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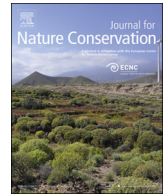
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## Assessing, quantifying and valuing the ecosystem services of coastal lagoons



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### ABSTRACT

The natural conservation of coastal lagoons is important not only for their ecological importance, but also because of the valuable ecosystem services they provide for human welfare and wellbeing. Coastal lagoons are shallow semi-enclosed systems that support important habitats such as wetlands, mangroves, salt-marshes and seagrass meadows, as well as a rich biodiversity. Coastal lagoons are also complex social-ecological systems with ecosystem services that provide livelihoods, wellbeing and welfare to humans. This study assessed, quantified and valued the ecosystem services of 32 coastal lagoons. The main findings of the study are: (i) the definitions of ecosystem services are still not generally accepted; (ii) the quantification of ecosystem services is made in many different ways, using different units; (iii) the evaluation in monetary terms of some ecosystem service is problematic, often relying on non-monetary evaluation methods; (iv) when ecosystem services are valued in monetary terms, this may represent very different human benefits; and, (v) different aspects of climate change, including increasing temperature, sea-level rise and changes in rainfall patterns threaten the valuable ecosystem services of coastal lagoons.

### 1. Introduction

Coastal lagoons occur along 13% of the coastlines of all continents (Barnes, 1980). These areas are important for many biogeochemical processes (Sousa, Lillebø, Gooch, Soares, & Alves, 2013) and they are known for their high productivity. These shallow water bodies support important habitats such as wetlands, mangroves, salt-marshes and seagrass meadows (Basset, Elliott, West, & Wilson, 2013). This typical, mosaic landscape provides support for a rich biodiversity, including vital habitats for bivalves, crustaceans, fish and birds. They provide a physical *refugium* from predation and are used as nursery and feeding areas for some endangered species (Franco et al., 2006). Coastal lagoons are also characterized by harbouring a large part of the human population that may depend directly on these ecosystems (Willaert, 2014). However, these are one of the most threatened ecosystems in the world. Habitat destruction, pollution, water withdrawal, over-exploitation and invasive species are the main causes of their degradation (MA - Millennium Ecosystem Assessment, 2005; Barbier, Acreman, & Knowler, 1997). Coastal lagoons are sentinel systems that are very vulnerable to potential impacts associated with climate change (Eisenreich, 2005), particularly, as these systems have a key role in regulating the fluxes of water, nutrients and organisms between land, rivers and the ocean (Brito, Newton, Tett, & Fernandes, 2010; Newton et al., 2014). Sea level rise, increased temperature and changes in precipitation patterns would affect flushing rates, salinity, dissolved oxygen concentration, and biogeochemical properties. These changes could alter the composition and diversity of natural communities, as well as their sensitivity to eutrophication (Anthony et al., 2009), and their capabilities to support goods and services (Cossarini et al. 2008;

Melaku Canu et al. 2011).

Lagoons deliver ecosystem goods and services that provide not only livelihoods but also numerous benefits to human health and welfare, which makes them complex social-ecological systems (Newton et al., 2014). The main services provided by coastal systems include food provisioning (mainly fish and shellfish), freshwater storage, hydrological balance, climate regulation, flood protection, water purification, oxygen production, fertility, recreation and ecotourism (Solidoro, Bandelj et al., 2010; Solidoro, Cossarini, Libralalto, & Salon, 2010; Barbier, 2012; Lopes & Videira, 2013). Coastal lagoon ecosystems also support a wide range of human activities, including economic sectors such as fisheries and aquaculture, as well as leisure and tourism (Newton et al., 2014). Therefore, these ecosystem goods and services are not only economically valuable but they also have societal, aesthetic and heritage value due to their contribution to improvements in mental and psychological health (Sandifer, Sutton-Grier, & Ward, 2015). The conservation of coastal lagoons is therefore relevant for their ecological importance, along with the valuable ecosystem services (ES) they provide for human welfare. Holistic management involving economists, ecologists, and environmental scientists that assesses the services of these social-ecological systems is thus required (Barbier et al., 2011; Carpenter et al., 2009; Turner & Daily, 2008).

The discussion about ecosystem services and their categories (De Groot, Wilson, & Boumans, 2002; Costanza, 2008) has been ongoing for more than 20 years, and despite recent efforts, there is no consistent definition or classification. The Millennium Ecosystem Assessment (MA - Millennium Ecosystem Assessment, 2005) was the booster in providing a globally recognized classification for ecosystem services consisting of “*the functions and products of ecosystems that benefit humans, or*

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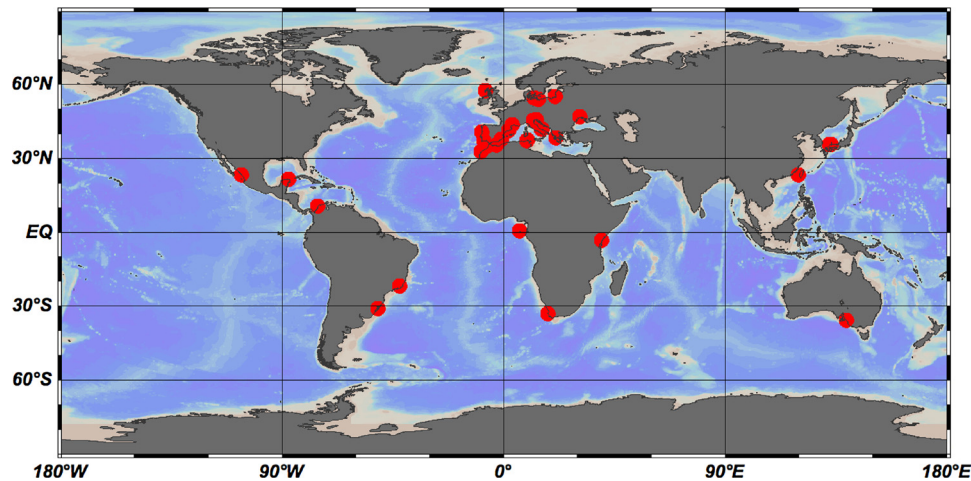


Fig. 1. Geographic location of all the coastal lagoons considered in this study.

yield welfare to society". Nevertheless, the simplicity of this concept can be prone to misinterpretations and lack of consistency across different users. The Economics of Ecosystems and Biodiversity project (TEEB, 2010) was based on the MA and provided an updated classification, which clearly distinguishes services from benefits. Ecosystem services are defined by TEEB as "the direct and indirect contributions of ecosystems to human well-being", and it is explicit that services can benefit people in multiple and indirect ways (e.g. food provisioning service have multiple benefits including health, pleasure and sometimes even cultural identity). The Common International Classification of Ecosystem Services (CICES) attempted to be more comprehensive than the MA and TEEB classification and is tailored to environmental and economic accounting. This classification defines ecosystem services as "the contributions that ecosystems make to human well-being, and arise from the interaction of biotic and abiotic processes", separating services from ecological phenomena (Haines-Young & Potschin, 2013). CICES focuses on final services or products from ecological systems that people directly consume or use; the welfare gains they generate are classified as benefits.

This issue is particularly important in the case of biodiversity conservation, where effective management towards sustainable development relies on an accurate and widely accepted definition of ecosystem services (Boyd & Banzhaf, 2007; Egoh et al., 2007; Fisher, Turner, & Morling, 2009). Thus, a well-defined unit of services enables their identification, mapping and measurement across different ecosystems, allowing the integration and comparison of different data sources. This assessment of the state of ecosystems and their services at all geographic levels forms the basis for improved environmental policies (Lele, Springate-Baginski, Lakerveld, Deb, & Dash, 2013), e.g. the EU Biodiversity Strategy, that aims to counter the trend of biodiversity loss and ecosystem services degradation. Natural resource decisions are usually based on values humans place on ecosystems and the benefits they provide (Daily et al., 2009; Ingram, Redford, & Watson, 2012). The monetary valuation of ecosystem services allows the translation of their ecological importance into monetary terms to be perceptible for all stakeholders. The economic value is therefore a measure of the well-being provided by the consumption of goods or services, and can be assessed by market and non-market valuation techniques. Although this wide range of valuation methods are very useful for ecosystems' management and decision-making processes, coastal lagoons are under-represented across valuation studies (Barbier et al., 2011). A report by the European Commission (EC, 2017) underlines the importance of correct accounting and valuation of ecosystem services.

The aim of this study is to give an overview of the existing knowledge and gaps about the ecosystem services from coastal lagoons. The objectives are to assess, quantify and value the ecosystem services of

coastal lagoons at a global level, to provide and share this information among coastal lagoon scientists in a common framework that could support further, more detailed studies.

Four research questions have been addressed:

- 1) **Assessment:** What are the ecosystem services that are provided by coastal lagoons?
- 2) **Quantification:** What are the quantities of the ecosystem services that are provided by coastal lagoons?
- 3) **Evaluation:** What is the value of the ecosystem services that are provided by coastal lagoons?
- 4) **Climate change:** How will climate change affect the ecosystem services that are provided by coastal lagoons?

## 2. Methodological approach

### 2.1. Location of coastal lagoons in the study

Thirty two coastal lagoons were included in this study, located in five different continents: America, Europe, Africa, Oceania and Asia. The global distribution of the coastal lagoons included in this study is presented in Fig. 1. The names, coordinates and basic data are given in Table 1.

### 2.2. Historical context

The community of coastal lagoon scientists started to coalesce in the last two decades of the 20th Century. Previously, coastal lagoon scientists had been included in groups such as the Estuarine Research Federation. However, coastal lagoons were never a central topic to these groups. Another factor was the wide range of names applied to coastal lagoons (Newton et al., 2014) that made searching the literature difficult. Even countries with many coastal lagoons, such as Portugal and Italy, had different terms. The European Water Framework Directive (WFD) used the term 'transitional waters' that included some estuarine coastal lagoons, but not all coastal lagoons fit the salinity condition.

The Italian community of scientists started to coalesce into a network called Lagunet that held meetings and small conferences. This promoted the formation of other national networks in France, Greece, Spain, Portugal, North Africa, Baltic countries and, finally, the formation of EuroMegLag, an international network of coastal lagoon scientists, (<http://www.euromedlag.eu/>). The community now holds conferences every two years and invites coastal lagoon scientists from all over the world to participate.

**Table 1**  
Location and characteristics of the 32 coastal lagoons in the survey.

Name of coastal lagoon	Adjacent sea/ Ocean	Continent and Country (ies)	Type of Lagoon	Coordinates	Area with permanent water (km <sup>2</sup> )	Wetland (km <sup>2</sup> )	Mean depth (m)	Salinity range	Climate	Population (within 50 km)	GDP per capita* (Euro)	References
Bizerte Lagoon	Mediterranean Sea	Africa (N), Tunisia	choked	Lat: 37.183°N Lon: 9.850°E	128		7	33.3-36.1	Semi-arid	445072	3770.5	Sakka Hlaili, Grami, Hadi Mabrouk, Gosselin and Hamel (2007), Boukef et al. (2010), Fertouna Bellakhal, Dhib, Béjaoui, Turki and Aleya (2014), Béjaoui, Harzallah, Moussa, Chapelle and Solidoro (2008), Béjaoui et al. (2016)
Cal Tet	Mediterranean Sea	Europe (S), Spain	choked	Lat: 41.302°N Lon: 2.122°E	0.13			2-3	Temperate	3239337	40100	Cañedo-Argüelles and Rieradevall (2011), Roselli et al. (2013)
Cartagena Bay	Caribbean Sea	South America, Colombia	N.A.	Lat: 10.335°N Lon: 75.527°W	84		16	0-37	Equatorial	1 000 000	6000	UNEP – United Nations Environment Programme (1999), Lonin, Parra, Andrade and Yves-Francois (2004), Cardique (2006), Restrepo, Zapata, Diaz, Garzón-Ferreira and Garcia (2006), DANE-Departamento Administrativo (2016)
Coorong	Southern Ocean	Australia	Choked	Lat: 35.933°S Lon: 139.30°E	140	490	2		Temperate	30000	33000	Rolf and Dyack (2010), Rolf and Dyack (2011), Clara et al. (2017)
Curonian Lagoon	Baltic Sea	Europe (E), Lithuania/Russia	restricted	Lat: 55.00°N Lon: 21.00°E	1600	1000	3.6		Temperate	800000	12000	Breber, Povilanskas and Armaitienė (2008), Povilanskas, Armaitienė, Breber, Razinkovas-Baziukas and Taminskas (2012), Taminskas, Pileckas, Šimanauskienė and Linkevičienė (2012), Povilanskas, Razinkovas-Baziukas and Jurkus (2014)
Dars-Zingst Bodden	Baltic Sea	Europe (C), Germany	restricted	Lat: 54.383°N Lon: 12.616°E	197		2	0.5-14	Temperate	105500	22800	Winkler (2001), Schiewer (2008), Kruse et al. (2015)
Estero de Urías	Pacific Ocean	North America, Mexico	choked	Lat: 23.193°N Lon: 106.36°W	18		2-12	25.8-38.4	Subtropical	502547	8199.1	Paez-Osuna, Montano-Ley and Bojorquez-Levya (1990), Cardoso-Mohedano et al. (2015a), Cardoso-Mohedano et al. (2015b), Ruiz-Fernández et al. (2016), Ruiz-Fernández et al. (2016), Souchu et al. (1998), La Jeunesse and Elliott (2004), Mongruel et al. (2013), Loiseau, Roux, Junqua, Maurel and Bellon-Maurel (2014), La Jeunesse et al. (2015), La Jeunesse et al. (2016)
Etang de Thau	Mediterranean Sea	Europe (S), France	restricted	Lat: 43.40°N Lon: 3.612°E	75	7	4	28-42	Temperate	110000	23566	Ben Rejeb-Jenhani (1989), Tamisier and Boudouresque (1994), Chaouachi and Ben Hassine (1998), Sated and Elloumi (2007), Trabelsi et al. (2012)
Ichkeul Lake	Mediterranean Sea	Africa (N), Tunisia	choked	Lat: 37.167°N Lon: 9.667°E	155 /78	110	1	5-50	Semi arid	539713	3770.5	
Lagoa de Aratuama	South Atlantic	South America, Brazil	choked	Lat: 22.0°S Lon: 42.0°W	210		3	52	Semi arid	200-500 000		

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Table 1 (continued)

Name of coastal lagoon	Adjacent sea/ Ocean	Continent and Country (ies)	Type of Lagoon	Coordinates	Area with permanent water (km <sup>2</sup> )	Wetland (km <sup>2</sup> )	Mean depth (m)	Salinity range	Climate	Population (within 50 km)	GDP per capita* (Euro)	References
Lagoa dos Patos	South Atlantic	South America, Brazil	choked	Lat: 31.0S Lon: 51.0°W	10200		5	1-31	Temperate	4 500 000		Kjerfve, Schettini, Knoppers, Lessa and Ferreira (1996), Knopper and Kjerfve (1999), Braga, Vianna and Kjerfve (2003), Souza, Kjerfve, Knoppers, de Souza and Damasceno (2003), Kjerfve and Oliveira (2004) Philomena (1994), Knoppers and Kjerfve (1999), Kjerfve and Knoppers (1999), Odebrecht et al. (2005), Fujita and Odebrecht (2007) Y,
Lake Nakautomi	Sea of Japan	Asia (E), Japan	choked	Lat: 35.452°N Lon: 133.191°E	86.2		5.4	14-30	Temperate	472817	27753	Nakata, Horiguchi and Yamamuro (2000), Yamamuro, Hiratsuka, Ishitobi, Hosokawa and Nakamura (2006), Ishitobi, Kamiya and Yamamuro (2014), Katsuki et al. (2008)
Lake Shinji	Sea of Japan	Asia (E), Japan	lchoked	Lat: 35.450°N Lon: 132.783°E	79.25		4.5	> 3.5	Temperate	476967	28020	Yamamuro et al. (2000), Nakata et al. (2000), Yamamuro et al. (2006), Ishitobi et al. (2014)
Langebaan Lagoon	Atlantic Ocean	Africa (S), South Africa	choked	Lat: 33.153°S Lon: 18.063°E	41.1		4	34.5-35	Temperate	80500	5206	Day (1959), Kerwath et al. (2009), Nel and Branch (2014), AEC (2015),
Lesina lagoon	Mediterranean Sea	Europe (S), Italy	restricted	Lat: 41.90°N Lon: 15.417°E	55		0.7	11-32	Temperate	250000	16000	Turpie, Forsythe and Letley (2017) Manini, Breber, D'Adamo, Spagnoli and Danovaro (2002a), Manini, Breber, D'Adamo, Spagnoli and Danovaro (2005), Roselli et al. (2013), Ferrarin et al. (2010), Cuvata and Di Matteo (2016)
Loch Bi	Atlantic	Europe, Scotland		Lat: 57.372°N Lon: 7.372°W	7.035		< 2	1.68-22.1	Temperate	4703	11919.7	Angus (2017)
Malanza Lagoon	Atlantic	Africa (W), São Tomé and Príncipe	choked	Lat: 0.457°N Lon: 6.531°E	0.69	2	1-1.5	0-25	Tropical	170000	3015.3	Pisoni et al. (2015), de Lima et al. (2016), Félix et al. (2017)
Mar Menor	Mediterranean Sea	Europe (S), Spain	restricted	Lat: 37.770°N Lon: 0.786°W	135		3.6	38-51	Temperate	755666	18929	Brito, Silva, Beltrán, Chainho and de Lima (2017), Pérez-Ruzafa, Marcos and Gilabert (2005), De Pascalis, Pérez-Ruzafa, Gilabert, Marcos and Ungiesser (2012), Maynou, Martínez-Banos, Deimestre and Franquesa (2014), Marcos, Torres, López-Capel and Pérez-Ruzafa (2015), Velasco, Pérez-Ruzafa, Martínez-Paz and Marcos (2017)

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Table 1 (continued)

Name of coastal lagoon	Adjacent sea/ Ocean	Continent and Country (ies)	Type of Lagoon	Coordinates	Area with permanent water (km <sup>2</sup> )	Wetland (km <sup>2</sup> )	Mean depth (m)	Salinity range	Climate	Population (within 50 km)	GDP per capita* (Euro)	References
Marano and Grado	Adriatic Sea, Mediterranean Sea			Lat: 45.708°N Lon: 13.352°E								Ferrarin et al. (2010), Bettoso, Acquavita, D'Aletti and Mattassi (2013), Acquavita et al. (2015), Canu, Rosati, Solidoro, Heimbürger and Acquavita (2015), Canu and Rosati (2017)
Messolonghi Central Lagoon	Patraikos Gulf / Mediterranean	Europe (SE), Greece	leaky	Lat: 38.351°N Lon: 21.340°E	285/149.4		1.2	17.3–48.5	Temperate	209029	9300	Katselis, Koutsikopoulos, Dimitriou and Rogdaki (2003), Katselis, Koukou, Dimitriou and Koutsikopoulos (2007), Cabana, Nicolaidou, Sigala and Reizopoulou (2017)
Moulay Bouselham	Atlantic	Africa (NW), Morocco		Lat: 34.846°N Lon: 6.276°W					Temperate			Birks, Birks, Flower, Peglar and Ramdani (2001), Labbardi, Ettahiri, Lazar, Massik and El Antri (2005), Ayache et al. (2009), Thompson and Flower (2009), Maanan et al. (2013), Maanan et al. (2015a)
Nador	Mediterranean Sea	Africa (N), Morocco	leaky	Lat: 35.166°N Lon: 2.856°W	115		4.8	32.7–40.2	Temperate	248418	9500	
Oualidia	Atlantic	Africa (N), Morocco	choked	Lat: 32.7445°N Lon: 9.03°W	10/3.5		2	22.5–35.9	Semi-Arid	18616	4500	Zourarah et al. (2007), Maanan (2008), Maanan et al. (2014), El Asri, Zidane, Maanan, Tamsouri and Errhif (2015), Maanan et al. (2015b)
Qigu lagoon	South China Sea	Asia (E), Taiwan (W)	leaky	Lat: 23.133°N Lon: 120.067°E	32 /11	32	1	30.65	Tropical	10500	21295.6	Lin et al. (2001), Hsiao et al. (2016)
Ria de Aveiro	N.E. Atlantic	Europe, Portugal (W)	restricted	Lat: 40.633°N Lon: 8.75°W	330/46	90	2	0–35	Temperate	353 688		Hesse et al. (2015), Lillebø, Stålhacke, and Gooch (2015), Lillebø et al. (2016), Sousa, Sousa, Alves and Lillebø (2016), Clara et al. (2017), Sousa et al. (2017)
Ria Formosa	N.E. Atlantic	Europe (S), Portugal (S)	leaky	Lat: 36.983°N Lon: 7.922°W	111/55	50	1.5	35.5–36.9	Temperate	225901	17786	Mudge and Bebianno (1997), Newton et al. (2003), Ferreira, Dias and Taborda (2008), Brito et al. (2012), Newton et al. (2014)
Szczecin (Oder) Lagoon	Baltic Sea	Europe (C), Germany/ Poland	restricted	Lat: 53.833°N Lon: 14.167°E	687		3.8	0.3–4.5	Temperate	840000	11000	Schernewski and Dolch (2004), Löser and Sekścińska (2005), Radziejewska and Schernewski (2008), Wolnomiejski and Witek (2013), Stybel, Kleissler, Schulz and Piotr (2014)
	Black Sea	Europe (E), Ukraine	choked	Lat: 46.667°N Lon: 31.183°E	221.5/129	18.36	5.4	23–29	Temperate	127800	160	

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Table 1 (continued)

Name of coastal lagoon	Adjacent sea/ Ocean	Continent and Country (ies)	Type of Lagoon	Coordinates	Area with permanent water (km <sup>2</sup> )	Wetland (km <sup>2</sup> )	Mean depth (m)	Salinity range	Climate	Population (within 50 km)	GDP per capita* (Euro)	References
Tyligul'skiy Liman lagoon												Tuchkovenko and Loboda (2014), Tuchkovenko, Bogatova and Tuchkovenko (2015a)
Varano Lagoon	Mediterranean Sea	Europe (S), Italy	restricted	Lat: 41.833°N Lon: 15.750°E	65		3.5	25-32	Temperate	200000	16000	Tuchkovenko, Kushmir and Loboda (2015b), Tuchkovenko, Loboda and Khokhlov (2015c) Gubanova, Tuchkovenko, Khokhlov, Stepanenko, and Baggett, 2015 Manini, Breber, D'Adamo, Spagnoli and Danovaro (2002b), Roselli et al. (2013), Cuvata and Matteo (2016)
Venice Lagoon	Adriatic Sea, Mediterranean Sea	Europe (S), Italy	restricted	Lat: 45.436°N Lon: 12.330°E	550/459	47	1.5	8-33	Temperate	262246		Nunes, Rossetto and de Blaeij (2003), Alberini, Rosato, Longo and Zanatta (2005), Alberini, Zanatta and Rosato (2007), Rapaglia et al. (2011), Pranovi, Sarà and Provani et al. (2013b), Salon et al. (2008), Solidoro et al. 2010, Cossarini et al. 2008
Watamu -Mida Creek	Indian Ocean	Africa (E), Kenya	Choked	Lat: 3.35°N Lon: 39.850°E	14.1	17.4	5	33-37	Tropical	500000	1400	Kitheka, Mwashote, Ohowa, and Kamau (1999), Dahdouh-Guebas, Kairo, Koedam, and Mathenge (2000), Kairo, Dahdouh-Guebas, Gwada, Ochieng and Koedam (2002), Frank et al. (2017), Owuor et al. (2017)
Yalahau Lagoon	Gulf of Mexico, Caribbean Sea	North America, Mexico	choked	Lat: 21.465°N Lon: 87.276°W	275	1526	< 4	36	Tropical	11942	10787	Flores-Verdugo et al. (1990), Tran, Valdes, Euan, Real and Gil (2002), Herrera-Silveira and Morales-Ojeda, 2010, Rubio-Cisneros et al. (2014), Rubio-Cisneros, Aburto-Oropeza and Ezcurra (2016)



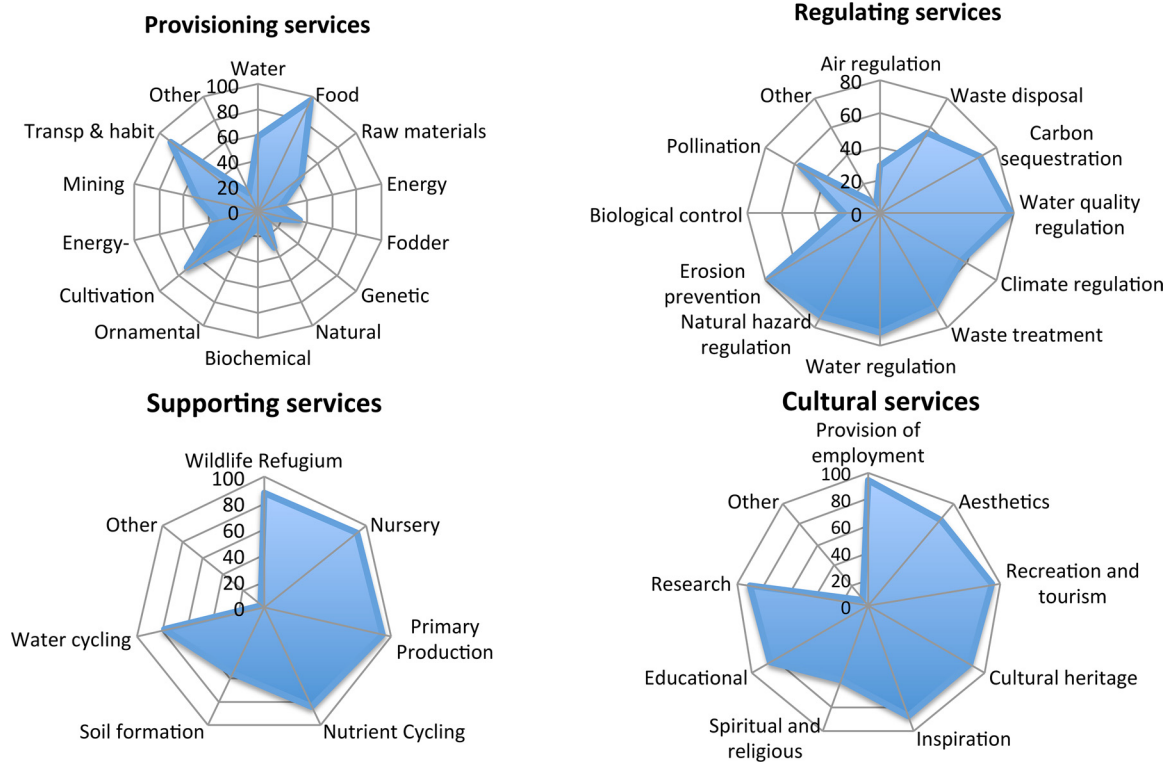


Fig. 2. Percentage of coastal lagoons acknowledged as providing each type of Ecosystem Service (ES). Note that 100% correspond to 32, i.e. the total number of lagoons participating in this study. N = 32.

### 2.3. Data collection

Coastal lagoon scientists were contacted using the network described in the *Historical context* section above to participate in the survey. Although most of the lagoons in the study are in Europe and the Mediterranean, a concerted effort was made to contact scientists in all continents, apart from Antarctica, see Fig. 1.

The scientists were asked to provide information in a tabular format in 4 steps:

- 1) Basic information about the coastal lagoon system, such as coordinates and surface area.  
The summary of the results are shown in Table 1.  
The first step also included a list of ecosystem services (ES) provided by the coastal lagoon.  
The summary of the results are shown in Fig. 2.
- 2) Quantification of the ES provided by the coastal lagoon.  
The summary of the results are shown in Table 2 and Fig. 3.
- 3) Valuation of the ES provided by the coastal lagoon.  
The summary of the results are shown in Figs. 4–7.
- 4) An assessment of the effects of climate change on the ES of the lagoon.

Table 2

Quantification of ecosystem services (ES) provided by coastal lagoons. All values represent the average for all coastal lagoons with available data. These ES are only examples taken from the full database. N = 22.

Ecosystem Service	Quantity	Units
Water provisioning	$114.01 \times 10^6$	m <sup>3</sup>
Food provisioning	$9.57 \times 10^3$	tonnes
Carbon sequestration	$0.32 \times 10^6$	Mg C
Nursery	$67.97 \times 10^6$	km <sup>2</sup>
Jobs	$1.68 \times 10^3$	–
Research (number of hits in Google Scholar)	$35.23 \times 10^3$	–

The summary of the results are shown in Fig. 8.

In some cases, additional processing was required. Data was transformed to obtain comparable datasets. In most cases, this involved calculating annual values from daily means or scaling up the values for the whole lagoon. This was done only when possible. When comparable datasets were not possible to obtain, data were dismissed and not included in the analysis. Please note that valuation data are only indicative, given that for most cases it was not possible to derive comparable values, i.e. taking into consideration the year of the estimate and precise currency exchange rates. Therefore, in this analysis, all values are presented in Euros, converted from the original currency using the European Central Bank exchange rate quoted on 21st February 2017.

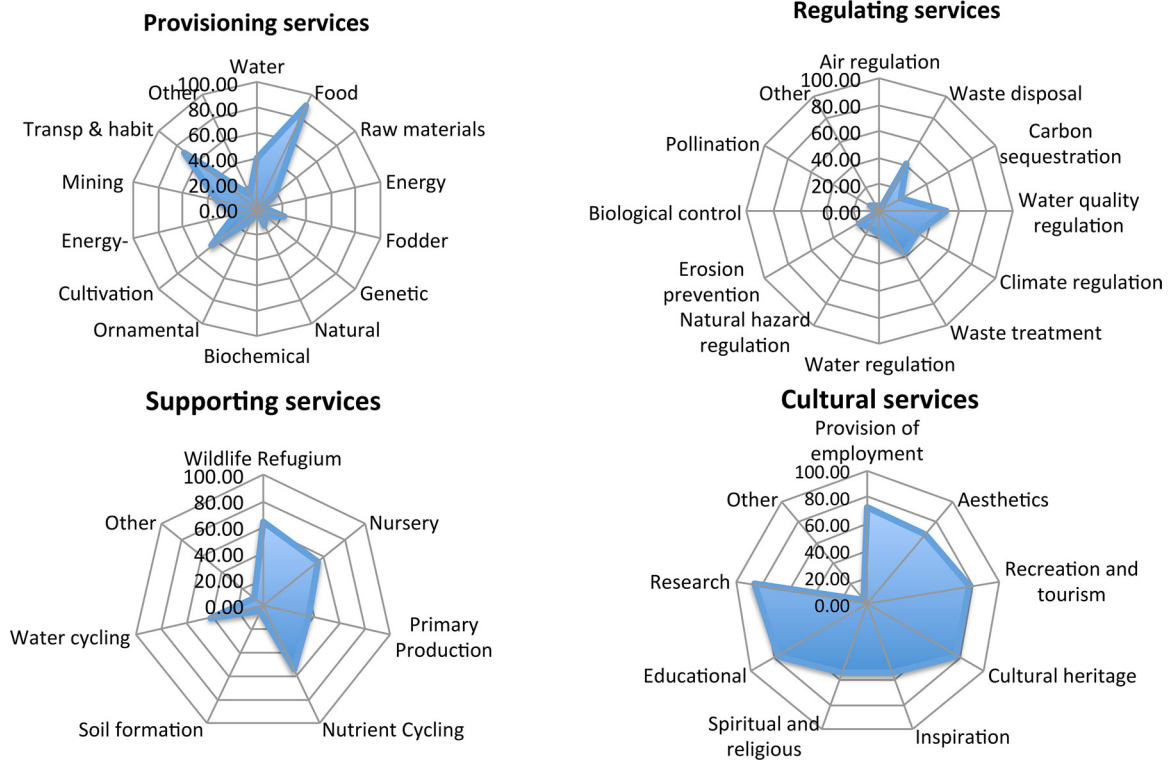
### 3. Results

50 invitations to participate were sent out using mailing lists from EuroMedLag and other mailing lists from other networks and projects. There were 32 respondents (64.0%), who provided the basic information about a coastal lagoon (Table 1). Of these, 15 were from Europe (46.9%), 3 from Asia (9.4%), 8 from Africa (25.0%), 1 from Oceania (3.1%), 2 from N. America (6.3%) and 3 from S. America (9.4%).

32 respondents (64.0%) provided the information listing which ecosystem services were provided by the coastal lagoon (Fig. 2). Almost all coastal lagoons were recognised as important in providing food (96.9% of respondents) and job opportunities (93.8%), as well as allowing its use for recreation and tourism-related activities (93.8%). Research activities were acknowledged by 90.6% of the respondents. Supporting services such as the nursery and primary production functions were also found to be relevant throughout the locations (90.6% and 93.8%, respectively).

22 respondents (68.8%) provided the information quantifying (amounts) the ecosystem services provided by the coastal lagoon (summarised in Table 2 and Fig. 3). Data on food provisioning were

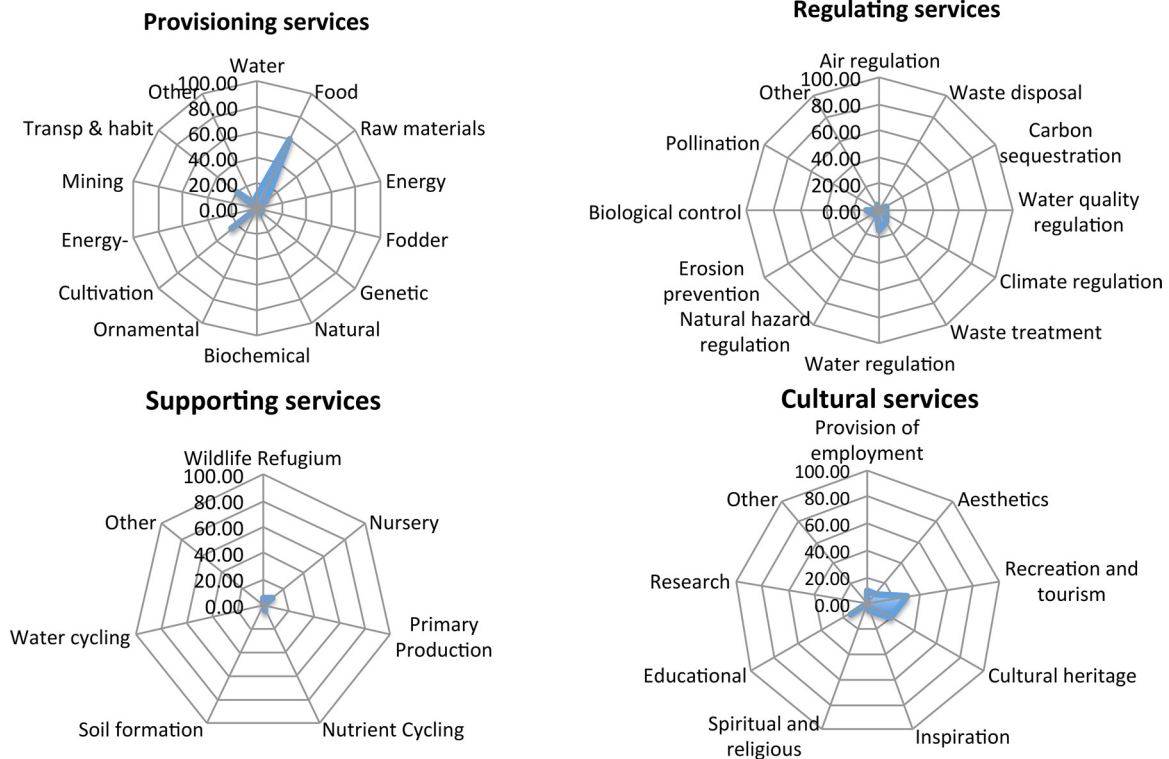




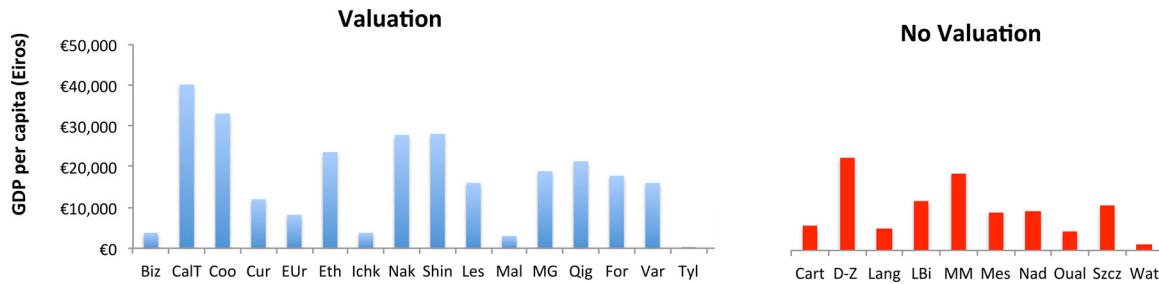
**Fig. 3.** Percentage of responses for ES quantification. Note that 100% correspond to 22, i.e. the total number of lagoons sending information quantifying the ecosystem services. N = 22.

provided by 90.9% of these (22). A measure of research activities (number of hits in Google Scholar) was also obtained for 86.4% of the lagoons. In general terms, although supporting and regulating services were identified as very relevant (Fig. 2), scientists had difficulties in

quantifying those ES. The regulating service with the highest number of responses (50.0%) was the water quality regulation. Most scientists were able to account for the water renewal rate in lagoons. For supporting services, the highest number of responses was obtained for



**Fig. 4.** Percentage of responses for ES valuation. Note that 100% correspond to 20, i.e. the total number of lagoons sending information valuing the ecosystem services. N = 20.



**Fig. 5.** Gross Domestic Product (GDP) per capita (Euros) reported for each region where lagoons are located. Values are distributed according to the availability of valuation data. If no valuation data exist, they are represented in the right part of the graph. Note that each lagoon region represents one bar. See details of specific GDP values in Table 1. Note that: Biz-Bizerte Lagoon, CalT – Cal Tet, Coo – Coorong, Cur – Curonian, EUR – Estero de Urías, Eth – Ethang de Thau, Ichk – Ichkeul Lake, Nak – Lake Nakumi, Shin – Lake Shinji, Les – Lesina Lagoon, Mal – Malanza Lagoon, MG – Marano and Grado, Qig – Qigu Lagoon, For – Ria Formosa, Var – Varano Lagoon, Tyl – Tyligulskyi Liman Lagoon, Cart – Cartagena Bay, D-Z – Darss-Zingst Bodden, Lang – Langebaan Lagoon, LBi – Loch Bi, MM – Mar Menor, Mes – Messolonghi Central Lagoon, Nad – Nador, Oual – Oualidia, Szcs – Szczecin (Oder) Lagoon, Wat – Watamu-Mida Creek.

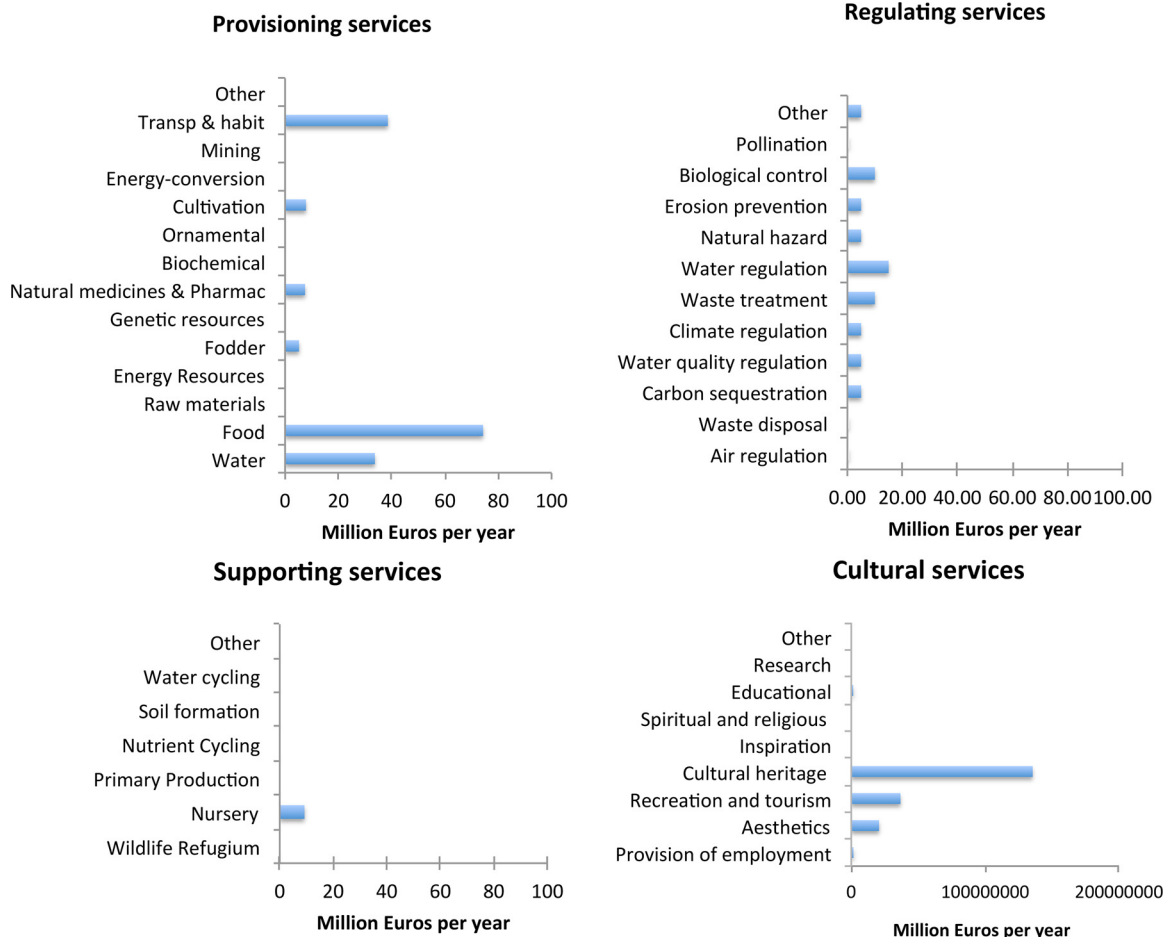
wildlife *refugium* (63.6%), accounting for the number of reserves and natural parks, and nutrient cycling (54.6%), accounting for the nutrient inputs into the lagoons.

20 respondents (62.5%) provided the information on the monetary value of ecosystem services provided by coastal lagoons (Fig. 4). Food provisioning was the ES with the highest response rate (60.0%). Valuation figures for cultivation were reported by 25.0% of the respondents. Touristic and recreational, as well as cultural heritage values were also provided by 30.0% and 20.0% of the respondents, respectively. Most valuation figures for these ES were based on market values techniques. Moreover, estimates were obtained both from formal studies and other informal sources, such as newspapers, etc. It is

interesting to note the great lack of data for most ES. Thus, although ecosystem services are recognised as existing and important, their value is still largely unknown.

The Gross Domestic Product (GDP) per capita (Euros) reported for each region where the lagoons are located is presented in Fig. 5. The GDP per capita reported for lagoons with no valuation data seems slightly lower than the GDP per capita obtained in lagoons with valuation data. However, the range of variation is high for the lagoons with valuation data.

In general terms, food provisioning and cultural heritage were the services with the highest monetary valuation, representing more than 70 Million Euros per year (Fig. 6). Cultural heritage reached large



**Fig. 6.** Valuation of Ecosystem Services (ES) provided by each lagoon. These figures represent average values in Million Euros per year N = 20.

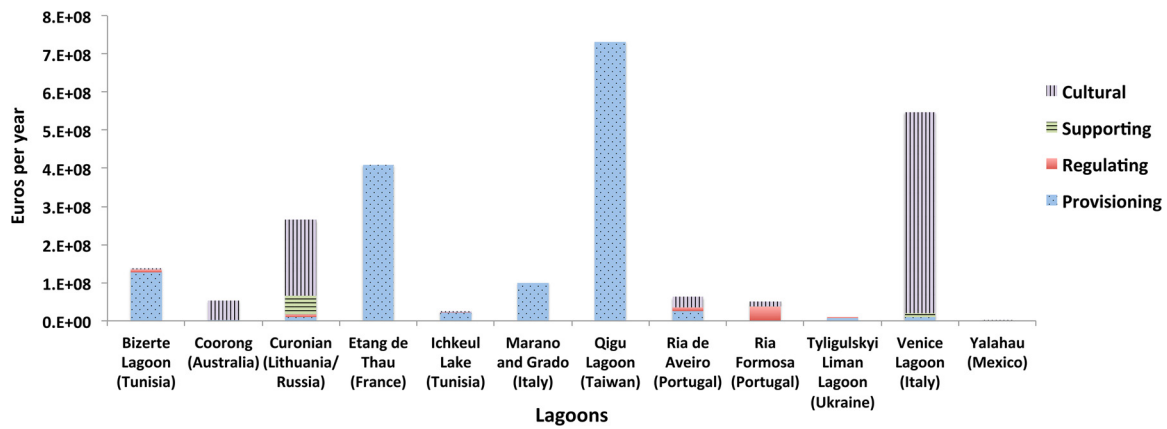


Fig. 7. Valuation estimates of Ecosystem Services (ES) in each lagoon. Please note the distribution of the monetary value by ES groups (provisioning, regulating, supporting and cultural).

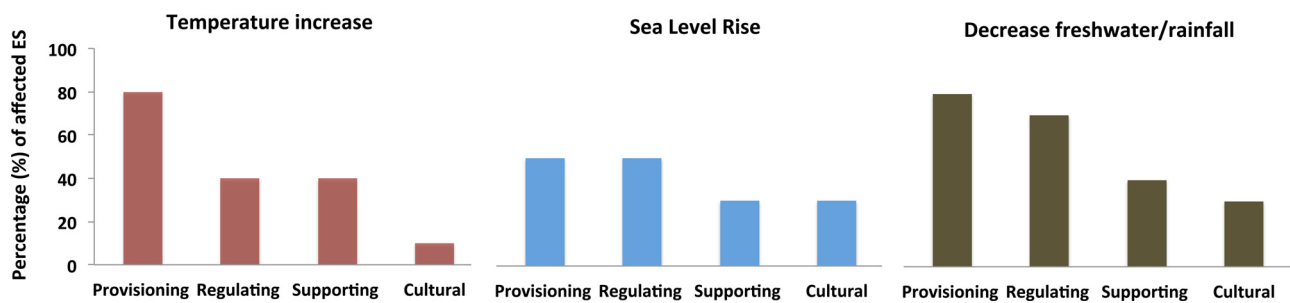


Fig. 8. Percentage of Ecosystem Services (ES) potentially affected by climate change. These represent anticipated effects.

numbers, more than 135 Million Euros per year. Only four lagoons reported values for this ES and this average is strongly dependent on the figures estimated for the Venice lagoon, where this ES reaches 12 Million Euros/km<sup>2</sup> of land (Alberini, Rosato, Longo, & Zanatta, 2005). Water provisioning, transport and habitation were also found as having high monetary values, almost reaching up to 40 Million Euros per year. Note that all currencies were converted to Euros according to 2017's exchange rate (see methods section for details).

Considering the ES valuation data obtained for each lagoon, the relevance of provisioning services that combines all individual ES becomes clearer in most coastal lagoons (Fig. 7). According to the estimates obtained, cultural services represent approximately  $5.30 \times 10^8$  Euros per year in the Venice lagoon and only  $0.01 \times 10^8$  Euros per year in the Ichkeul Lagoon. The range of values obtained depends mainly on the availability of data. For example, Clara et al. (2017) reported a valuation estimate of  $0.26 \times 10^8$  Euros per year in Ria de Aveiro (Portugal), but this number only considers recreational activities, while most lagoons have values for 2–3 cultural services.

Given the importance of these ecosystem services and the current global changes (Eisenreich, 2005), scientists were asked to identify the ES most likely to be affected by changes such as temperature increase, sea level rise, decrease in freshwater inputs and rainfall (Fig. 8). These were the factors identified as the most relevant for coastal lagoons. They were indicated in at least 8 lagoons. Other factors (e.g. extreme events) were indicated only occasionally (once). Provisioning services were identified as the ones at higher risks, indicated at least by 50% of the lagoons. Cultural services were identified as the ones at lower risk ( $\leq 30\%$ ).

#### 4. Discussion

##### 4.1. There is still confusion about ecosystem services

Several of the respondents had difficulties with the classification of

ecosystem services because they were considering different typologies (De Groot et al., 2002; MA - Millennium Ecosystem Assessment, 2005; Costanza, 2008; TEEB, 2010; Haines-Young & Potschin, 2013). During this study it became apparent that most people were familiar with the classification of the Millenium Assessment (MA - Millennium Ecosystem Assessment, 2005) and not with other classifications, such as the one proposed by the Economics of Ecosystems and Biodiversity (TEEB, 2010) or the Common International Classification of Ecosystem Services (CICES; Haines-Young & Potschin, 2013). Data submission templates were left broad enough to allow the maximum response rate but they also indicate the difficulties in using a common approach. The debate about the definition and classification of ecosystem services is important and has been active in the last decades, varying according to the ecological focus or the economic use (Braat & de Groot, 2012). These different approaches have their own strengths and weaknesses. MA was criticized for double counting the benefits from the services. For example, in the case of water-related services, nutrient cycling is a supporting service, water flow regulation is a regulating service and they contribute to several benefits, such as good water quality and recreational services (Fisher et al., 2009). The most recent approaches (e.g. TEEB and CICES) avoid the risk of double counting by distinguishing between intermediate and final services (Hasler et al., 2016). Nonetheless, the integration of the two visions, environmental and economic, in one simple approach can make the difference in managing activities and developing policies. More and more, environmental problems are framed in an economic context and cost-benefit analyses are performed to make decisions. The monetary figures tend to have high impact and empower scientists and policy makers. Adequate communication and understanding between all partners from different backgrounds (ecology, economy and policy) is therefore key to facilitate the process of adaptive management and the ecosystem approach.

#### 4.2. Coastal lagoons provide a wide range of ES

This study revealed a high number of ES that are considered as important in most coastal lagoons located worldwide. In particular, the provision of food and tourism recreation (> 95%) are important for lagoons. This result was somehow anticipated, as these are some of the most productive marine ecosystems, being the perfect location for nature-based and aquatic activities (e.g. Kjerfve, 1994; Anthony et al., 2009). This is also in line with what has been reported for other coastal ecosystems (e.g. Barbier et al., 2011; Brander et al., 2012; Vo, Kuenzer, Vo, Moder, & Oppelt, 2012), such as mangroves and estuaries. Moreover, more than 85% of the scientists also highlighted transport and habitation, and other supporting services such as its role as a wildlife *refugium*, nursery, etc. Lagoons also regulate water and water quality, climate, erosion and natural hazards as well as carbon sequestration. The range of ES provided is wide and there is the need to develop common approaches to quantify these ES using a comparable methodology.

#### 4.3. Coastal lagoons provide a large quantity of ES

Coastal lagoons are highly productive, are in high demand for recreational activities, and integrate complex biogeochemical processes that contribute to the regulation of water cycles, climate, and carbon sequestration (Chmura, Anisfeld, Cahoon, & Lynch, 2003). Quantification data for food provisioning, tourism and recreational activities were obtained for approximately 80% of the lagoons. In these productive systems, food provisioning can be key in the regional economy. For example, the Ria Formosa in Portugal provided up to 90% of the national production of clams (Newton et al., 2003). In a review study, Boerema, Geerts, Oosterlee, Temmerman and Meire (2016) indicated that food production and climate regulation are the ES with the highest number of quantification studies. However, it is interesting to highlight that climate regulation data was obtained only for 23.3% of the lagoons included in this study, suggesting the difficulty in evaluating this service for these systems.

How can we quantify all these ES? How accurate are the quantification estimates available in the literature? Boerema et al. (2016) reported an important lack of consensus on what constitutes an ES and a variety of measures to quantify ES, leading to low quality estimates. In fact, the data obtained in this study are not always comparable because: 1) different entities are reported, e.g. some report the aquaculture production of the most important fish species and others do not identify the organisms or do not describe if those quantities are from aquaculture or catches; 2) different units to express similar entities are used, i.e. data may be given in tonnes per annum or in tonnes per hectare or tonnes per farm, which requires additional information, such as the area considered for the production or the number of farms actively operating, which is not generally available. Scientists reported what is available. One of the problems is that this information is obtained from governmental studies and statistical reports that often have different formats. Again, a common framework to guide the process of data collection and estimation would reduce these differences.

It seems even more difficult to quantify those ES that have a critical functional role in the ecosystem, such as water regulation and carbon sequestration. Only 15% or less of the respondents provided quantification data for these roles. In these cases, estimates were almost entirely derived from scientific approaches with final outcomes that were comparable between them (Mg C/annum; e.g. Lin, Hung, Shao, & Kuo, 2001; Sousa et al., 2017). For carbon sequestration ES, one of the first steps is to estimate the carbon stock and then the flux, i.e. the amount of carbon that is effectively taken up from the environment in a specific time. This is an example of the level of detail and difficulty in directly quantifying ES.

Both the ecological and sociological characteristics of coastal lagoons are dynamic. Changes in the way people use coastal lagoons are

expected, as well as changes in the ES provided by lagoons. It is important to find strategies to incorporate this dynamic nature in the methodologies used to evaluate ES. For example, the geomorphology of a coastal lagoon may change due to sediment movement and prevent temporary or permanent ship navigation. In addition, large ships can also contribute to the erosion of the lagoon due to increased turbulence (Rapaglia, Zaggia, Ricklefs, Gelinas, & Bokuniewicz, 2011). Another example of a change in ES provided by a lagoon can be shown for the Ria de Aveiro, where aquatic vegetation (*molíço*) was collected using traditional boats (*Moliceiros*). The harvested vegetation was used as fertilizer and supported important agricultural activities in the fields in the vicinity of the lagoon. Nowadays, this biomass is no longer used as a natural fertilizer and the *Moliceiros* have been converted to a different activity and are now used by guided tour operators. While this may be considered as cultural erosion, it may also be considered to be a form of cultural adaptation. Another example is the gondoliers of Venice, who adhere to strong traditions, but they are now mainly used by tourists, rather than Venetian residents.

#### 4.4. Coastal lagoons provide valuable ES

Although the ES discussion has been going on for more than 20 years, it was only in the last decade that scientists and technical officers have really started to focus on the quantification and valuation of those services. In a review study, Torres, Catalina, and Hanley, 2016 have reported 8 valuation studies on coastal areas (capes, peninsulas, barrier islands, etc.) and 37 valuation studies on coastal waters (bays, gulfs, sounds, fjords, inland seas, etc.). Little is known about the valuation of ES in coastal lagoons and only few studies were available in the literature (e.g. Rolf & Dyack, 2010; De Wit, Rey-Valette, Balavoine, Ouisse, & Lifran, 2015).

Coastal lagoons are amongst the most used and valuable ecosystems on earth. TEEB (2010) estimated that two-thirds of the ecosystem services that make up the planet's natural capital are derived from ocean and coastal biomes. In practical terms, some ES are easier to assign a monetary value than others, for example recreation and tourism have been receiving attention in the past years especially in areas as coastal lagoons due to their attractiveness for recreational activities (e.g. Rolf & Dyack, 2010; Clara et al., 2017). However, there are other services such as erosion or pollution control, that have been neglected because they are difficult to estimate, there is a lack of available data, or it is difficult to conceive and transmit an economic value for these types of services (Barbier et al., 2011, 1997).

Even for the same ES, there are several valuation techniques that can be used. Non-market valuation techniques can be divided in two distinct types: revealed preference methods (estimates of people's preferences based on their behavioural choices) and stated preference methods (based on asking people their preferences). They have very different ways of achieving estimates and for some ES both methods can be used which can cause some confusion when comparing the results. Problems for the comparison of estimates of the valuation can also arise from the different survey approaches (the way questions are posed in questionnaires) and even different statistical analysis used (different modelling choices).

#### 4.5. Climate change will affect the ES of coastal lagoons

The level, rate and effects of climatic changes across the globe are expected to vary from region to region (IPCC, 2014). Increase in temperature, sea level and storminess or extreme events are the main changes that are likely to affect coastal lagoons. Coastal lagoons are generally shallow, and therefore are prone to the effects of temperature increase (Lloret, Marin, & Marin-Guirao, 2008; Brito, Newton, Tett, & Fernandes, 2012; Chapman, 2012). Temperature is one of the most important parameters for biological processes, influencing the functioning of the ecosystem, from basic chemical reactions to the timing



(phenology) of lagoon processes, affecting reproduction, migrations, etc. Additionally, increased water temperature causes a decrease in dissolved oxygen, essential for aerobic organisms. Provisioning services provided by coastal lagoons are therefore likely to be at risk by temperature increase. This was acknowledged by 80% of the scientists participating in this study. Sea level rise is also likely to cause relevant impacts in the services provided by lagoons. Lloret et al. (2008) and Brito et al. (2012) have already discussed how light reduction in the bottom may lead to the decay of benthic primary producers and alter the whole structure of the food web, with obvious effects on the trophic state. Benthic primary producers have a key functional role in these systems, being involved in several processes that constitute the basis for supporting and regulating services. The increase in the frequency and intensity of extreme weather events is also likely to happen. Some regions across the globe are expected to experience precipitation decreases while others may receive increases (IPCC, 2014). In the latter regions, increased precipitation and storminess can augment watershed runoff and erosion resulting in a greater flux of terrestrial sediments and pollutants to the coast during runoff events (Anthony et al., 2009). Meanwhile, in regions with reduced precipitation, the decrease in freshwater input was also identified as an important change in coastal lagoons, as it can cause extreme changes in the salinity regime, especially during warmer seasons, as well as changes to a lagoon's water circulation and flushing rate (Lee & Park, 2013). Changes in precipitation regimes will also affect freshwater and nutrients inputs carried by the rivers, with cascading effects on lagoon biogeochemistry (Cossarini et al., 2008; Solidoro, Cossarini et al., 2010) and provisional services (Melaku Canu et al., 2011).

## 5. Conclusion

The assessment exercise showed that there is a high awareness in the scientific community about the ecosystem services of coastal lagoons. However, there are important challenges and knowledge gaps that have been revealed in this survey that could provide the basis for further research. In particular, the following were identified:

- 1) The definitions of Ecosystem Services are still not generally accepted. This makes comparative studies difficult. The recommendation is that the researchers use a commonly agreed typology for ES.
- 2) The quantification of ES is made in many different ways, using different units. This makes comparison and in some cases calculations difficult. The recommendation is that standard units should be used, for example yield (kg) per area (meter sq.) per annum (year). Further information about the lagoon, such as total area, is also important for the result to be useful.
- 3) The evaluation of ES is even more problematic. Some ES are difficult to value in monetary terms, for example coastal aesthetics and different approaches to valuation are used. The recommendation is that the non-monetary evaluation methods should be standardized, so that the results can be compared.
- 4) The valuation of ES is also problematic. When ES are valued in monetary terms, what this represents in terms of human benefits and livelihoods is very variable. It may depend on whether it is a developing country or a developed country, the basic wage or salary of the local population and the percentage of income spent on food. For example, a coastal lagoon may provide a high value good, e.g. high value bivalves such as oysters or clams. However, these may be too expensive for the local population to afford and are exported to another country. Values in terms of Gross Domestic Product may not reflect this, especially in countries where there is a large GINI coefficient or index. The recommendation is that valuation should be given in context of the local economy, not just in absolute terms.
- 5) Another problem for comparison are fluctuations in exchange rates and value of goods. In the case of exchange rates, this can be overcome by quoting the original currency and the date of exchange calculation. However, prices may also vary for different reasons, for example the collapse of a bivalve aquaculture due to disease in one country may affect the prices in neighbouring countries. Once more, dates are important for monetary values to be useful.
- 6) Different aspects of climate change, including increasing temperature, sea-level rise and decreased rainfall and changes in precipitation regime threaten the valuable ES of coastal lagoons.
- 7) The conservation of coastal lagoons is important not only for their ecological importance, but also because of the valuable ES they provide for human welfare and wellbeing.

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