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Valuing ecosystem services from blue forests: A systematic review of the valuation of salt marshes, sea grass beds and mangrove forests

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ABSTRACT

Coastal ecosystems provide a number of life-sustaining services, from which benefits to humans can be derived. They are often inhabited by aquatic vegetation, such as mangroves, sea grasses and salt marshes. Given their wide geographic distribution and coverage, there is need to prioritize conservation efforts. An understanding of the human importance of these ecosystems can help with that prioritization. Here, we summarize a literature review of ecosystem service valuation studies. We discuss (1) the degree to which current valuation information is sufficient to prioritize blue carbon habitat conservation and restoration, (2) the relevancy of available studies, and (3) what is missing from the literature that would be needed to effectively prioritize conservation. Given the recent focus on blue carbon ecosystems in the international conservation, there are a number of areas where research on blue forest ecosystem assessment and valuation could be improved, from enhancing available methodologies to increasing valuation of rarely studied ecosystem services and wider geographic coverage of valuation studies. This review highlights these gaps and calls for a focus on broadening the ecosystem services that are valued, the methods used, and increasing valuation in underrepresented regions.

Contents

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1. Introduction

Coastal zones are home to a wide range of ecological and economic activity. While only occupying about 4% of total land area and 11% of oceans, they are some of the planet's most productive ecosystems (Millennium Ecosystem Assessment, 2005). Coastal ecosystems provide a number of life-sustaining services, from which benefits to humans (and the monetary value associated with those benefits) can be derived (Barbier, 2011). Despite their importance, coastal zones are also among the most threatened ecosystems on earth: humans are degrading and destroying these ecosystems worldwide at an increasing rate, and subsequently jeopardizing the availability of these critical services (Halpern et al., 2008; Millennium Ecosystem Assessment, 2005). A better understanding of how these ecosystems function, the services they provide (in both ecological and economic terms), and what is at stake should we lose them is a necessary part of any coastal zone management plan (Fisher et al., 2009).

Coastal zones can begin up to 100 km inland and include ocean waters extending from the upper intertidal zone to 40 m in depth (Duarte et al., 2013). These areas where land meets sea are marked by the presence of aquatic vegetation, such as seagrasses, salt marshes and mangroves, with plants either fully or partially submerged. These habitats are often referred to as blue carbon ecosystems or blue forests, because they act as carbon sinks, similar to their terrestrial counterparts (Mcleod et al., 2011; Pendleton et al., 2012). By capturing and sequestering carbon from the atmosphere, blue forests have an important role in climate change mitigation. Blue forest ecosystems also provide several other ecosystem services, including the provision of nursery habitats, raw materials, coastal protection, and enhancing water quality, to name a few (Lau, 2013). Studies have indicated that vast amounts of these ecosystems have been and are currently being lost or degraded worldwide. Over the last 20–50 years, 50% of salt marshes, 35% of mangroves, and 29% of seagrasses have been lost (Barbier, 2012; Millennium Ecosystem Assessment, 2005; Mcleod et al., 2011; Waycott et al., 2009).

Researchers have increasingly used the results of ecosystem service valuation studies to argue for the conservation of coastal ecosystems, particularly blue forests (Barbier et al., 2011). Several review papers have recently summarized valuation studies that have been conducted for these habitats; however, many of the studies covered are based primarily on studies that are more than 10 years old (Barbier et al., 2011, 2016; Dewsbury et al., 2016; Torres and Hanley, 2016; Vegh et al., 2014). For example, Dewsbury et al. (2016) cites 32 published seagrass economic valuations; however, only 9 were conducted in the last 10 years; the remaining 23 studies were conducted between 1977 and 2006. Torres and Hanley (2016) provide a review of coastal and marine ecosystem valuation studies. Similarly, the vast majority of their cited studies that specifically provide values for blue forest ecosystem services are more than 10 years old. The prevalence of older, possibly outdated data is also seen in Barbier et al. (2011) Salem and Mercer (2012) and Vegh et al. (2014). Barbier et al. (2011) also provide a review of estuarine and coastal ecosystem service values. Their review only cited one estimate for seagrass services (fisheries); however, that estimate was published in 2006. Barbier et al. (2011) cite more values for salt marshes (N = 5); however, these studies too are older than 10 years and the more recent studies only provide values for wetlands in general. Similarly, for mangroves, they only cite three studies, all of which are 10 or more years old. Salem and Mercer (2012) conducted a meta-analysis of the economic value of mangroves citing 62 mangrove valuation studies, only 9 of which were published in the last 10 years with the majority published in the 1980s and 1990s. Lastly, Vegh et al. (2014) also provide a recent review of the mangrove ecosystem services valuation literature, citing 72 mangrove valuation studies. Only 29 of these studies were published after 2006 and many do not actually provide ecosystem service valuation estimates that are specific to mangroves; only 11 were published in the last 5 years and most do not rely on recently collected data. The present review highlights the challenge of outdated valuation research and compiles valuation studies that have been done more recently.

Furthermore, very few papers have critically examined the methods and particularly the assumptions that underlie such studies, the methods used to estimate values, or the gaps in valuation for blue carbon ecosystems. We take a step back to examine the methods and underlying assumptions used in the historical valuation of blue forest ecosystem services. We provide a review of the services provided by mangrove, seagrass and salt marsh ecosystems and the methods that have been used to calculate economic values of those ecosystem services to date. Our aim is to help direct the future valuation of blue ecosystems and the use of these valuation estimates in blue forest management.

There are many international efforts aimed at conserving blue forest ecosystems, but given the wide geographic distribution and coverage of mangroves, seagrasses and salt marshes, there is great need to prioritize the areas to focus conservation efforts. An understanding of the human importance of these ecosystems can help with that prioritization. Here, we review ecosystem service valuation studies that have been conducted for each of these ecosystems over the last 10 years (2007–2016). First, we start with a description of how we conducted our literature review. Second, we summarize the results of the review. Finally, we provide a discussion of (1) the degree to which current ecosystem service valuation information is sufficient to prioritize blue carbon habitat conservation and restoration, (2) the relevancy of available studies, and (3) what is missing from the valuation studies (ecosystem service valuation and threats) that have been done that would be needed to effectively prioritize conservation.

2. Background

2.1. Blue carbon ecosystems

Globally, blue carbon ecosystems occupy a significant portion of the coastline (Fig. 1, Table 1). Seagrasses are flowering plants that are fully submerged in shallow marine waters. Optimal conditions for seagrasses include low sunlight exposure, soft substrates (i.e., sand, mud) and wave-protected areas (Duarte, 2002). Seagrass meadows are principally found in North America (UNEP-WCMC, 2016). Salt marshes are intertidal grasslands that form along continental margins, bays, and estuaries. They are characterized by sharp zonation of plants and low species diversity, but very high primary and secondary production. Salt marshes are principally located in Europe and North America (Mcowen et al., 2017). Mangroves are coastal forests that have adapted to high salinity conditions and are mostly found in the tropics and subtropics (Barbier et al., 2011). Mangroves are found in highest abundance in the tropical latitudes of Africa, Asia and Central and South America (Giri et al., 2011). All three habitats are represented to some extent in all regions of the world with the exception of mangroves in Europe.

Despite the relatively small geographical space they occupy (Fig. 1), blue forests provide a number of ecosystem services (Lau, 2013). By reducing the impact of incoming waves and stabilize sediments, they provide coastal protection and erosion control for adjacent shorelines (Rao et al., 2015; Shepard et al., 2011). They act as natural filters by removing nutrients from the sediment,

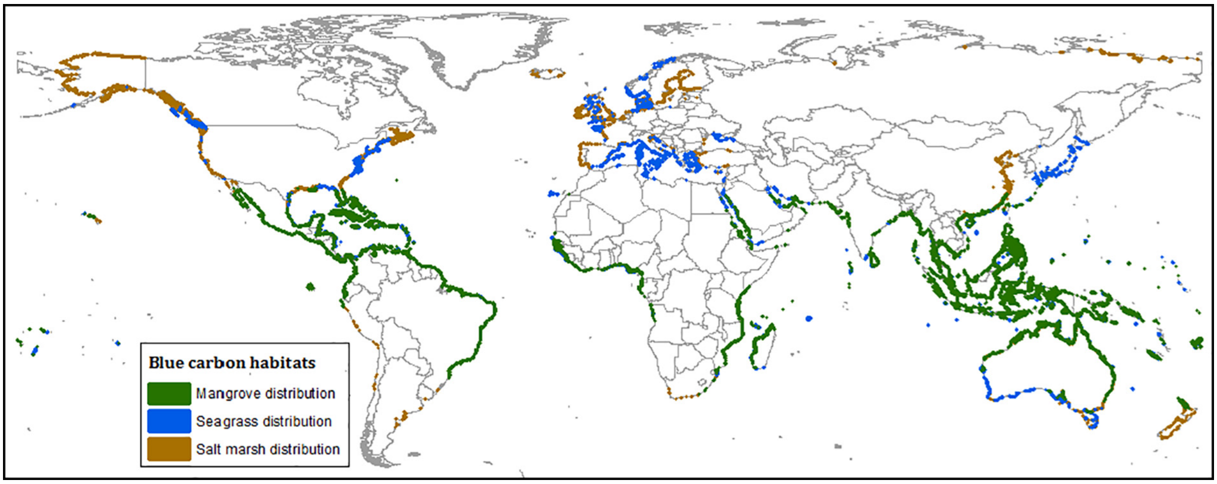

Fig. 1. Global distribution of blue carbon ecosystems. Data source: (Giri et al., 2011; Mcowen et al., 2017; UNEP-WCMC, 2016).

Table 1
Known global extent and distribution of blue carbon ecosystems. Data source: (Giri et al., 2011; Mcowen et al., 2017; UNEP-WCMC, 2016).

Region	Mangrove		Seagrass		Salt marsh	
	Hectares	% of total	Hectares	% of total	Hectares	% of total
Africa	2,631,069	22.9%	6247	2.8%	1565	0.4%
Asia	3,276,758	28.6%	23,690	10.8%	22,008	6.3%
Australia and South Pacific	1,578,385	13.8%	2622	1.2%	16,644	4.7%
Central and South America	2,991,043	26.1%	10,368	4.7%	5315	1.5%
Europe	0	0%	23,614	10.7%	162,039	46.2%
Middle East	23,995	0.2%	351	0.2%	174	0.0%
North America	965,678	8.4%	153,266	69.6%	143,239	40.8%
Global total	**11,466,928**		**220,158**		**350,984**	

decreasing the concentration of suspended particles, reducing turbidity and improving water quality (Hussain and Badola, 2008; Wieski et al., 2010). They maintain fisheries (i.e., shrimp, crabs, clams, and juvenile fish) by serving as habitats and nurseries (Kamimura and Shoji, 2013; Lee et al., 2014; Liquete et al., 2016). Their unique landscapes support tourism and recreation (Failler et al., 2015; Wegscheidl et al., 2015). When harvested, they can also be used for food and raw materials (Brander et al., 2012; Mojiol et al., 2016).

In the context of carbon sequestration, these ecosystems are even more effective carbon sinks, both in the short and long-term storage of carbon, than terrestrial forests (Mcleod et al., 2011; Pendleton et al., 2012). These habitats play a critical role in the global sequestration of atmospheric carbon. For just the top meter of sediment, carbon storage has been estimated at approximately 259 Mg of carbon per hectare for tidal marshes, 407 Mg carbon/ha for mangroves, and 142 Mg carbon/ha for seagrass meadows (Pendleton et al., 2012). Long-term rates of carbon accumulation in blue forest habitats have been estimated to range between 18 and 1713 g of carbon per square meter annually (Mcleod et al., 2011). The rate of carbon sequestration and the size of the carbon sink in blue forest sediments increases overtime as sediment accretes (Mcleod et al., 2011). There are examples of the significance of these carbon sinks, including a seagrass meadow in Spain and mangrove forest in Belize that each have over 10 m of carbon rich sediments that have been dated over 6000 years (Lo Iacono et al., 2008; McKee et al., 2007). It is estimated that this detritus burial accounts for half of the total carbon burial in the ocean (Duarte et al., 2005).

It should be noted that, while these ecosystems are structurally different, each with unique biotic and abiotic components, they do not operate in isolation wherever they are co-located. There is a synergistic connectivity across these ecosystems and their services (Lau, 2013). For example, suspended particle deposition by salt marshes not only facilitates nutrient uptake, but also improves the water quality where seagrasses grow, aiding in their ability to provide other ecosystem services, such as fishery production (Barbier et al., 2011).

The degradation and loss of blue carbon ecosystems is increasing worldwide (Mcleod et al., 2011; Millennium Ecosystem Assessment, 2005). This trend affects at least three important ecosystem services: the number of viable fisheries, the provision of nursery habitats, and filtering/detoxifying services linked to water quality (Barbier et al., 2011). Yet, further decline in marine ecological diversity will weaken other ecosystem services as well (i.e., coastal protection against storms) (Worm et al., 2006). In terms of climate change mitigation, there is serious risk of losing these highly efficient carbon sinks at a time when atmospheric carbon emissions are rising (Siikamaeki et al., 2012).

The threats to blue carbon ecosystems are complicated and multi-faceted. Seagrasses are most frequently affected by eutrophication, overharvesting, coastal development, aquaculture, dredging and vegetation disturbance, climate change, and sea level rise. Salt marshes have been impacted heavily by marsh reclamation, vegetation disturbance, climate change, sea level rise, pollution, biological invasion, and altered hydrological regimes. Similarly, mangroves are generally threatened by mangrove disturbance, degradation and conversion; coastline disturbance, pollution, overharvesting for firewood, and upstream soil loss (Barbier et al., 2011). Additionally, these habitats can be affected by other direct drivers of ecosystem change, such as technology adaptation, and indirect drivers such as changes in demographics (i.e., population boom, especially near coasts where population density is already high); economic changes (i.e., policies regarding trade, market conditions); socio-political changes (i.e., governance; legal frameworks, especially in developing countries where local property rights of coastal communities are often nonexistent); science and technology; and cultural and religious beliefs (Millennium Ecosystem Assessment, 2005).

2.2. Ecosystem services and valuation

There is a general consensus that human beings benefit from nature, but how best to define this relationship is still being determined. The Millennium Ecosystem Assessment (2005) uses a broad definition that equates 'the benefits people obtain from ecosystems' with the term 'ecosystem services.' TEEB differentiates between ecosystem processes (i.e., primary production), functions (i.e., maintaining a viable fish population), services (i.e., food), and benefits to humans (i.e., health and nutrition) (TEEB, 2010). Other studies have argued for even greater distinctions between services and benefits, intermediate and final services, and direct and indirect contributions made by ecosystem services (Boyd and Banzhaf, 2007; TEEB, 2010; USEPA, 2009). There is agreement, however, that any economic value assigned to an ecosystem service must be measured in relation to human welfare: first, by defining the ecosystem service, determining how a change in that service creates an impact (positive or negative) on an individual's well-being and then, how that impact can be measured in economic terms (Barbier et al., 2011; Bockstael et al., 2000).

The TEEB devised a typology of ecosystem services based on four categories: (1) Provisioning (e.g., food, water, raw materials); (2) Regulating (e.g., carbon sequestration, water purification, coastal protection); (3) Habitat (e.g., fish nurseries); and (4) Cultural and Amenity (e.g., recreation and tourism). These services contribute to different types of values. Direct-use values are derived from services that are used directly by humans: these can be consumptive (i.e., food) or non-consumptive (e.g., recreation). Indirect use values are derived from services that provide benefits outside of the ecosystem itself and do not involve an action by humans (e.g., carbon sequestration, coastal protection). A total economic valuation would also consider non-use values, or the existence value people place on services with no intention of using them, and option values, derived from having the service available for potential use in the future (Millennium Ecosystem Assessment, 2005).

Despite the many ecosystem services attributed to blue carbon ecosystems, the values associated with those services are either sparse, unreliable, or unavailable in the literature. Some valuation studies have been conducted for seagrasses and mangroves, with salt marshes receiving the least attention (Barbier et al., 2011). This paucity of information is a setback for planning and management strategies. The role of valuation is to provide decision-makers with estimates of gains and losses associated with different policy options, to gauge the relative economic importance of different activities, and to assess how changes in the environment affect human well-being. For those services that generate a marketed output (e.g., fish, raw materials), price is often the metric used to reflect the value placed by the consumer. However, most ecosystem services do not have marketed outputs, and therefore no observable prices. This is especially true for services related to regulatory and habitat functions. Failure to measure the value of non-market services leads to benefits being underpriced or excluded from the decision-making process and risk of exploiting and degrading these ecosystems or converting them to other uses with more obvious economic gains.

When dealing with ecosystem services that are difficult to replace or restore, for coastal zone management to be effective, there must be a comprehensive analysis of values, including the non-market values of ecosystem services (Granek et al., 2010). The challenge is multi-dimensional: how to integrate changes in the structure and function of an ecosystem, that lead to changes in the ecosystem service and ultimately human welfare (in the form of benefits), and then translate these changes into economic terms (NRC, 2005). To address some of these issues, non-market valuation methods have evolved each having its own advantages and limitations.

Using the existing non-market valuation literature, policymakers often try to get approximate values of ecosystem services and how these values may respond to changes in environmental conditions of the resources they are trying to manage (Smith and Pattanayak, 2002). The transfer of values (i.e., benefit transfer) from the literature to policy can involve complicated attempts to adjust those values taken from previous studies in a given location to accommodate local applications somewhere else. For this reason, policymakers relying on benefit transfer must be aware of each study's context (e.g., when, where, and how the values were derived) in order to judge the accuracy, relevance, and appropriateness of the values being transferred (Brouwer, 2000).

Several valuation methods have been developed, such as: (1) production-based methods (i.e., bio-economic modelling, factor income, production function) that look at the contribution of coastal resources as inputs in the production of consumer goods bought and sold in traditional markets; (2) cost-based methods (i.e., avoided, conversion, damage, mitigation, opportunity, replacement, or restoration cost) that estimate the cost of avoiding damage to other economic activities (related to coastal resources) due to conservation efforts; (3) revealed preference methods (i.e., market price, consumer surplus, net price, public investments, substitute goods, hedonic pricing, travel cost); (4) and stated preference methods (i.e., contingent valuation, choice modelling, contingent ranking, participatory valuation) that simulate a market and demand for ecosystem services through the presentation of hypothetical scenarios to survey respondents (TEEB, 2010).

3. Material and methods

3.1. Literature search

We conducted a systematic literature review in order to better understand the universe of studies that have been conducted to assess the economic value of ecosystem services provided by mangroves, seagrass beds and salt marshes. Our search focused on studies explicitly rooted in the ecosystem service and economic valuation literature. We defined our search criteria by combining the habitat types with each of the possible 21 valuation methods described in (TEEB, 2010). Given wide acceptability, we followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement as a guide for this review (Moher et al., 2010). We conducted the literature search using the Web of Science scientific citation database. We searched the titles, keywords and abstracts of all peer-reviewed articles published between 1900 and the end of 2016 using the following search criteria: (1) (mangrove∗ OR seagrass∗ OR saltmarsh∗ OR "salt marsh∗") AND ("ecosystem∗ servic∗") AND (valu∗); 2) (mangrove∗ OR seagrass∗ OR saltmarsh∗ OR "salt marsh∗") AND (economic) AND (valu∗) and 3) (seagrass OR mangrove OR saltmarsh OR "salt marsh") AND ("benefit transfer" OR "avoided cost" OR "conversion cost" OR "damage cost" OR "mitigation cost" OR "opportunity cost" OR "replacement cost" OR "restoration cost" OR "bio-economic modelling" OR "factor income" OR "production function" OR "consumer surplus" OR "hedonic pricing" OR "market price" OR "net price method" OR "public investments" OR "substitute goods" OR "travel cost method" OR "choice modelling" OR "contingent ranking" OR "contingent valuation" OR "participatory valuation"). We first excluded all non-English literature. This search terms resulted in a total of 565 articles. Once duplicates were removed, there were a total of 406 articles.

Given the structure of the Web of Science database, grey literature was inherently excluded. However, we recognize that many valuation studies that have been conducted for these habitats are not ultimately published in the peer-reviewed literature. Rather, they are published as working papers and government reports for specific purposes. In order to capture a selection of these valuation studies, we used the first and second search criteria on Google Scholar on December 31, 2016. This resulted in 4995 possible sources. Ultimately, we limited our review to the first 1000 publications as sorted by relevance, given that Google Scholar will not display more than the first 1000 publications that appear in a search.

There are likely additional grey literature publications on valuation studies for ecosystem services in these habitats that do not mention the specific key words included in our search criteria. However, it is not feasible to develop search criteria that will identify all possible valuation studies.

3.2. Selection criteria

In order to select articles to include in this review, as a first selection, we screened the 1406 publications (406 from Web of Science, 1000 from Google Scholar) (Fig. 2). We only retained publications if the title, abstract or key words mentioned the valuation of mangroves, seagrasses or salt marshes or if the content was unclear reading only the abstract. We also only retained publications published in 2007 or later in order to gather values published in the last 10 years. Through this second selection, we retained a total of 527 publications for full-text reading and analysis. We were unable to find the full text for seven publications. For those that we were able to locate, after reading the full-text, we included publications in the final selection only if they presented the results of a valuation study focused on the ecosystem services of mangroves, seagrasses or salt marshes. If a publication did not provide economic values of ecosystem services in mangroves, seagrasses or salt marshes, it was excluded from this analysis. We also excluded publications where ecosystem service values were calculated for a defined geographic area and could not be explicitly allocated for mangroves, seagrasses or salt marshes. In addition, publications were excluded if they provided values, but neglected to describe the methods used to arrive at those values. This resulted in 101 publications (7.2% of the screened publications) that were included in the analysis described in this paper. The studies are listed in Appendix A.

3.3. Data extraction

For those publications selected during the final selection phase, we reviewed the full text and extracted qualitative and quantita-

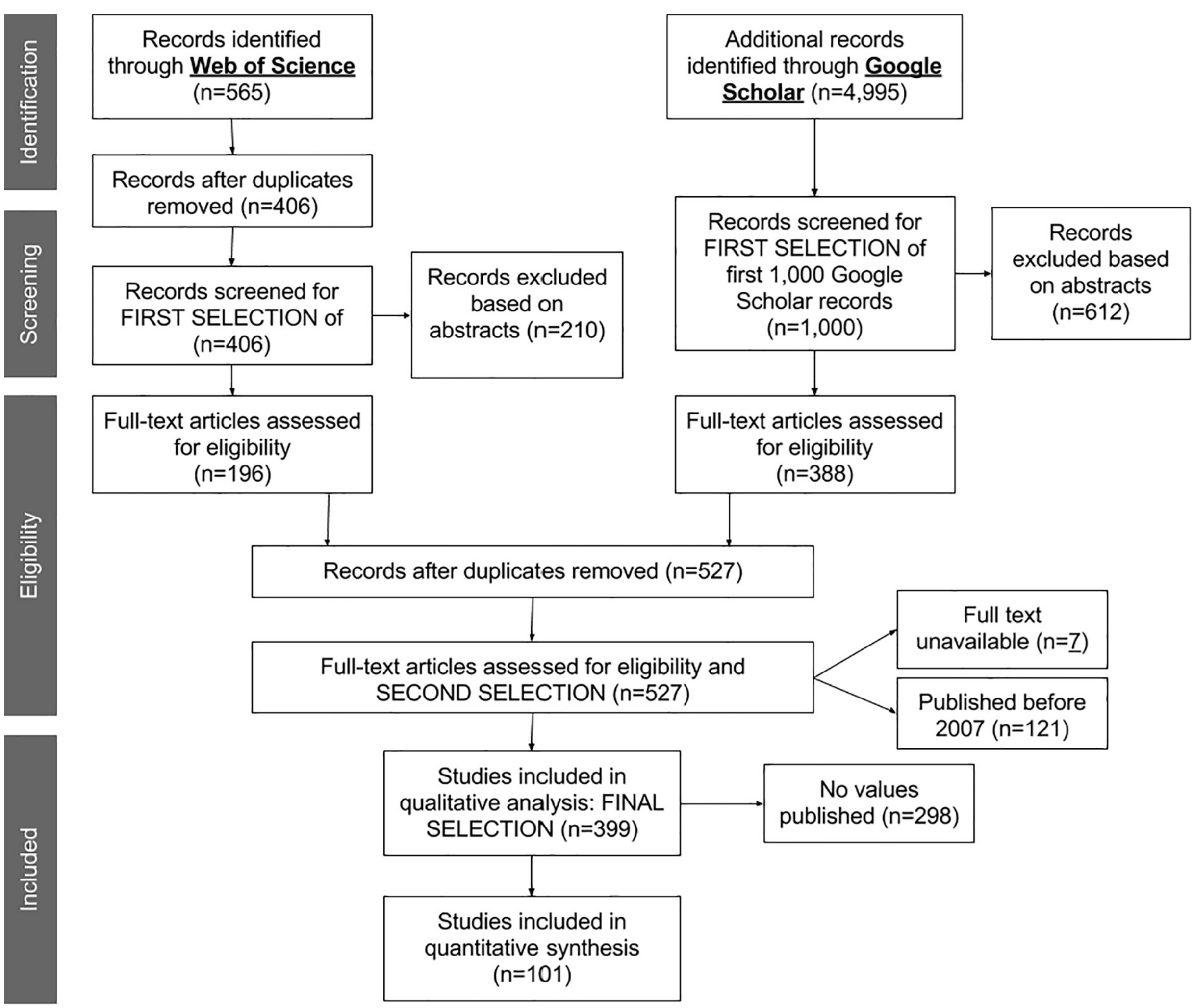

Fig. 2. Methodology and search criteria used in the systematic literature review following a modified version of the PRISMA (Preferred Reporting Items for Systematic Reviews) statement rules and template (Moher et al., 2010).

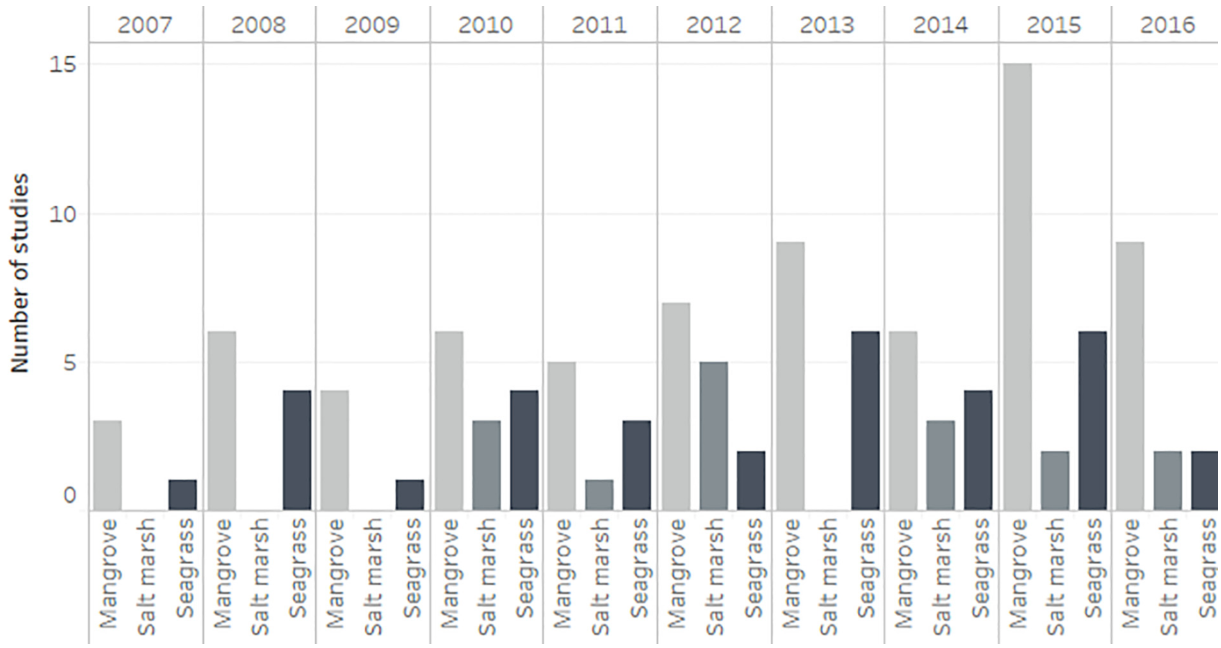

Fig. 3. Number of valuation studies published per year.

Table 2
Relative geographic distribution of valuation studies focused on each ecosystem by region.

Region	*Mangrove*		*Seagrass*		*Salt marsh*	
	# of studies	% of mangrove studies	# of studies	% of seagrass studies	# of studies	% of salt marsh studies
Africa	10	14%	1	3%	0	0%
Asia	37	53%	8	25%	1	7%
Australia and South Pacific	7	10%	4	13%	0	0%
Central and South America	4	6%	3	9%	0	0%
Europe	0	0%	9	28%	3	20%
Middle East	3	4%	1	3%	0	0%
North America	8	11%	5	16%	10	67%
Global	1	1%	1	3%	1	7%
Total	**70**		**32**		**15**	

tive data that could be used to compare and contrast valuation studies carried out in mangroves, seagrasses and salt marshes. For each publication, we extracted the publication year; type of publication; the ecosystems discussed; the geographic area where the study was conducted; threats to the studied ecosystems; the valuation methods used; and the estimated ecosystem service values. We also recorded the year for which the values were calculated. A small number of studies presented values that spanned two years. In these cases, we kept the earlier year (e.g., November 2014 to February 2015 was recorded as 2014). Ecosystem service values were organized into categories based on the classification scheme (Appendix 1) and valuation methodologies (Chapter 5) presented in TEEB (2010).

4. Results

In total, the literature review yielded 101 studies published between 2007 and 2016 in the peer-reviewed (n = 78) and grey (n = 29) literature where economic values were calculated for ecosystem services provided by mangroves, seagrass meadows or salt marshes. One of the studies published separate estimates for seagrass and salt marsh. Another study published two estimates for seagrass services, but in two different locations. Given this, our analysis separates the values and methods used in these two studies to ultimately represent an N of 103.

Overall, there has been a slight increase in the number of valuation studies conducted for blue carbon ecosystems over the last ten years, with 2015 showing a significant increase compared to other years. Researchers have evaluated mangrove ecosystem service values (N = 70) significantly more frequently than either seagrass (N = 32) or salt marsh (N = 15) ecosystem service values (Fig. 3). In general, mangrove valuation studies are concentrated in Asia (N = 37) and Africa (N = 10), with a small number of studies that were conducted in the other regions. Researchers have conducted small number of seagrass valuation studies in all regions. North America, on the other hand, dominates the literature on salt marsh valuation (Table 2, Fig. 4).

Although the studies have all been published in the last decade, the values that they report are frequently much older than the publication date. Over a third of the studies published values using data older than 2007, in some cases back to the 1990s. A third of the studies reported values for years between 2007 and 2011 and the final reported values for years after 2011 (Fig. 5). On average, studies reported value estimates that were 4.13 years old. However, there are numerous studies that report values that were over five years old at the time of publication, some as old as 14–16 years older than the publication date.

The majority of the studies described threats to the ecosystem of interest. Although the studies were not identical in terms of how they reported threats, the nomination of potential threats

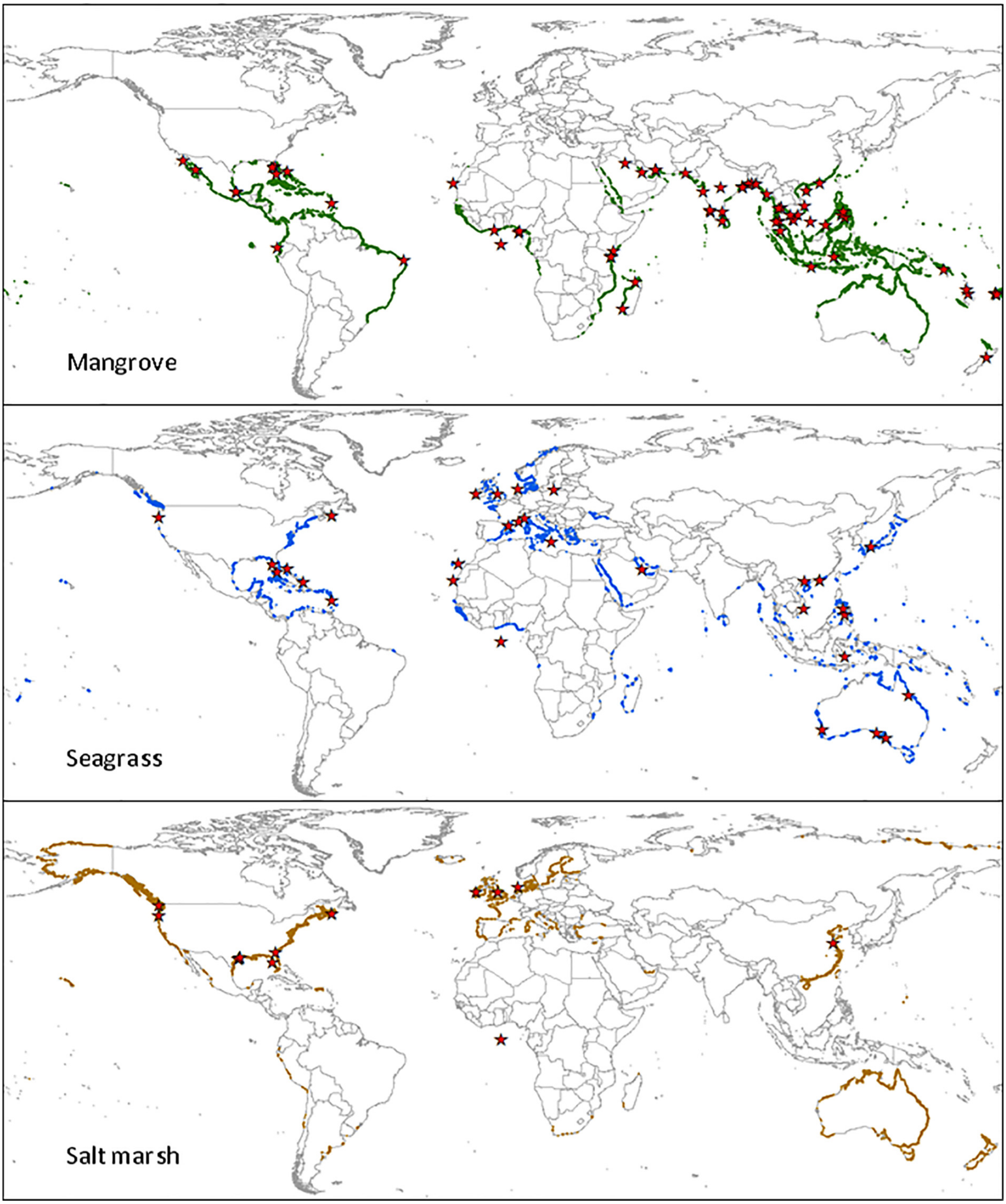

Fig. 4. Map of locations where ecosystem service valuation studies have been conducted for mangroves, sea grass meadows or salt marshes.

provides insight into the potential for changes in the area of intact blue carbon ecosystems as well as challenges that resource managers are likely faced with in each region. The studies place the most emphasis on threats associated with land conversion, pollution, deforestation, aquaculture and unsustainable resource use. The most cited threats in these studies have also been highlighted by the general literature on blue carbon ecosystems (Mcleod et al., 2011; Murray et al., 2011; Pendleton et al., 2012).

All combined, studies reported a total of 329 individual ecosystem service value estimates. Although the wider literature regularly cites the large number of ecosystem services and benefits provided by mangroves, seagrasses and salt marshes, valuation studies rarely attempt to calculate values for more than a select number of services. The studies in this review, for example, valued an average of 1.8 (North America) and 2.2 (Europe) to 4.1 (Asia) and 4.9 (Africa) ecosystem services per study. Furthermore, a

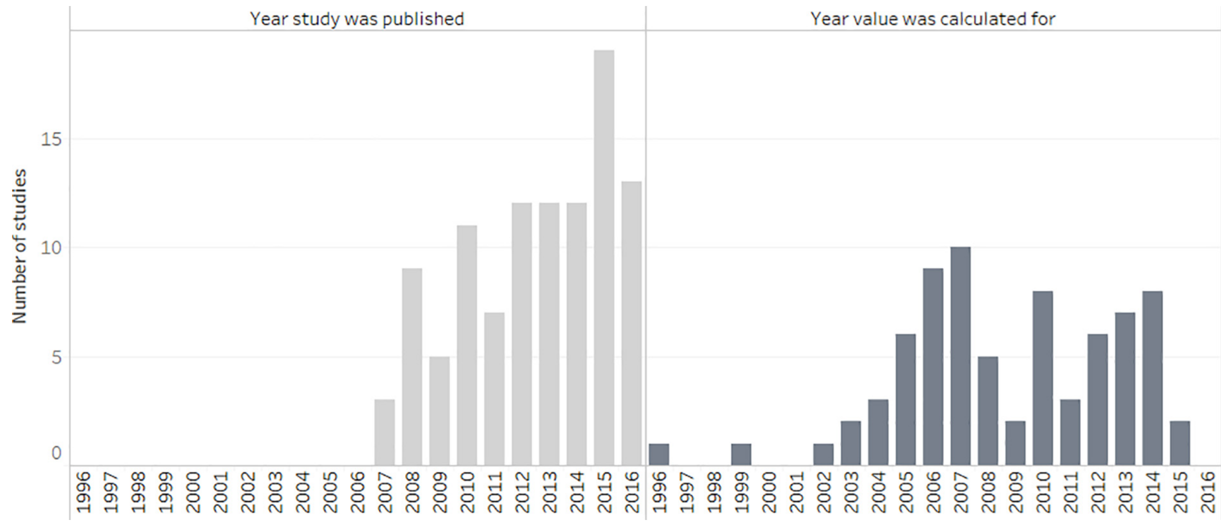

Fig. 5. Number of valuation studies by publication year compared to the year of their actual values.

Table 3
Frequency of studies that developed blue forest ecosystem service valuation estimates for each ecosystem service category over time, per the TEEB classification scheme.

		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total
Provisioning	Food	1	5	3	9	3	5	4	3	14	7	54
	Raw material	0	3	3	3	2	4	6	2	10	4	37
	Water	0	0	1	1	0	1	0	1	2	0	6
	Medicinal resources	0	1	0	0	0	0	1	0	1	0	3
	Genetic resources	0	0	0	0	0	0	0	0	1	0	1
	Ornamental resources	0	0	0	0	0	0	0	0	0	0	0
Regulating	Climate regulation	0	2	2	3	3	6	6	5	7	4	38
	Moderation of extreme events	3	3	2	3	1	3	6	2	8	4	35
	Waste treatment	0	4	2	1	1	4	1	3	6	2	24
	Erosion prevention	1	1	1	2	0	3	4	0	4	0	16
	Maintenance of soil fertility and nutrient cycling	0	2	1	2	1	1	1	1	1	0	10
	Regulation of water flows	0	0	1	1	0	1	0	0	1	0	4
	Biological control	0	0	1	0	0	0	1	0	0	1	3
	Air quality regulation	0	0	0	0	0	1	0	1	0	0	2
	Pollination	0	0	0	0	0	0	0	0	0	0	0
Supporting	Maintenance of life cycles of migratory species	3	2	1	2	1	4	5	3	4	2	27
	Maintenance of genetic diversity	0	1	0	1	1	1	1	1	1	1	8
Cultural	Opportunities for recreation and tourism	0	0	4	6	2	6	5	3	8	6	40
	Information for cognitive development	0	2	2	1	1	1	0	1	3	0	11
	Aesthetic information	0	0	1	1	0	2	1	1	0	1	7
	Spiritual experience	0	0	0	0	0	0	0	0	2	0	2
	Inspiration for culture, art and design	0	0	0	0	0	0	0	0	0	0	0

subset of ecosystem services tend to be valued much more frequently than others. For example, researchers tend to calculate values for food, opportunities for recreation and tourism, raw materials, moderation of extreme events, and climate regulation far more than any of the other ecosystem services provided by blue carbon ecosystems. In addition, provisioning services overall tend to be valued much more frequently than the other categories of ecosystem services (Table 3).

On the contrary, there are some ecosystem services that have rarely, or sometimes never, been valued. In particular, pollination, ornamental resources or inspiration for culture/art/design were never valued, for blue carbon ecosystems between 2007 and 2016. These trends are seen more clearly when valuation studies are divided into the region where the studies were conducted (Fig. 6). Cumulatively, studies conducted in Asia and Africa have valued many more ecosystem services than in other regions.

An analysis of the valuation studies reviewed here shows limited diversity in the employment of valuation methods that have been used to value the ecosystem services of blue carbon habitats (Fig. 7). Although some studies employed multiple valuation methods to value ecosystem services in their respective study areas, benefit transfer and market price dominate the valuation literature. The highest diversity of methods employed is seen amongst the Asian studies, followed by North America. Of the 17 methods that were used by the studies in this review, only benefit transfer was used by at least one study in every region. Market price was used by studies in all regions except for the Middle East. Factor income/production function and replacement cost are also used heavily. Conversely, half of the methods identified in TEEB (2010, chapter 5) as appropriate for valuing ecosystem services were not used at all between 2007 and 2016. These include avoided cost, bio-economic modelling, consumer surplus, contingent ranking, conversion cost, damage cost, mitigation cost, public investments, restoration cost, and travel cost method. However, four methods that were not included in TEEB (2010) were introduced in select studies: social cost of carbon and marginal abatement cost for valuing carbon sequestration, emergy analysis for valuing nutrient cycling, and expert survey for valuing genetic diversity. A sizeable

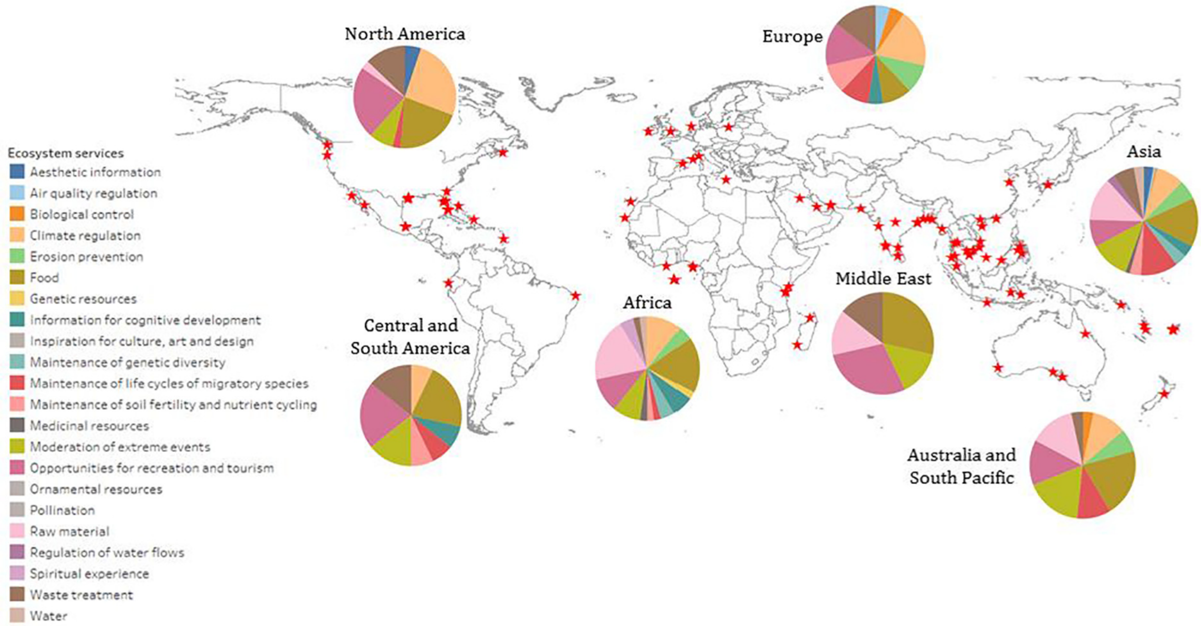

Fig. 6. Relative frequency of valuation studies that calculated values for blue forest ecosystem services by region. The stars represent the location of valuation studies included in this review.

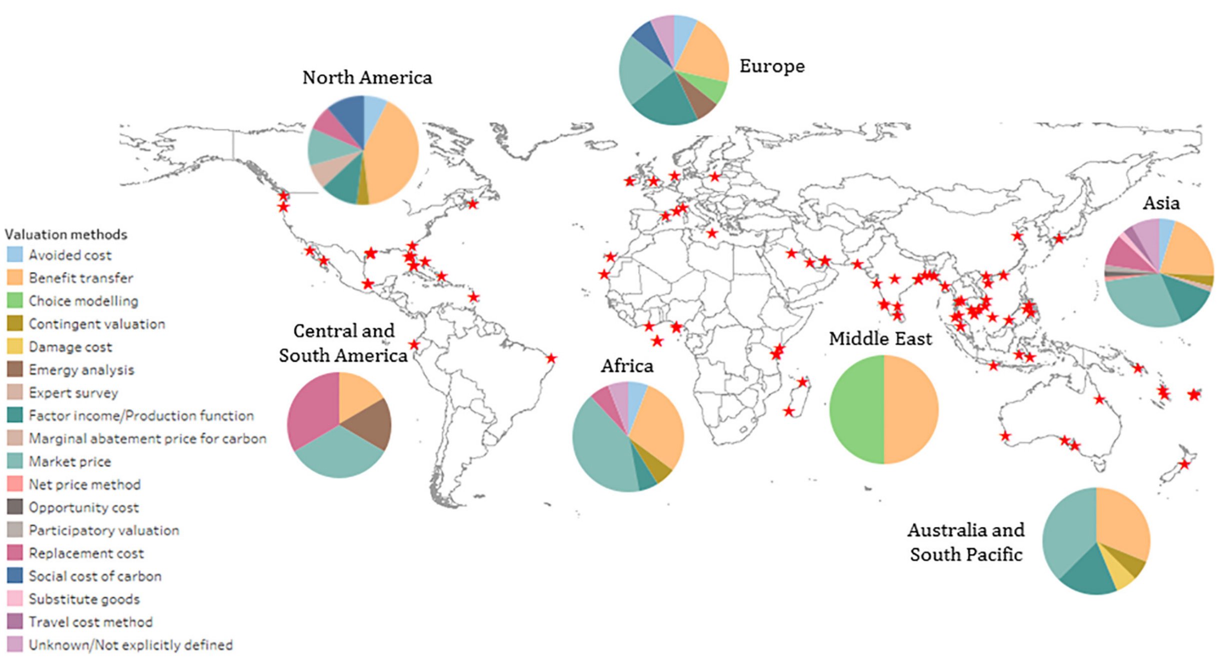

Fig. 7. Relative frequency of the use of valuation methods by region. The stars represent the location of valuation studies included in this review.

number of studies did not report the method they used to calculate ecosystem service values, representing 10% of the reported ecosystem service values.

In general, food and raw material provisioning and opportunities for recreation and tourism have been assessed using the most diverse set of valuation methods (Table 4). Benefits transfer has been used to value almost every category of ecosystem service provided by blue carbon ecosystems. Researchers have used market price to measure food, raw material, climate regulation (via carbon sequestration), and opportunities for recreation and tourism. Avoided cost and replacement cost are generally used to value waste treatment and moderation of extreme events. Production functions have been most frequently applied to food and nursery ground (i.e., maintenance of life cycles) provision. All of the other available valuation methods are rarely used. It should be noted that some of the methodologies are only applicable to a subset of ecosystem service categories (e.g., social cost of carbon can only be used to value carbon sequestration).

5. Discussion

Following the United Nations Ocean Conference in June 2017, 193 countries committed to a Call for Action and concrete steps

Table 4
Summary of valuation methods used by ecosystem service type and the relative magnitude of their use. Note that some of the methodologies are only applicable to a subset of ecosystem service categories.

Ecosystem service \ Method	Avoided cost	Benefit transfer	Bio-economic modelling	Choice modelling	Consumer surplus	Contingent ranking	Contingent valuation	Conversion cost	Damage cost	Factor income/ Production function	Hedonic pricing	Market price	Mitigation cost	Net price method	Opportunity cost	Participatory valuation	Public investments	Replacement cost	Restoration cost	Substitute goods	Travel cost method	Social cost of carbon	Marginal abatement cost	Emergy analysis	Expert survey	Unknown/Not explicitly defined
Food		10-15		1-2			1-2			6-10		>15				1-2		1-2								3-5
Water		3-5																								1-2
Ornamental resources																										
Genetic resources		1-2																								
Medicinal resources		1-2																								1-2
Raw material		10-15		1-2						1-2		>15		1-2	1-2	1-2				1-2						3-5
Waste treatment	1-2	10-15		1-2												1-2		3-5								1-2
Air quality regulation		1-2														1-2										
Moderation of extreme events	3-5	>15					1-2		1-2							1-2		6-10								3-5
Regulation of water flows		1-2																1-2								1-2
Erosion prevention		10-15							1-2									1-2								1-2
Climate regulation		6-10								1-2		>15			1-2	1-2						3-5	1-2			1-2
Maintenance of soil fertility and nutrient cycling		3-5														1-2		1-2						1-2		1-2
Maintenance of life cycles of migratory species	1-2	10-15								6-10		1-2				1-2										3-5
Maintenance of genetic diversity		3-5														1-2									1-2	1-2
Pollination																										
Biological control		1-2		1-2						1-2																
Spiritual experience		1-2																								
Aesthetic information		3-5														1-2										1-2
Opportunities for recreation and tourism		>15		1-2			3-5			1-2		6-10				1-2					1-2					3-5
Inspiration for culture, art and design																										
Information for cognitive development		3-5										3-5				1-2										1-2

# of studies: 1-2; 3-5; 6-10; 10-15; >15

to protect coastal ecosystems as a means of meeting Sustainable Development Goal 14 of the 2030 Agenda (UN General Assembly, 2017). Through the Call for Action, countries agreed to implement long-term and robust strategies to reduce the use of plastics and microplastics, to develop and implement effective adaptation and mitigation measures that address ocean and coastal acidification, sea-level rise and increase in ocean temperatures, to target the other harmful impacts of climate change on the ocean, and to enhance sustainable fisheries management. The Call for Action also includes specific measures to protect coastal and blue forest ecosystems, coral reefs, and wider interconnected ecosystems. Undertaking ecosystem service assessments and quantitative valuation exercises, such as those presented in this review, often provide key data used to identify conservation and management actions for these ecosystems (Pabon-Zamora et al., 2008; Pascual et al., 2017).

Despite a broad recognition of the importance of such data (Pascual et al., 2017; World Bank, 2016), we find that there are serious gaps in the valuation of blue forests, most notably involving methodology, coverage, ecosystem services valued, and the year values are from. First, there is a lack of variety and robustness in the valuation methods used. TEEB (2010) identifies 21 valuation methods that could be used to value ecosystem services, yet only half of these methods have been applied to blue carbon habitats. Moreover, benefits transfer and market price methods dominate the literature, with at least one of them used in 62% of the published studies and both methods used in 10% of the studies included in this review. This is likely due to how rapid a valuation can be completed since both methods are often low cost and convenient/fast, specifically because they rely on adjusting existing data to local conditions or readily available market values of products that come from blue forest ecosystems. As a result of a lack of primary data collection for many parts of the world, many studies use benefit transfer with little critical discussion given to the accuracy or validity of the valuation studies upon which these benefit transfers are based.

Values are regularly used without consideration for possible problems regarding the original valuation studies or relevance to the case study of interest. Using this review as an example, over 20% of the studies simply applied global value estimates to ecosystem services in their specific case study site. Only a third of the studies attempted to use values from source studies in the same country, but only a few of them used truly comparable sites for the transfer. None of the studies in this review used adjusted unit value transfer or function transfer and only one used meta-analysis in attempt to control for differences between the study site and transfer source.

Second, although mangroves are fairly well covered in the literature, seagrass and saltmarsh ecosystem services are poorly studied compared to mangroves, which are covered in 70 of the studies in this review. In particular, salt marsh ecosystem services valuations appear in only 15 studies and seagrass ecosystem services valuations appear in 32 studies (Table 2), despite the critical ecosystem services they provide and the fact that salt marshes account for a larger proportion of overall blue forest coverage (2.9%) than seagrass meadows (1.8%) globally (Table 1). There are also many areas of the world where valuation studies have not been completed or where there are limited studies available in English (e.g., Central and South America and Australia), despite the presence of blue carbon ecosystems in all regions of the world. In addition, Asian case studies (included in 45% of the studies although the region only accounts for 28% of blue forest ecosystem coverage) and North American case studies (included in 22% of the studies although the region only accounts for 3% of blue forest ecosystem coverage) are overrepresented in the valuation literature compared to the other regions. Valuation studies are particularly lacking in South and Central America and Africa, where 45% of the Earth's blue forest habitat area is located, but only 18 valuation studies were conducted between 2007 and 2016.

Third, certain ecosystem services are valued much more frequently than others (e.g., food is valued in 52% of studies, tourism is valued in 39% of studies), likely because market prices may be easily accessible for them. Several important services are poorly (i.e., valued in < 5% of studies) addressed (i.e., medicinal and genetic resources, air quality, regulation of water flow, biological control, spiritual experience) or entirely absent (i.e., ornamental resources, pollination, inspiration for culture/art) in the valuation literature, most likely due to poor data availability and the difficulty of quantifying the extent of service provision. The fact that humans benefit from many social and cultural ecosystem services that blue forest ecosystems provide is important to note. Many of these services cannot be valued by economic methods. Therefore, additional methods must be developed to adequately account for these services in policy decisions. Another important consideration is to whom the identified ecosystem services accrue (e.g., local population vs. tourists, poor/vulnerable communities vs. affluent sectors of the population, etc.).

Fourth, even though we focus here on studies published in the last 10 years, the data used in the studies was on average over 4 years old at the time of publishing, and sometimes over a decade old. This indicates that the majority of existing value estimates may not reflect current values of these ecosystem services. This can pose a significant problem for studies that rely on benefit transfer, as an example, by perpetuating old values in consecutive studies and potentially undervaluing/overvaluing the ecosystem services of blue forest ecosystem services.

It is imperative to note some methodological concerns regarding valuation. There are a number of problems that can arise through the use of benefit transfer, although rarely are these problems thoroughly discussed in valuation studies. A key to economic valuation is to reflect the relative socio-economic importance of the services and benefits that ecosystems provide to local communities and beyond and to properly reflect economic decisions related to those services (Emerton, 2014). However, values estimated using benefit transfer are often created using values that were originally created by statistically extrapolating value estimates to entire biomes (e.g., Costanza et al., 2014; de Groot et al., 2012). As Pendleton et al. (2016) note, this tends to inflate value estimates. In addition, these global value estimates are not appropriate at the local level given differences in context and how individual communities value services and benefits provided by their local ecosystems. In addition, it can be highly inaccurate to use values for one site that were originally calculated for another site with very different biophysical, ecological and socio-economic characteristics (Emerton, 2014; Troy and Wilson, 2006). O'Higgins et al. (2010) further criticizes the benefit transfer method by highlighting the need for primary data collection given that every site has unique ecological systems, threats, economic externatialies and social contexts. It is therefore important to carefully scrutinize the source of the value estimates being used and thoroughly discuss the potential issues that the source value could have on the case study of interest.

A second methodological issue arises through very different methodological approaches that are take to estimate the value of carbon sequestration and storage. Many studies use carbon offset prices from regulated and voluntary markets. While this approach could reflect foregone financial revenues that could be had by the "ecosystem owner", in practice very few payments have been made for blue carbon. Furthermore, the prices used in studies vary across countries and markets and are influenced by technological, regulatory, economic and social factors. The UK Government uses abatement costs as a measure of the value of carbon, but these estimates assume the value of blue carbon is that it displace the next "least cost" carbon sequestration measure (Department of Energy and Climate Change, 2009). Economic valuation studies that use the social cost of carbon attempt to capture the net economic impact of carbon emissions and so provide a theoretically more appropriate measure of the net economic benefit of the avoided carbon emissions provided by blue carbon ecosystems (National Academies of Sciences, 2017). Nevertheless, even social cost of carbon estimates vary by methodology, model, and assumptions about the discount rate (e.g., values range from $5 (Pearce, 2003), to $50 (Tol, 2005), to $312 (Stern, 2007), respectively). Only 4 of the 36 of the studies in this review that estimated values for carbon sequestration attempted to address the social cost of carbon (Cooper et al., 2012; Jerath, 2012; Jerath et al., 2016; Reddy et al., 2016) and only two studies provided value estimates using multiple methods, namely market price, marginal abatement cost and social cost of carbon (Jerath, 2012; Jerath et al., 2016).

Another concern arises with the use of the replacement cost method that is commonly used to estimate the value of shoreline protection provided by these ecosystems. Replacement cost approaches were used in 11 of 103 studies, half of which were published recently in 2015. The replacement cost method suffers from the fact that unless the analyst can be certain that the proposed replacement would be undertaken, the cost could exceed the willingness to pay for the service lost (perhaps substantially since there is no upper bound) (See Barbier (2016) for a critique).

Lastly, in order to comprehensively assess ecosystem services, there are some key ecological considerations to keep in mind. It is necessary to incorporate the multiple and synergistic characteristics of these ecosystems (Barbier, 2012). However, studies continue to value each service independently, but ecological interactions suggest that there is a connectivity between these coastal ecosystems, which impacts the availability and/or quality of the services (Barbier et al., 2011). By assessing ecosystem services collectively, studies could better delineate between functions, services, and benefits to avoid the problem of double counting that may arise due to the fact that some services (i.e. supporting and regulating services) are inputs to the production of others (Boyd and Banzhaf, 2007; Fisher et al., 2009; TEEB, 2010). Finally, ecosystem services are not uniform across a seascape: there are spatial differences (i.e. extent of a mangrove forest and its ability to stop storm waves) and temporal differences (seasonal fluctuations and density of biomass of seagrass). This variability may influence the economic value of some services and should be considered by researchers and policymakers alike (Barbier et al., 2011).

6. Conclusion

Blue forest ecosystems are known to provide a wide range of ecosystem services and benefits that contribute to local community well-being, livelihoods, and food security (Hejnowicz et al., 2015; Lau, 2013; Salem and Mercer, 2012). As the importance of these ecosystems has moved to the forefront of international climate change and conservation discussions, the demand has grown for analysis of which ecosystems and ecosystem services have the highest value to people (Richardson et al., 2015). In parallel, resource managers and policy makers are regularly faced with making decisions and trade-offs regarding human use of coastal and marine resources, as well as weighing the potential benefits of investments in blue forest conservation and restoration

(Atkinson et al., 2016; Martín-López et al., 2014). Economic valuation has emerged over recent decades as a key tool for informing these decisions (Pascual et al., 2017; TEEB, 2010). Refinements to valuation methodologies in recent years have been improving the accuracy of ecosystem service values of blue forests. Improvements in the valuation literature are particularly important for the development of appropriate Payment for Ecosystem Services (PES) schemes (e.g., bundling or stacking of PES opportunities with blue carbon payments) and communicating the value of blue forest ecosystems to national and international policymakers.

Although, research on valuation methods has evolved significantly over the last four decades, resulting in an expansion of the literature base, more needs to be done to improve where and how these methods are applied. Many ecosystem services provided by mangroves, salt marshes, and seagrasses remain poorly studied, especially indirect use values and non-use values. Given the recent focus on blue carbon ecosystems in the realm of international conservation (e.g., the Paris Agreement, UN SDG 14), coastal managers would benefit from an increase in valuation of the ecosystem services provided by blue forests. Based on our review, we recommend that future valuation studies focus on broadening the ecosystem services that are valued beyond those that can easily be valued using their market price, for example, the provision of drinking water and medicinal products, water flow regulation, biodiversity, and cultural values aside from tourism and recreation. We also find that not enough new, primary valuation estimates are available in the literature. While the benefit transfer method is one of the most common valuation methods used, it risks recycling old value estimates without pushing our base of knowledge forward. In general, we caution that an over-reliance on particular methods, such as benefit transfer, may limit the robustness of value estimates and may perpetuate biased estimates. There remain problems with continued use of replacement cost and the mis-use of carbon prices to estimate the economic value of carbon storage and sequestration. Future valuation studies should attempt to apply a broader array of existing methods, with a focus on collecting primary data to support those methods. The application of future blue forest valuation studies should strive to avoid these valuation "traps" and should focus on developing more rigorous valuation estimates.

Lastly, we recommend an increase in the geographic coverage of valuation studies in order to improve value estimates by region and ecosystem type. South America and the Middle East are not well represented in the literature for any of the blue forest ecosystems. The seagrass valuation literature is also particularly sparse in North America, Africa and the Island nations between southeast Asia and Australia. Salt marsh valuation studies are noticeably absent from Australia, Asia and southern Europe. Although there have been many more mangrove valuation studies, there are still gaps in the application of valuation methods to mangroves in Australia and the island nations to the north, which are home to substantial areas of mangrove forests.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ecoser.2018.01.006.

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