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The seagrass *Posidonia oceanica*: Ecosystem services identification and economic evaluation of goods and benefits

Carole Sylvie Campagne [a,*], Jean-Michel Salles [b], Pierre Boissery [c], Julie Deter [a,d]

[a] Andromède Océanologie, 7 place Cassan, 34280 Carnon, France
[b] CNRS, UMR LAMETA, 2 Place Viala, 34060 Montpellier, France
[c] Agence de l'Eau Rhône-Méditerranée-Corse, Délégation de Marseille, Immeuble le Noailles, 62 La Canebière, 13001 Marseille, France
[d] Université de Montpellier 2, Institut des Sciences de l'Evolution (ISEM), UMR 5554 UM2, CNRS, IRD, Campus de l'Université de Montpellier 2, place Eugène Bataillon, 34095 Montpellier cedex 5, France

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ABSTRACT

Posidonia oceanica is a marine angiosperm endemic from the Mediterranean. Despite their protection, its meadows are regressing. The economic valuation of ecosystem services (ES) assesses the contribution of ecosystems to human well-being and may provide local policy makers help in territorial development. To estimate the economic value of *P. oceanica* seagrass and the meadows that it forms to better account its presence in coastal development, identification and assessment of ES provided are first performed. Then goods and benefits (GB) and their economical values are estimated. In total, 25ES are identified and 7 GB are economically evaluated. The economic value of GB provided by *P. oceanica* ranges between 25.3 million and 45.9 million €/year which means 283–513 €/ha/year. Because of the lack of existing available data, only 7 GB linked to 11/25ES have been estimated. Despite this overall undervaluation, this study offers a value for coastal development policies to take into account.

1. Introduction

In a context of general degradation of natural environments, finding solutions to reduce the loss of biodiversity is essential (MEA, 2005). The lack of economic evaluation of ecosystems and biodiversity is widely considered as having played a crucial role in their loss and continuous degradation (MEA, 2005; Secretariat of the CBD, 2010). Actually, in many cases, policy makers cannot properly take into account what has no economic value, thus justifying the need for an economic evaluation (Costanza et al., 1997). It is therefore important to identify, measure and perform the monitoring of natural capital in order to be simply considered and/or no longer undervalued and overexploited in management decisions concerning the natural environment (David Suzuki Foundation and Nature Action Québec, 2013). In 2011, the European Union (EU) adopted a strategy to protect and improve the state of biodiversity in Europe called the "EU Biodiversity Strategy to 2020". In the action 5 of Target 2 of this strategy, the European Commission asks Member States to map and assess the state of ecosystems and their services in 2014, to assess the economic value of these services and to promote the integration of these values into accounting and reporting systems at EU and national level by 2020 (European Commission, 2013).

In order to assess economic ecosystem, the concept of ecosystem services facilitates the linkage between anthropogenic pressures and ecosystem functions (Haines-Young and Potschin, 2013). Ecosystem services (ES) are defined by the Millennium Ecosystem Assessment (MEA, 2005) as "the benefits that people derive from ecosystems" (2005) while goods and benefits (GB) are contributions that human derive or create from ES (Potschin and Haines-Young, 2011; Haines-Young and Potschin, 2013). ES are different from ecosystem functions that are "biological processes of functioning and maintaining ecosystems" (Bouvron, 2009).

Seagrass meadows, composed of marine Magnoliophytes are present in most oceans and seas of the world (Green and Short, 2003), but especially along tropical coasts and in temperate regions (Den Hartog and Kuo, 2006). They play an important ecological role in marine environment (Unsworth et al., 2014) and provide ES of great value such as protection against coastal erosion, contribution to fishery by supporting food webs or absorption of pollutants by filtrating water (Short et al., 2011; UNEP/MAP, 2012; Ondiviela et al., 2014). Actually, lots of case studies show that seagrass

* Corresponding author.
E-mail addresses: sylviecampagne@gmail.com (C.S. Campagne), jean-michel.salles@supagro.inra.fr (J.-M. Salles), pierre.boissery@eaurmc.fr (P. Boissery), julie.deter@andromede-ocean.com (J. Deter).

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List of Acronyms

CBD	Convention on Biological Diversity
CICES	Common International Classification of Ecosystem Services
CSIL	Scientific Council of «Iles de Lérins»
ES	Ecosystem Services
EU	European Union
GB	Goods and benefits
MEA	Millennium Ecosystem Assessment
PACA	Provence-Alpes-Côte-D'azur
PAM/MAP	Mediterranean Action Plan
PNUE/UNEP	United Nations Environment Programme
UICN/IUCN	International Union for Conservation of Nature
SUEB	Strategy of European Union for Biodiversity
TEEB	The Economics of Ecosystems and Biodiversity

meadows support the well-being of societies by providing many kinds of ES (Cullen-Unsworth et al., 2014).

Since the work of Costanza et al. (1997), the cumulative total of economic evaluation studies has considerably increased (De Groot et al., 2012) and valuation methods have been improved (TEEB Foundations, 2010). While the result of Costanza et al. (1997) highlights the importance of seagrass, only few recent economic studies concern seagrass species (e.g. Dirhamsyah, 2007). Mostly, recent economic studies on seagrass species concern an economic evaluation of one specific ES (e.g. Spurgeon, 1998; Samonte-Tan et al. 2007; MacArthur and Boland, 2006; Unsworth et al. 2010; Pendleton et al. 2012). In spite of their importance recognized in the scientific literature; there is a lack of ecological knowledge for many seagrass species, and even the distribution is not completed for some of them (Duarte et al., 2008; Short et al., 2011). On the whole, seagrass meadows receive less attention that other habitat of similar importance and their role in the interaction between societies and nature is poorly known by populations and stakeholders (Duarte et al., 2008; Liquete et al, 2013; Cullen-Unsworth et al., 2014). Moreover seagrass habitats suffer degradation impacting in return their contributions to human well-being (Waycott et al., 2009; Cullen-Unsworth et al., 2014).

The objective of this study is to estimate the total economic value of the species *Posidonia oceanica* (L.) Delile and the meadows it forms. In Mediterranean Sea, this endemic seagrass species is the most common and the best known seagrass (Boudouresque et al., 2012). In order to help its consideration and better accounting in decision-making and management, the purpose of our economic evaluation is not to give a market value or to prepare a commodification of natural assets but to link economic value with elements of the natural environment (TEEB in Policy, 2010). First, identification and assessment of *P. oceanica*'s final ES are performed. Then, based on the methodology developed by The Economics of Ecosystems and Biodiversity (TEEB) Synthesis (2010), GB and their economic values are estimated from the ES listed in the first place. We use preference-based approach of use value, which has never been applied to *P. oceanica.* Finally, a total economic valuation of GB provided by *P. oceanica* along the French coast is estimated.

2. Materials and methods

This study focuses on a country-scale, namely France. Indeed, laws, decrees and cultural habits are defined at a national level. This evaluation is thus conducted and directed in a French socio-economic context, i.e. it assesses the benefit that people derive from *P. oceanica* (considering French cover areas) in France.

2.1. Ecology of the species P. oceanica

P. oceanica meadows are almost present all around the Mediterranean from the coastline to 40 m deep excepted in straits and in the estuaries of major rivers (Blouet et al., 2011). Light and secondary salinity are the main natural factors influencing their distribution and density (Boudouresque et al., 2012). The plant consists of roots, leaves with a length of 20–80 cm and erect or creeping stems buried in the sediment called rhizomes (Boudouresque et al., 2012). Over time, the plant builds up a set of rhizomes, roots and sheaths in the sediment, which is called "matte" (Boudouresque et al., 2012). The leaves of *P. oceanica* have approximately a one year lifespan (Boudouresque et al., 2012). In the autumn, dead leaves break away from the rest of the plant and then become stranded on beaches where, by accumulation, they form the "banquettes" (Boudouresque et al., 2012).

The *P. oceanica* meadow is largely protected in EU (European Habitats Directive 1992 EU Regulation 1967/2006, Barcelona Convention (1976) amended in 1995 and the Bern Convention (1976) amended in 1996; Salomidi et al., 2012). Moreover, in France, *P. oceanica* is protected by legislations at national and regional level (e.g. articles in the National Town Planning Code, in the Environment Code and with local protections as "Coastal Act" or the prefectural Protection Biotope). Despite all these national and international protections, *P. oceanica* is on the IUCN Red List since November 2010 (Pergent et al., 2010) and studies show the decline of its meadows since the second half of 20th century: lost between 10% and 38% in areal extent in hundred years especially near urban areas (Thomas et al., 2005; Deter et al., 2013; Marbà et al., 2014). The origin of this regression is mainly coastline artificialization (Andromède, 2013). Because of a slow growth (3–4 cm/year; Meinesz and Lefèvre, 1984; Boudouresque et al., 2012), natural colonization and recolonization of *P. oceanica* is extremely low (Eliott et al., 2007). Restoration techniques by transplanting and seeding have been developed to compensate for seagrass species regression but with a mitigated success (Fonseca, 1992; Molenaar et Meinesz, 1995; Van Katwijk et al., 2009).

Recently, Vassallo et al. (2013) published an economic valuation of the seagrass *P. oceanica* with an emergy analysis. This thermodynamic based methodology used for the calculation of resources employed by nature (Vassallo et al., 2013) has been applied to the meadow located in the Marine Protected Area "Isola di Bergeggi" (Ligurian Sea, NW Mediterranean) and resulted in a value of 172 €/m^2/year, which is equivalent to 1.72 M€/ha/year (€ 2013).

2.2. The method of valuation used

The methodology we use is based on an exhaustive review of existing economic evaluations that we complete with evaluations made with transfer methods, or whenever possible we conduct our own field economic evaluations.

2.2.1. Identification of ecosystem services provided by P. oceanica

ES provided by *P. oceanica* are identified and evaluated according to the available literature. ES are then classified according to the Common International Classification of Ecosystem Services (CICES) V4.3 (2013), which is the latest classification of ES developed by The European Environment Agency, revised in January 2013 and recommended by the European Commission (2013).

2.2.2. Valuation of goods and benefits and their economic values

The list of GB is established from the list of ES, keeping in mind that some GB are equal to the ES they derive from. As regards the economic evaluation, three situations may occur depending on the ES and GB studied and on existing literature:

(i) The economic evaluation of one *P. oceanica*'s ES or GB already exists and is directly considered in our study after having checked the reliability of the work.
(ii) An existing study close to the desired economic assessment is used with a benefit transfer method (TEEB in Policy, 2010; David Suzuki Foundation and Nature Action Québec, 2013). In this situation, an adjustment is applied to each specific case depending on the ES and GB evaluated. Only studies published after 2000 are considered in order to minimize biases.
(iii) The evaluation is directly performed by applying an economic evaluation method. The different methods used are defined and detailed in TEEB in Policy (2010). Provisioning services like fishing externalities are evaluated using direct market prices. When market prices are not available, assessment are based on markets alternative such as the damage costs avoided or the production function (TEEB in Policy, 2010). The avoided damage costs are the costs humans do not have to bear thanks to the provided ES or GB (TEEB in Policy, 2010) and the production function measures how modifications of the environment can alter ES or GB provided by human. Situations encountered and methods used for each ES or GB predominantly depend on available literature and are detailed in the results.

The values for each GB are presented in euros (€) in 2014 per hectare per year. If necessary, an inflation factor is applied in order to update a value in the year 2014 following the website http://france-inflation.com/calculateur_inflation.php. The value in hectares is obtained from GB's value divided by the concerned seagrass area: 27,220 ha on the French Mediterranean (excluding Corsica) coast (Boudouresque, 2010 and confirmed by unpublished data from Andromède Océanologie), 58,022 ha along the Corsican coast (unpublished data from Andromède Océanologie) or $3.5 * 10^6$ ha for the total area covered by the species within the entire Mediterranean (Laffoley and Grimsditch, 2009). The annual value is the one of the available year or is determined by averaging the values of GB over several years. In all cases, values are evaluated in the socio-economic context of their evaluation and they should not be separated from their interpretations or have external evaluation uses.

2.2.3. Economic evaluation of the species P. oceanica

The last step is to estimate an economic value for the species *P. oceanica* considering the evaluation of all its ecosystem GB. To do this, the aggregation method is used (TEEB Foundations, 2010). This method consists of the sum of each value of GB estimated to reach a final total value. Note that the economic value estimated does not reflect the value of ecosystem functions or services itself but the GB provided (Mangos et al., 2010).

3. Results

The review of the available literature (250 scientific researches, papers or reports) puts forward 25 ecosystem services listed in Table 1. In total, our study estimates seven economic values (Table 1) of GB. The values and methods used are summarized in Table 2. Details concerning the calculations are described for each GB as follows:

3.1. Provisioning services

3.1.1. Use as material

The dead leaves of *P. oceanica* have been used since prehistoric times all around the Mediterranean (Boudouresque and Meinesz, 1982). There are several types of potential uses of the dead leaves: as building insulation (German Company, NeptuGmbH, www.compost.gr), as compost element in Tunisia (Kouki et al., 2012) and in Greece (Hellas Compost, www.neptugmbh.de/preise-fuer-neptutherm). Research on the use of dead leaves of *P. oceanica* highlights the possibility of using leaves as wastewater decontaminating elements such as: methylene blue (Cavas, 2011; Dural et al., 2011), methyl violet (Cengiz and Cavas, 2010), uranium (Aydin et al., 2012) or orthophosphate (Wahab et al., 2011). Nowadays, use of *P. oceanica* banquettes depends on each country's regulations. In France, use or action of the species, and thus of the banquettes, is prohibited or strictly controlled (Boudouresque et al., 2012). It is possible to obtain a derogation in order to clean the beaches for tourism and constitutes an important cost for coastal cities (Créocean and CSIL, 2011). In the Provence-Alpes-Cote d'Azur French region (South East of France), less than half of the removed dead leaves are put in landfills (Créocean and CSIL, 2011). Nevertheless, some of the removed dead leaves are valorised in the constitution of "miles leaves" or for the reunion of dunes (Créocean and CSIL, 2011). Considering all valuations and potential uses of *P. oceanica* banquettes, the cost of removing them should be repaid if derogation has been given. Consequently, we retain a value of 0 €/ha/year for the banquettes when used as material.

3.1.2. Use as bioindicator

Because of its high sensitivity to environmental alterations, *P. oceanica* is recognized as a good indicator of marine water quality and coastal system health (Pergent-Martini et al., 2005; MacArthur and Boland, 2006; Gera et al., 2012). As part of the objectives of the EU Water Framework Directive (WFD, 200/60/EC) for a good aquatic environment, the Annex 5 lists *P. oceanica* as indicator of coastal water quality in the Mediterranean. Moreover, thanks to its high capacity to accumulate heavy metals (in particular in its rhizomes where we can date different sections), *P. oceanica* is an interesting bioindicator that helps to know the concentration of heavy metals in an ecosystem but also to help retrace the historical variation (Catsiki et al., 1987; Giaccone et al., 1988; Pergent-Martini et al., 2005).

In France, the cost for coastal water monitoring using *P. oceanica* reaches 105,000 €/year (Boissery, unpublished data) and is mainly paid by the French Water Agency (80%), the remaining amount is to be paid by other organizations. The total annual funding in France (Corsica included) calculated by adding 20% is then $105{,}000 * 1.2 = 126{,}000$ €. The use of *P. oceanica* meadows as bioindicator in France in 2014 is thus estimated at 1.5 €/ha/year based on the cost/area ratio $(126{,}000/(27{,}000 + 62{,}350) = 1.5)$.

3.2. Regulation and maintenance services

3.2.1. Protection from coastal erosion

Mangos et al. (2010) assessed the value of the benefits associated with protection against coastal erosion from the Mediterranean marine ecosystems in which only the role of *P. oceanica* meadows is scientifically recognized (Hemminga and Duarte, 2000; Cantasano, 2009; Koch et al., 2009; Boudouresque

Table 1
Ecosystem services and valued goods and benefits of the species *Posidonia oceanica* classified according to CICES V4.3 Common International Classification of Ecosystem Services (Haines-Young and Potschin, 2013).

CICES V4.3[A]		Ecosystem services of *Posidonia oceanica* and the meadows that it forms[B]	Goods and benefits valued economically[C]
Sect ion	Division		
Provisioning	Materials	Dead leaves used as material: bioindicator, roof isolation, industrial water waste absorbents (methyl violet or blue)[b,c,h]	Use as material and use as bioindicator
		Use as food for farmed animals and compost[c,e,f]	Use as material
Regulation & maintenance	Mediation of waste, toxics and other nuisances	Water purification by filtration[a,c,e]	Wastewater treatment
		Sequestration of nutrients and contaminants by *P. oceanica*[a,c,e]	Wastewater treatment
		Sequestration of nutrients and contaminants by organisms living in and on the *P. oceanica* meadows and dead or alive organisms within the sediment trapped in the matte[e]	Wastewater treatment
		Decrease of the sound of waves thanks to *P. oceanica* banquettes and the meadows near the coastline[b,c]	X
	Media-tion of flows	Coastline erosion protection by *P. oceanica* banquettes[b,c,e,h]	Protection from coastal erosion
		Decrease of wave power and current in *P. oceanica beds* [a,b,c,e,h]	Protection from coastal erosion
	Maintenance of physical, chemical, biological conditions	Habitat for many species: living area, nursery, spawning ground, predators protection area, hunting area, source of food[a,b,e,h]	Fishery contribution
		Habitat for protected species[c,e,h]	X
		Limitation of invasive species invasion like *Caulerpa taxifolia* thanks to *P. oceanica*[g]	X
		Stabilization/consolidation of seabeds and/by sediments depositions: matte creation[a,b,c,h]	Protection from coastal erosion
		Increase of fauna diversity and micro-organisms and thus, increase of physico-chemico processes in the soil[a]	Wastewater treatment
		Water oxygenation[b,c,e]	Fishery contribution
		Nutrient cycling[a]	Wastewater treatment
		Carbon sinks and sequestration in the plants, the matte and the trapped sediments[b,c,d,e]	Carbone sequestration
Cultural	Physical and intellectual interactions	Visit of *P. oceanica* meadows: snorkelling and submarine vision boat[i,j]	X
		Fishing cuttlefish, angling in the *P. oceanica* meadows[j]	X
		Research subject[a]	Knowledge contribution
		Education opportunities[a]	X
		Cultural value and heritage[e]	X
		Artistic inspiration: theatre, painting, sculpture[a,e]	X
	Spiritual, symbolic other interac-tions	Emblematic species of the Mediterranean Sea[i]	X
		Enjoyment of wild and charismatic existing species[a]	X
		Willingness to preserve for future generation[e]	X

[A] Haines-Young and Potschin (2013). Groups, class and class type of CICES are not represented; neither all subdivisions are presented in the ES *P. oceanica* list.
[B] References of ecosystem services of *P. oceanica* and the meadows that it forms: (a) Barbier et al. (2011); (b) Boudouresque et al. (2012); (c) Borum et al. (2004); (d) Fourqurean et al. (2012); (e) Green and Short (2003); (f) Kouki et al. (2012); (g) Pergent et al. (2008); (h) Pergent et al. (2012); (i) Visiobulle (http://www.visiobulle.com/) pers. comm. and (j)Andromède Océanologie, expert judgement.
[C] Cases with an X represent ES not economically valued because of missing or inaccessible data.

Table 2
The 14 ecosystem services of *Posidonia oceanica* valued and their economic value.

Ecosystem services valued ranged depending on goods and benefits valued	Goods and benefits	Estimated values in €/ha/year (2014)		Year(s) of data sources	Methods used
		Min	Max		
Provisioning services					
Dead leaves used as material Use as food for farmed animals and compost	Use as material	0.00		–	Market prices
Dead leaves used as material	Use as bioindicator	1.5		2014	Market prices
Regulation and maintenance services					
Coastline erosion protection by *P. oceanica* banquettes Decrease of wave power and current in *P. oceanica* beds Stabilization/consolidation of sea beds and/by sediments depositions: matte creation	Protection from coastal erosion	188.0		2001	Damage cost avoided
Water purification by filtration Sequestration of nutrients and contaminants by *P. oceanica* Sequestration of nutrients and contaminants by organisms living in and on the *P. oceanica* meadows and dead or alive organisms within the sediment trapped in the matte Increase of fauna diversity and micro-organisms and thus increase of physico-chemical processes in the soil Nutrient recycling	Wastewater treatment	60.0		2005	Benefit transfer method
Carbon sinks and sequestration in the plants, the matte and the trapped sediments	Carbone sequestration	7.7	230.0	2014	Damage cost avoided
Water oxygenation Habitat for many species: living area, nursery, spawning ground, predators protection area, hunting area, source of food	Fishery contribution	27.0	35.0	2005 and 2010	Production function
Cultural services					
Research subject	Knowledge contribution	0.33		2001–2014	Market prices
	Total (rounded to the nearest unit)	284 28,500 21.2	514 51,500 43.9	€/ha/year €/km^2/year million €/year	

et al., 2012). This assessment is based on three *P. oceanica*'s ecosystem services: reducing the hydrodynamics of waves and current in the meadows (Chen et al., 2007; Pergent et al., 2012), formation of banquettes on the beach (Mateo et al., 2003; Simeone, 2008) and sediment accumulation and stabilization/consolidation by formation of the matte (Gacia et al., 1999; De Falco et al., 2000; Koch et al., 2009). Using data from 2001 and the damage cost avoided method, Mangos et al. (2010) estimated that the expenditure of European protection against erosion is approximately 160,000 € per protected kilometre with 3300 km protected in Mediterranean (Mangos et al., 2010). Thus the avoided damage cost related to the protection against erosion service provided by *P. oceanica* is valued at 151.4 €/ha/year from a 2001 data at the scale of the Mediterranean, and represents 188 €/ha/year in 2014 with the inflation.

3.2.2. Wastewater treatment

Domestic and industrial wastewaters discharged into the sea are one of the main sources of input of marine pollutants (UNEP/MAP, 2012). Quality of Mediterranean water, monitored by different monitoring networks, depends on our more or less good capacity/desire to treat wastewaters but also of the marine environment to buffer the remainder. In case of inadequate water quality, treatment should be improved by a retro-control effect. On the Mediterranean French coast (including Corsica), the total volume of domestic and industrial wastewater discharged in 2009 was 76.5 million of m^3 for a Mediterranean French coastal population of 5.5 million (French Water Agency, unpublished data).

In order to economically value this service, the amount of the environmental tax for the preservation of natural resources in France in 2009 is used: 0.19 €/m^3 (Agence de l'Eau Rhône Méditerranée et Corse, 2008). This price is valued as a substitute for protection expenditure (Mangos et al., 2010). Thus, in 2009, this tax had amounted to 14.5 million €.

In order to have an amount that will only encompass the wastewater treatment service performed by the coastal system, a ratio of 1/3 is applied (Costanza et al, 1997). Indeed, Costanza et al. assumed that one third of nutrient recycling is done by estuaries, one third by the coastal system and the rest by open oceans. Moreover, because of its importance in the Mediterranean ocean ecosystem, we consider the part performed by the coastal system as being the representative part of *P. oceanica* meadows. So the calculation is: $(76.5 * 10^6) * 0.19 * (1/3) = 4.8 * 10^6$ €/year.

Using the French *P. oceanica*'s area (Corsica including) and the inflation, we obtain a value of the contribution of *P. oceanica* to wastewater treatment of 60 €/ha/year in 2014.

3.2.3. Carbone sequestration and storage

Ecosystems formed by seagrass beds are considered as the largest ocean carbon sinks in the world (Nellemann et al., 2009). When it is not destroyed, *P. oceanica* is an exceptionally effective long-term carbon sink thanks to its significant low input and loss rate (Pergent et al., 2012). This is an important service for the Mediterranean Sea and the Mediterranean countries (Laffoley and Grimsditch, 2009; MacCord and Mateo, 2010). In this study, we choose to consider only long-term sequestration formed by *P. oceanica* (plant and matte) because it forms a carbon stock with a residence time of 4–6 to thousand years (Pergent et al., 2012). The rate of carbon sequestration in the long-term performed by *P. oceanica* is estimated between 6 and 175 g C/m^2/year (which represents 10–25% of the net primary production of *P. oceanica* (Pergent et al. 2012)) which is 0.06–1.75 in *t* C/ha/year and then 0.22–6.56 *t* CO_2/ha/year with 1 C *t* = 3.67 *t* CO_2 (Trumper et al., 2009). The price per ton of CO_2 varies from US $ 1 to US $ 100

(MacCord and Mateo, 2010), but according to the recommendations of the French Centre for Strategic Analysis (CAS) we took the value of 32 € per ton in 2008 (CAS, 2009a,b), or 35 €/*t* in 2014 taking the inflation into account. So, GB provided by long-term sequestration of carbon achieved by *P. oceanica* in 2014 are thus estimated between 7.7 and 230 €/ha/year.

3.2.4. Fishery improvement contribution

Water oxygenation is an important function in a marine ecosystem (Chen et al., 2012). It allows breathing for living marine organisms and allows men to enjoy the marine environment through food resources with fishing for example. *P. oceanica* meadows produce at 10 m depth more than 14 litres of oxygen per day per m^2 (Bay, 1978). The service derived from the oxygenation function is not directly used by men because the oxygen is released in the water and is thus indirectly important through fishing. In order to avoid any double counting, we evaluate the oxygenation function though the contribution of seagrass to fishery.

In 2010, the Auction of Sète (the most important in French Mediterranean) harvested more than 4000 tons of fish on the French Mediterranean coasts (excluding the Corsican coasts) and sold them all for some 14.7 million € (Mélanie Chadourne, Auction of Sète, Pers. Comm.). *P. oceanica* covers 27,220 ha of this fishing area. According to the available literature, we listed 51 aquatic species that will be at least once in their lives in *P. oceanica* meadows. We compared this list to the list of species sold at the Auction of Sète in 2010 (Mélanie Chadourne, Auction of Sète, Pers. Comm.), and identified 16 species sold and associated with *P. oceanica* seagrass: *Atherina*, *Boops boops*, *Conger conger, Diplodus annularisor, Labrus tinca*, *Diplodus cervinus*, *Diplodus Sargus*, *Gobius* sp., *Mullus surmuletus*, *Oblada melamura*, *Pagrus pagrus*, *Paracentrotus lividus*, *Sarpa salpa*, *Scorpaena* sp., *Sepia officinalis*, *Spicara* sp. and *Symphodus occelatus* (Boudouresque, 2010; Guidetti et al., 1998). Prices used are auction selling prices of 2010, so a little bit more important than the purchase price for fishermen. For these species, the quantities fished (242,551 kg) multiplied by the area of *P. oceanica* meadows which is included in the fishing area (27,220 ha) and multiplied by the selling price per quantities (which depend on the fish species) in 2010 at the Auction of Sète give the value of 32.85 €/ha in 2010 to the contribution of *P. oceanica* meadows in the production of fishery resources. With the inflation, we obtain a value of 35 €/ha in 2014.

Mangos et al. (2010) estimated the value of benefits related to the natural resources provided by marine ecosystems in the Mediterranean Sea, including *P. oceanica* meadows, with data from 2005. Considering only the behaviour of adult fish, they found that 3% of total catches in the Mediterranean are related to *P. oceanica* meadows (Mangos et al., 2010); it corresponds to 2379 €/km^2 of *P. oceanica* meadows area in 2005 and thus 27 €/ha/year in 2014 with the inflation. The first approach is more complete as regards the relationship between species and seagrass than the second approach which only takes the behaviour of adult stages into account. The contribution of *P. oceanica* meadows to fishery resources ranges thus between 27 and 35 €/ha/year.

3.3. Cultural services

3.3.1. Knowledge contribution

P. oceanica has been analysed in many studies for its quality of bioindicator through its sensitivity or its absorption capacity. More generally, these studies allow a better understanding of physiognomy, physiology and stress suffered by aquatic plants in case of modification of their environment. Thus this species contributes to the general human knowledge. According to Dirhamsyah (2007) and Pugh and Skinner (2002), the value of the knowledge contribution can be estimated through the cost of research projects. LIFE is the EU's financial instrument supporting environmental and nature conservation projects throughout the EU. Since 1992, LIFE has co-financed 4000 projects, contributing approximately 3.1 billion € to the protection of the environment. We focus on LIFE programmes because contrary to national projects, data concern a European level (approximately the same global socio-economic context), are complete and available on the European Commission website.

Six LIFE programmes concerning *P. oceanica* have been funded between 2001 and 2014. The period of programmes implementation is limited to the data available on the website of the European Commission (http://ec.europa.eu/environment/life/project/Projects/). The average annual funding is estimated to 0.33 €/ha/year between 2001 and 2014 in the European Union.

Table 3
Ecosystem services of *Posidonia oceanica* unvalued and suggestions of methods to make an economical valuation.

Ecosystem services unvalued ranged depending on goods and benefits valued	Suggestion for economic valuation
Regulation and maintenance services	
Tourism's contribution: water purification, sequestration of nutrients and contaminants and coastline erosion protection	Study of the impact on tourism of the presence of the species *P. oceanica*
Decrease of the sound of waves thanks to *P. oceanica* banquettes and the meadows near the coastline	Sound comparative study between tracks with or without seagrass and economic evaluation of willingness to pay for this service
Habitat for protected species	Stated preferences methods
Limitation of invasive species invasion like *Caulerpa taxifolia* thanks to *P. oceanica*	Study of the limitation of the invasion of invasive species based on the presence of seagrass and review of actions taken against invasive species
Cultural services	
Visit of *P. oceanica* meadows: snorkelling and submarine vision boat	Production function or travel cost method
Fishing cuttlefish, angling in the *P. oceanica* meadows	
Education opportunities	Stated preferences methods (contingent valuation method or choice modeling)
Cultural value and heritage	
Artistic inspiration: theatre, painting, sculpture	
Emblematic species of the Mediterranean Sea	
Enjoyment of wild and charismatic species existing	
Willingness to preserve for future generation	

3.4. Unevaluated ES

Eleven among 25 ES are not economically evaluated; they are presented in Table 1 by an "X" in GB's column and in Table 3 with a suggestion of method to make an economical valuation of them. The main reason of this incompleteness is the lack of available data. Among the eleven unevaluated ES, eight concern cultural services. Indeed, only one of the nine identified cultural ES is included within the economic assessment of this study, while cultural services are an important part of the ES (MEA, 2005).

Because of the particular importance of tourism in the Mediterranean, we make here a point of the data we have for this contribution even when they are still insufficient for a real valuation. The Mediterranean is one of the main touristic destinations in the world (Rais, 2008). In 2011, the Mediterranean coast attracted 283 million international tourists, nearly 30% of the global tourism, while international tourism generated the same year revenue of $224 billion in the Mediterranean (Bourse, 2012). The value of coastal tourism in France was estimated to be 4 billion € in 2005 (Mangos et al., 2010). The tourism contribution of seagrass is recognized by its coastline stabilization and then touristic beach maintenance but also through the maintenance of water quality (thanks to the wastewater contribution and decrease of current and wave power which allows a decrease of water turbidity (Rais, 2008)). Indeed, *P. oceanica* meadows contribute to tourism through a large number of ES. Purification of seawater and sequestration of nutrients and contaminants by the species and the meadow that its forms, lead to better quality and clarity of sea water, which is important for seaside activities (Boudouresque et al., 2012; Virot, 2012). Moreover, all services that contribute to coastal protection against erosion generate financial gains for investments on the coast and contribute to the durability of beaches for tourists. However, while *P. oceanica* meadows are important for tourism economy, tourist's impacts are mostly negative on the *P. oceanica* meadows (Boudouresque et al., 2009). Indeed, the development of infrastructures for tourism such as artificial beaches and marinas are one of the causes of *P. oceanica* decline and disappearance (Ruiz, 2009; Marbà et al., 2014).

3.5. Total economic evaluation of the species P. oceanica

The economic value estimated for the contribution of *P. oceanica* to human well-being ranges between 284 and 514 €/ha/year (Table 2, rounded to the nearest unit) which equates to 28,500 and 51,500 €/km^2/year and to a value comprised between 21.2 million and 43.9 million €/year for the species. The data and values used for the evaluation date from 2001 to 2014. This value includes 14 out of 25 ecosystem services.

This value makes possible to quantify the economic loss caused by *P. Oceanica's* regression. Taking into account that the area of *P. oceanica* decreased by 10% over the last 100 years (Thomas et al., 2005; Boudouresque et al., 2012) and that its current total surface is $3.5 * 10^6$ ha (Laffoley and Grimsditch, 2009), the loss of *P. oceanica* meadows over the last century is $389 * 10^3$ ha. With our result, this reduction means an annual loss for the Mediterranean countries of $1.11–2.00 * 10^6$ € in the benefits deriving from the *P. oceanica* ecosystem that people enjoy. In France, this decrease has caused and goes on causing an annual loss of $27–49 * 10^3$ €.

4. Discussion

4.1. The importance of ecosystem services provided by P. oceanica meadows

Marine ecosystems contribute to human well-being in a various number of ES (Barbier, 2011; Barbier et al., 2011). Local populations and economies of littoral countries are dependent from the ES provided by marine ecosystems. Thus, monitoring and protection are important to maintain the ES provided and decrease the current deterioration of marine ecosystems (MEA, 2005). For those purposes, a continuous improvement of knowledge concerning the different marine ecosystems is essential.

This study identifies the totality of the 25 ES provided by *P. oceanica* meadows presented in Table 1. This high number of ES reported highlights the diversity of *P. oceanica*'s contribution, confirms the importance of *P. oceanica* to human well-being and its major role in the Mediterranean Sea. For the sole service of carbon sequestration, the *P. oceanica* meadows sequester on the long-term a quantity superior to twice the global average of seagrass sequestration (83 g C/m^2/year) and up to some 70 times the rate of tropical forests (2.3–2.5 g C/m^2/year) (Laffoley and Grimsditch, 2009). Of course, these values should be nuanced depending on the plant maturity and health condition: for example a sick plant provides less ES than a healthy one. Moreover, when *P. oceanica* is destroyed, ES stop being provided and counter-effects are even observed such as the release of the captured carbon dioxide. Indeed, when the meadow is destroyed, the "matte" is no longer protected from erosion: the carbon stored during millennia returns into the environment and contributes to climate change (Pergent et al., 2014).

4.2. Bias and limits in economic values of goods and benefits valued

Because of a lack of available data, only seven GB are evaluated. These non-evaluated ES mainly concern cultural services as well as contribution to tourism (Tables 1 and 2). In addition to the non-evaluation of some ES or GB, each evaluated GB includes biases and limitations. Because of a lack of available and/or accessible data, it is impossible to entirely valuate each GB and these results are thus mostly under-evaluated. Another bias is that for several evaluated GB like fishery contribution, valuation extracted from studies were conducted at different geographical scales in order to avoid missing data.

4.3. Economic evaluation approaches

We use a preference-based approach limited to use values. It is the most common and known approach to evaluate ES (TEEB synthesis, 2010). Our approach is rather similar to that used by Mangos et al. (2010) following the lead of Costanza et al. (1997). Vassallo et al. (2013) used a thermodynamic approach based on an emergy analysis considering two key concepts: solar emergy itself and solar transformity. Emergy is a supply side approach, valuing ES 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). Using the ES cascade presented by Potschin and Haines-Young (2011), a thermodynamic approach evaluates the biophysical structure, process or function of the environment while we evaluate GB in the social and economic system.

Nevertheless, none of the available approaches or methods is perfect or universally recognized, so it is of real importance to compare results (at least the order of magnitude) obtained with different methods.

4.4. Economic evaluation of P. oceanica seagrass beds

The economic value of *P. oceanica* seagrass and the meadow it forms is estimated between 284 and 514 €/ha/year, or 28 500 and 51 500 €/km^2/year based on data from 2001 to 2014.

4.4.1. An underestimated value?

Vassallo et al. (2013) valuated the main ES provided by *P. oceanica* to 172 €/m^2/year, which is equivalent to 1.72 M€/ha/year (€ 2013). This value differs from our result by a magnitude of $4 * 10^3$. Even if these values are both economic valuations of the ecosystem services provided by *P. oceanica*, the methods used are different. But we can see that 99% of the value of Vassallo et al. (2013) comes up from the sediment retention services while the most part of our value (47%) is made up (taking means of each GB value) by the equivalent GB "protection from coastal erosion" deriving from three ES: "coastline erosion protection by *P. oceanica* banquettes", "decrease of wave power and current in *P. oceanica* beds" and "stabilization/consolidation of sea beds and/by sediments depositions: matte creation".

Costanza et al. in 1997 estimated at USD 19,004/ha/year (USD 1994) the services provided by global seagrass and

22,500 €/ha/year with inflation (http://www.dollartimes.com/calculators/inflation.htm) and the Euro-Dollar exchange rate (http://www.x-rates.com/). This value is much higher (a hundred times) than our estimate. This can be explained by an underestimation in our study (11 out of 25 ES are not evaluated) but also by a difference in evaluated services, the use of different economical evaluation methods, a different socio-economic context and a different scale. Indeed, Costanza et al. considered all global seagrass and not a single species like in our study. In addition, they consider only five ES and two are economically evaluated (nutrient cycling and raw materials) with one (nutrient cycling) evaluated by a replacement cost method and representing 99.9% of the final value. We partially evaluate this service through the GB associated to wastewater purification using a different method: a transfer method with adjustment, following a more recent study (Mangos et al., 2010) and with the same localization as our study (Mediterranean Sea). The comparison between studies with different economic valuations allows noting divergence in the order of magnitude and so standing back from our final result. The final value (28,500 and 51,500 €/km^2/year based on data from 2001 to 2014) was estimated with the method of aggregation which is the summation of all the economically evaluated values. The aggregation of all ES's values provides a partial estimation of the total economic value stream that a species can provide to men (Molnar, 2012). In addition, the method of aggregation leads to sum values evaluated with a variety of methods (CAS 2009a). In view of the overall underestimation, it is advisable to take the values of contributions of *P. oceanica* separately and not to separate them from the socio-economic context of their assessment as well as from the year of the data used.

4.4.2. The consequence of *P. oceanica* regression

Considering our result, the decline of *P. oceanica* that occurred during the last hundred years represents a loss ranging between 1.11 and $2.00 * 10^6$ € every year in the contribution to man and his well-being. In addition of this annual economic loss, the destruction of *P. oceanica* caused a long-term decline of some ES usually provided, like the release of carbon, heavy metals and sediments sequestered until destruction in the "matte".

This value should be expected to increase more and more because even if recent improvements in restoration techniques improve the success rate of recolonization (Boissery, 2014) restoration does not permit to replace destroyed meadows or provide the same ES. Indeed, the destruction of *P. oceanica* meadows is considered as irreversible on human-life time scales (Montefalcone et al., 2007).

In France, *P. oceanica* meadows are monitored for an average cost of 100,000 €/year (Boissery, unpublished data). In addition, measures are undertaken against damages caused by mooring: 4.7 million € are invested in these actions (organized mooring, awareness campaigns, etc.) each year (Boissery, unpublished data). Thus, in France, the cost of monitoring and protection of *P. oceanica* meadows (4.8 million €/year) only represents approximately 0.11–0.23% of the value of ES provided by it.

5. Conclusion

Our goal was to estimate the economic value of *P. oceanica* seagrass and the meadow that it forms. This objective is partly achieved because our estimation is an underestimate of the total contribution of *P. oceanica* to human well-being. However, these results are a first estimation obtained by a preferences-based approach of its economic value in France. It thus gives a rough estimate of *P. oceanica's* economic value and it avoids considering its total contribution to human well-being as zero. We also highlight the irreversible economic loss deriving from *P. oceanica's* destruction which increases every year, and the inadequate investment set up to preserve this natural resource. Further studies should be performed with priority being given to assessing the contribution to tourism. Indeed, we consider the non-assessment of contribution to tourism as the largest source of underestimation of our valuation.

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