oceanica* mesurée in situ par la methode du carbone 14. These de doctorat de specialite en Ecologie. Universite Aix-Marseille 11, Fac. Sci. Luminy, pp. 1–199.

MA (Millennium Ecosystem Assessment), 2005. Ecosystems and Human Well-being. Island Press, Washington, DC.

Marbà, N., Duarte, C.M., Cebrian, J., Gallegos, M.E., Olesen, B., Sand Jensen, K., 1996. Growth and population dynamics of *Posidonia oceanica* on the Spanish Mediterranean coast: Elucidating seagrass decline. Marine Ecology Progress Series 137, 203–213.

Meinesz, A., Lefevre, J.R., Astier, J.M., 1991. Impact of coastal development on the infralittoral zone along the Southeastern Mediterranean shore of continental France. Marine Pollution Bulletin 23, 343–347.

Moberg, F., Folke, C., 1999. Ecological goods and services of coral reef ecosystems. Ecological Economics 29, 215–233.

Montefalcone, M., Morri, C., Peirano, A., Albertelli, G., Bianchi, C.N., 2007a. Substitution and phase shift within the *Posidonia oceanica* seagrass meadows of NW Mediterranean Sea. Estuarine, Coastal and Shelf Science 75, 63–71.

Montefalcone, M., Albertelli, G., Morri, C., Bianchi, C.N., 2007b. Urban seagrass: Status of *Posidonia oceanica* facing the Genoa city waterfront (Italy) and implications for management. Marine Pollution Bulletin 54, 206–213.

Montefalcone, M., Albertelli, G., Morri, C., Bianchi, C.N., 2010. Pattern of wide-scale substitution within *Posidonia oceanica* meadows of NW Mediterranean Sea: invaders are stronger than natives. Aquatic Conservation: Marine and Freshwater Ecosystems 20, 507–515.

Montefalcone, M., Parravicini, V., Bianchi, C.N., 2011. Quantification of coastal ecosystem resilience. In: Wolanski, E., McLusky, D.S. (Eds.), Treatise on Estuarine and Coastal Science. Waltham, vol. 10(3), Academic Press, pp. 49–70.

Montefalcone, M., Rovere, A., Parravicini, V., Albertelli, G., Morri, C., Bianchi, C.N., 2013. Evaluating change in seagrass meadows: a time-framed comparison of Side Scan Sonar maps. Aquatic Botany 104, 204–212.

Niccolucci, V., Pulselli, F.M., Tiezzi, E., 2007. Strengthening the threshold hypothesis: Economic and biophysical limits to growth. Ecological Economics 60, 667–672.

Norton, B., Costanza, R., Bishop, R.C., 1998. The evolution of preferences: why 'sovereign' preferences may not lead to sustainable policies and what to do about it. Ecological Economics 24, 193–211.

Odum, H.T., 1988. Self-organization, transformity, and information. Science 242, 1132–1139.

Odum, H.T., 1992. Emergy and Public Policy Part I – II Environmental Engineering Sciences, University of Florida, Gainesville, FL.

Odum, H.T., 1996. Environmental Accounting: Emergy and Environmental Decision Making. John Wiley & Sons, London.

Odum, H.T., 2000. Handbook of Emergy Evaluation Folio #2: Emergy of Global Processes. Center for Environmental Policy. University of Florida, Gainesville, 30p.

Odum, H.T., Odum, E., 2000a. Modeling for All Scales: An Introduction to Systems and Simulation. Academic Press, San Diego.

Odum, H.T., Odum, E., 2000b. The energetic basis for valuation of ecosystem services. Ecosystem 3, 21–23.

Odum, H.T., Odum, B., 2003. Concepts and methods of ecological engineering. Ecological Engineering 20, 339–361.

Odum, H.T., Pinkerton, R.C., 1955. Time's speed regulator: the optimum efficiency for maximum power output in physical and biological systems. American Scientist 43, 321–343.

Ott, J.A., 1980. Growth and production in *Posidonia oceanica* (L.) Delile. P.S.Z.N. Marine Ecology 1, 47–64.

Paling, E.I., van Keulen, M., Wheeler, K.D., Phillips, J., Dyhrberg, R., Lord, D.A., 2001. Improving mechanical seagrass transplantation. Ecological Engineering 18, 107–113.

Paoli, C., Vassallo, P., Fabiano, M., 2008a. An emergy approach for the assessment of sustainability of small marinas. Ecological Engineering 33, 167–178.

Paoli, C., Vassallo, P., Fabiano, M., 2008b. Solar power: an approach to transformity evaluation. Ecological Engineering 34, 191–206.

Paoli, C., Gastaudo, I., Vassallo, P., 2013. The environmental cost to restore beach ecoservices. Ecological Engineering 52, 182–190.

Parravicini, V., Rovere, A., Vassallo, P., Micheli, F., Montefalcone, M., Morri, C., Paoli, C., Albertelli, G., Fabiano, M., Bianchi, C.N., 2011. Understanding relationships between human uses and coastal eco system status: a geospatial modelling approach. Ecological Indicators 19, 253–263.

Pasqualini, V., Pergent-Martini, C., Pergent, G., 1999. Environmental impacts identification along corsican coasts (Mediterranean Sea) using image processing. Aquatic Botany 65, 311–320.

Pauly, D., Christensen, V., 1995. Primary production required to sustain global fisheries. Nature 374, 255–257.

Pergent, G., Kempf, M., 1993. L'environnement marin côtier en Tunisie. 1. Rapport de synthèse. 2. Etude documentaire. 3. Ann. Agence Nationale pour la Protection de l'Environnement (Tunisie), Ifremer & GIS Posidonie, Marseille.

Pergent, G., Romero, J., Pergent-Martini, C., Mateo, M.A., Boudouresque, C.F., 1994. Primary production, stocks and fluxes in the Mediterranean seagrass*Posidonia oceanica*. Marine Ecology Progress Series 106, 139–146.

Pergent, G., Rico-Raimondino, V., Pergent-Martini, C., 1997. Fate of primary production in *Posidonia oceanica* meadows of the Mediterranean. Aquatic Botany 59, 307–321.

Pergent, G., Bazairi, H., Bianchi, C.N., Boudouresque, C.F., Buia, M.C., Clabaut, P., Harmelin-Vivien, M., Mateo, M.A., Montefalcone, M., Morri, C., Orfanidis, S., Pergent-Martini, C., Semroud, R., Serrano, O., Verlaque, M., 2012. Les herbiers de Magnoliophytes marines de Méditerranée – Résilience et contribution à l'atténuation des changements climatiques. IUCN, Gland, Switzerland and Málaga, Spain, 80p.

Perillo, G.M.E., Wolanski, E., Cahoon, D.R., Brinson, M.M., 2009. Coastal Wetlands: An Integrated Ecosystem Approach. Elsevier Science. 974p.

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., Tran, Q., Saltman, T., Cliff, B., 1997. Economic and environmental benefits of biodiversity. BioScience 47, 747–757.

Please cite this article in press as: Vassallo, P., et al. The value of the seagrass *Posidonia oceanica*: A natural capital assessment. Mar. Pollut. Bull. (2013), http://dx.doi.org/10.1016/j.marpolbul.2013.07.044

Pulselli, F.M., Coscieme, L., Bastianoni, S., 2011. Ecosystem services as a counterpart of Emergy flows to ecosystems. Ecological Modelling 222, 2924–2928.

Pulselli, F.M., Bravi, M., Tiezzi, E., 2012. Application and use of the ISEW for assessing the sustainability of aregional system: a case study in Italy. Journal of Economic Behavior & Organization 81, 766–778.

Redfield, A.C., Ketchum, B.H., Richards, F.A., 1963. The influence of organisms on the composition of sea-water. In: Hill, N.M. (Ed.), The Sea, vol. 2. Wiley, London, pp. 27–77.

Robertson, A.I., 1980. The structure and organisation of an eelgrass fish fauna. Oecologia 47, 76–82.

Rovere, A., Parravicini, V., Vacchi, M., Montefalcone, M., Morri, C., Bianchi, C.N., Firpo, M., 2010a. Geo-environmental cartography of the Marine Protected Area ''Isola di Bergeggi''(Liguria, NW Mediterranean Sea). Journal of Maps, 505–519.

Rovere, A., Vacchi, M., Parravicini, V., Bianchi, C.N., Zouros, N., Firpo, M., 2010b. Bringing Geoheritage underwater: definitions, methods and application in two Mediterranean marine areas. Environmental Earth Sciences 64, 133–142.

Rovere, A., Parravicini, V., Firpo, M., Morri, C., Bianchi, C.N., 2011. Combining geomorphologic, biological and accessibility values for marine natural heritage evaluation and conservation. Aquatic Conservation: Marine and Freshwater Ecosystems 21, 541–552.

Sànchez-Lizaso, J.L., Fernandez-Torquemada, Y., Gonzalez-Correa, J.M., 2006. Efectividad de los transplantes de *Posidonia oceanica* efectuados en el entorno del puerto deportivo Luis Campomanes (Altea). WWF, Universidad de Alicante, Spain.

Stergiou, K.I., Karpouzik, V.K., 2002. Feeding habits and trophic levels of Mediterranean fish. Reviews in Fish Biology and Fisheries 11, 217–254.

TEEB. 2010. In: Kumar, P. (Ed.), The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations Earthscan, London.

Tisdell, C.A., 1991. Economics of Conservation. Elsevier, Amsterdam, Netherlands.

Turner, R.K., 1993. Sustainability: Principles and Practice. Belhaven Press, New York/London.

Tversky, A., Kahneman, D., 1991. Loss aversion in riskless choice: a reference-dependent model. Quarterly Journal of Economics 106, 1039–1061.

Ulgiati, S., Brown, M.T., 2002. Quantifying the environmental support for dilution and abatement of process emissions: the case of electricity production. Journal of Cleaner Production 10, 335–348.

UNEP, MAP. 2010. Mediterranean marine ecosystems: the economic value of sustainable benefits. Blue Plan Notes n°17.

Vacchi, M., Montefalcone, M., Bianchi, C.N., Morri, C., Ferrari, M., 2010. The influence of coastal dynamics on the upper limit of the *Posidonia oceanica* meadow. Marine Ecology Progress Series 31, 546–554.

Van Beukering, P., Cesar, H.S.J., 2004. Ecological economic modeling of coral reefs: evaluating tourist overuse at Hanauma Bay and algae blooms at the Kihei Coast, Hawaii. Pacific Science 58, 243–260.

van der Heide, T., van Katwijk, M.M., Geerling, G.W., 2006. Een verkenning van de groeimogelijkheden van ondergedoken Groot zeegras (Zostera marina) in de Nederlandse Waddenzee. Radboud University, Nijmegen, The Netherlands.

Vassallo, P., Paoli, C., Tilley, D.R., Fabiano, M., 2009. Energy and resource basis of an Italian coastal resort region integrated using emergy synthesis. Journal of Environmental Management 91, 277–289.

Wallace, K.J., 2007. Classification of ecosystem services: problems and solutions. Biological Conservation 139, 235–246.

Please cite this article in press as: Vassallo, P., et al. The value of the seagrass *Posidonia oceanica*: A natural capital assessment. Mar. Pollut. Bull. (2013), http://dx.doi.org/10.1016/j.marpolbul.2013.07.044