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Mangrove Ecosystem Service Values and Methodological Approaches to Valuation: Where Do We Stand?

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Mangroves, seagrass meadows, and salt marshes, collectively termed "Blue Forests," are counted among the most valuable and productive coastal ecosystems on the planet. A recent literature review of the Blue Forest valuation research identified mangroves as the most frequently analyzed of these ecosystems, yet the literature demonstrates several deficits in terms of geographic location of studies, methods used to value the services, and most notably, a lack of valuation for cultural services. To better understand this, we analyzed the studies dealing specifically with mangroves from the original literature review to quantify what has been valued, where, by which methods, and the variation in the published values. We then use this information to synthesize our current level of knowledge on the type and value of services provided by mangroves, discuss data gaps, and address specifically the collection of data relevant to cultural ecosystem services (CES). Our results shed light on two principle issues affecting the mangrove valuation literature: overuse of benefit transfer in valuing mangrove ecosystem services and a lack of attention paid to the CES that mangroves provide. The mangrove valuation literature is not yet robust, lacking estimates of many ecosystem services, including CES, such as spiritual and aesthetic value. Most published studies focus on a small selection of ecosystem services based on the availability of benefit transfer values and the ability to easily measure values with market prices. Thus, many ecosystem services that cannot be valued monetarily, but that are often equally important to local communities, are ignored. Given the wide range of ecosystem services mangroves provide and the variety of valuation methods that need to be collectively employed, we argue that doing valuation studies well requires a multi-disciplinary approach, bringing together anthropologists, social scientists, ecologists and economists. Thoughtfully and thoroughly including the local stakeholders in valuation studies and the resultant policy discussions leads to a more holistic understanding of the services mangroves provide, and viable solutions with an increase in local willingness to act in accordance with those solutions.

Keywords: ecosystem services, mangrove, economic valuation, cultural ecosystem services, benefit transfer

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INTRODUCTION

Coastal vegetated ecosystems, such as mangroves, seagrass meadows, and salt marshes, are considered to be some of the most valuable and productive coastal ecosystems on the planet (Barbier et al., 2011; Mcleod et al., 2011; Wylie et al., 2016). Collectively termed "blue forest ecosystems," international climate and conservation discussions have been focusing on these habitat types (Pendleton et al., 2012; Himes-Cornell et al., 2018). One of the most talked about blue forest ecosystem services has been carbon sequestration/storage due to the growing recognition of the effectiveness of these habitats in climate regulation through pulling carbon out of the atmosphere (Murray et al., 2011; Pendleton et al., 2012). In addition, these habitats provide a number of important ecosystem services and benefits that contribute to poverty alleviation and food security, including food and raw material provision, opportunities for recreation and tourism, and moderation of extreme events as some of the more commonly cited services (Barbier et al., 2011; Brander et al., 2012; Salem and Mercer, 2012; Sandilyan and Kathiresan, 2012; Mukherjee et al., 2014; Barbier, 2016).

Mangrove forests in particular are the focus of many international conservation discussions. Despite the breadth and quantity of services that mangrove ecosystems provide, they are being degraded or lost at an alarming rate (Millennium Ecosystem Assessment, 2005; Barbier, 2012; Tallis et al., 2012). In response, researchers have been increasingly applying economic valuation methods to quantify ecosystem service provision as a tool for decision makers and conservation advocates (Barbier et al., 2011). The valuation of ecosystem services is a way of evaluating what society is willing to trade off to conserve a particular ecosystem service by either quantitatively or qualitatively assessing its value (TEEB, 2010). The aim of such an exercise is to inform policy or management decisions by providing a better understanding of what services and benefits an ecosystem provides to people and how the services might change under different management scenarios (Pendleton et al., 2015). They highlight who benefits, how they benefit, and where they benefit. In addition, ecosystem service assessment and valuation can improve ecosystem management through the enhanced recognition of these values in decision-making. It can also improve knowledge for informed decision-making, raise awareness on blue forest ecosystems, and to foster cooperation among blue forest stakeholders.

Although the vast majority of studies reported in the valuation literature are focused on specific ecosystems and geographic locations, Costanza et al. (1997) and de Groot et al. (2012) have provided estimates of the global values of ecosystem services based on previously published values. However, Costanza et al. (1997) calculated values for only 6 of the 20 ecosystem service categories (refer to **Table 4** for a complete listing) that are currently recognized in the literature (TEEB, 2010). de Groot et al. (2012) attempted to update those values and provided values for an additional seven ecosystem services by adding more recent valuation study data as well as estimates from older studies that were not included in the original 1997 publication. Similar to Costanza et al. (1997), de Groot et al. (2012) did not value the non-market cultural services of these ecosystems. While incomplete, practitioners in many regions of the world have relied on these global estimates in order to generate at least a first set of ecosystem service values for their respective case studies.

Himes-Cornell et al. (2018) identified the benefits transfer method (also referred to in the literature as "value transfer") as one of the most commonly used in blue forest ecosystem service valuation studies. This technique allows the researchers to transfer ecosystem service values calculated in previous studies done in a similar ecosystem to the system they are studying. This method circumvents the need for costly and time-intensive field studies (TEEB, 2010). There are several different methods, of various complexity, by which benefits transfer can be calculated. All ultimately include taking values from a "policy" site and converting them using parameters that can vary depending on the researcher's study questions and assumptions, to convert them into something relevant to the "study" site (TEEB, 2010). The resulting values are presented in terms of "value per unit are of ecosystem," or more rarely "value per beneficiary" (i.e., per person our household). This last term is complicated to calculate, because in many cases the beneficiaries are difficult to identify (TEEB, 2010).

In recent years, researchers have published a number of studies that provide general and site-specific values for mangrove ecosystem services (e.g., Camacho-Valdez et al., 2014; Amarnath and Mouna, 2016; Atkinson et al., 2016; Jerath et al., 2016; Mashayekhi et al., 2016; Mojiol et al., 2016; Sopheak and Hoeurn, 2016; Susilo et al., 2016). Although many advances have been made in the last few years there are still many challenges associated with unlocking the values of mangrove, and more generally coastal, ecosystem services and converting them into options for improved ecosystem management. The science still contains many gaps, there are very few "proof of concept" on-the-ground examples around the world, and the international community still does not fully recognize the value of these systems.

One of the gaps in unlocking the full value of ecosystems to humanity is in understanding the "Cultural Ecosystem Services (CES)" they provide. Even the definition of CES is ambiguous and therefore interpreted differently by different research groups (Daniel et al., 2012). The Millennium Ecosystem Assessment (2005) defined CES as "*the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.*" Despite the examples of CES the Millennium Ecosystem Assessment (2005) provides, this definition remains vague, primarily because these services have an emotional, rather than market value. An exception is "recreation and ecotourism," a benefit that is relatively straightforward to quantify monetarily (Garcia Rodrigues et al., 2017). Consequently, recreation and ecotourism are frequently included in valuation studies. In contrast, the rest of the values (i.e., spiritual, religious, aesthetic, inspiration, and sense of place) are very difficult to quantify, will vary with each culture and stakeholder group in question, and are even more difficult to quantify monetarily. This type of CES has been given the label "intangible," because not only are they difficult to identify, they are enmeshed with multiple

aspects of a peoples culture and ecosystem use (Chan et al., 2012b; Satterfield et al., 2013; Pert et al., 2015). Even with "recreation and ecotourism," it is questionable whose values are being quantified – the local stakeholders, or stakeholders further afield from a different population. Yet determining the cultural values of mangroves is important; for the local community and primary stakeholders these values represent an important facet of their lives, livelihood, and cultural identity. Recognition of these benefits and their inclusion in data collection is important for generating community investment in conservation actions and identifying the true cost of the decisions being made.

The primary goal of this paper is to explore the following questions: (1) Is the current literature robust enough to give us an accurate understanding of mangrove value? (2) Where do we stand on evaluating mangrove CES? Through a systematic literature review, we shed light on these issues and present considerations that should be kept in mind when valuing the ecosystem services provided by mangrove ecosystems. We assess these issues by reviewing some of the most widely cited ecosystem service valuation literature. We then show how the use of valuation methods for mangroves has changed over recent years and summarize the range of values that studies have produced. We compare our results to those in the three most frequently cited studies (Costanza et al., 1997, 2014; de Groot et al., 2012) to better understand the role of potentially changing methods in their estimates and we provide guidance about which valuation methods to use for which ecosystem services. Finally, the discussion explores the risks of relying on benefit transfer and a notable gap in the valuation literature related to CES.

MATERIALS AND METHODS

This study is an expansion of a previous study that analyzed the ecosystem service literature for blue forest ecosystems (Himes-Cornell et al., 2018, see this publication for a complete description of the literature review methods). The present study focuses on the 70 papers found in that study that attempted to value mangrove ecosystem services. Himes-Cornell et al. (2018) presented the results of a systematic literature review of papers published in the peer-reviewed literature and as gray literature between 2007 and 2016 (Himes-Cornell et al., 2018). The literature review identified the most recently published studies that present the results of a valuation exercise for mangrove, seagrass, and salt marsh ecosystems. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement as a guide for this review (Moher et al., 2010). First, we searched the titles, keywords, and abstracts of all peer-reviewed articles published between 2007 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"). Since economic values change over time, we limited the search to papers published after 2007 to ensure the data presented were recent and economically relevant. A total of 1,406 publications were screened, with only those publications that reported the results of a valuation study for one of the blue forest habitats and were in English being retained. Ultimately, 101 publications were identified, 70 of which reported values of ecosystem services produced by mangrove forests. For the present study, we extracted the publication year; the geographic area where the study was conducted; the valuation methods used; and the estimated ecosystem service values from these 70 papers. We organized ecosystem service benefits and valuation methods into categories based on the classification scheme published in TEEB (2010).

Given the CES gap in the literature, we gave particular attention to the papers in the literature review that included CES in their analyses. We determined what percentage of our mangrove literature review these papers comprised, what geographic location they represented and how they addressed CES. We asked what CES they identified, how they were defined, and how the authors valued them.

We then compare and contrast three frequently cited papers in the ecosystem service valuation literature for coastal habitats: Costanza et al. (2014, 1997) and de Groot et al. (2012). We summarize the methods used and values published in these papers, and compare those values to the summarized ecosystem service values generated with primary data collected for studies found in our literature review.

RESULTS

Overall, 70% of the mangrove studies we reviewed were published in the peer-review literature, 19% were published in the gray literature, and the remaining 10% were published as graduate degree theses. Here, we present results of the review of these mangrove ecosystem service valuation studies in terms of the relative frequency (proportion) of methods used, how methods are applied across geographical regions, and trends over time in the use of each method.

Relative Use of Valuation Methods

For mangroves, benefit transfer is by far the most utilized valuation method (**Table 1**). The data presented in **Table 1** show that market price method is the predominant valuation method for services that are paid for directly (i.e., food, raw material, carbon sequestration, recreation, and tourism), while benefit transfer is heavily used to value all other ecosystem services except for air quality regulation. Of those mangrove valuation studies published between 2007 and 2016, 32 of the 70 (45.7%) studies used benefit transfer to estimate the value of ecosystem services. With the exception of air quality regulation, all of

TABLE 1 | Count of studies using the valuation methods described in TEEB (2010) between 2007 and 2016 for each ecosystem service provided by mangroves.

Ecosystem service category	Ecosystem service	Avoided cost	Benefit transfer	Choice modeling	Contingent valuation	Damage cost	Factor income/production function	Marginal abatement cost	Market price	Net price method	Opportunity cost	Participatory valuation	Replacement cost	Social cost of carbon	Substitute goods	Travel cost method	Unknown/not explicitly defined
Provisioning	Food		12	1	1		6		20			1					2
	Genetic resources		1														
	Medicinal resources		1														1
	Raw material		10	1			2		15	1	1	1			1		3
	Water		5														1
Regulating	Air quality regulation											1					
	Biological control		1				1										
	Climate regulation		7				2	2	10		1	1		2			2
	Erosion prevention		10			1											2
	Maintenance of soil fertility/nutrient cycling		3									1	1				1
	Moderation of extreme events	2	17		1	1						1	5				3
	Regulation of water flows		2										1				1
	Waste treatment	1	9									1	3				1
Supporting	Maintenance of genetic diversity		5									1					1
	Maintenance of life cycles of migratory species	1	10				4		2			1					3
Cultural	Aesthetic information		2									1					2
	Information for cognitive development		3						4			1					1
	Opportunities for tourism and recreation		11	1	2		1		7			1				2	3
	Spiritual experience		2														

the ecosystem services were valued at least once using benefit transfer. All other valuation methods have been used relatively infrequently. There are five studies that reported values for a wide variety of mangrove ecosystem services but did not define what method they used to calculate those values (Khaleel and Jaleel, 2009; Hussain and Badola, 2010; Pernetta et al., 2013; Ajonina et al., 2014; Susilo et al., 2016). The full range of mangrove value numbers published in the literature between 2007 and 2016 are presented in the **Supplementary Appendix** by ecosystem service and year.

Geography of Method Application

We then looked at what and how ecosystem services have been valued based on geographic regions. The mangrove valuation studies we identified in this review are distributed across global mangrove habitat, with some regions being more thoroughly studied than others (**Figure 1**). The mainland areas of South and Southeast Asia have the greatest coverage of peer-reviewed literature. While some mangrove valuation studies have been conducted in and published for Oceania (Australia and the Pacific Islands), Indo-Malaysia, Africa, and Central and South America, there are still large portions of these regions for which valuation studies have not been published. Furthermore, mangroves in the Red Sea, Australia, and central Oceania do not appear to have been valued at all, despite extensive coverage of mangroves along their coastlines.

The relatively large number of studies conducted in Asia used a wide representation of valuation methodologies, whereas studies conducted in other regions employed a limited selection

FIGURE 1 | Global distribution of mangrove forests and local site specific mangrove valuation studies published between 2007 and 2016 in **(A)** southeast Asia, Australia and Oceania, **(B)** Africa and South Asia and **(C)** the Neotropics. Source for the mangrove forest distribution layer: Spaulding et al. (in preparation).

of available methodologies (**Table 2**). In fact, many methods were only ever used in Asian case studies (e.g., net price method, opportunity cost, participatory valuation, substitute goods, and travel cost method). Benefit transfer was used at least once in all regions, potentially due to the fact that there is often limited ability to do primary research. With regards to valuing carbon, only case studies in North America applied marginal abatement cost and the social cost of carbon methods.

Similarly, studies conducted in Asia valued a large range of mangrove ecosystem services (**Table 3**). Studies conducted in Africa showed comparable diversity in which services were valued. Only food, waste treatment, and opportunities for recreation and tourism were valued in all regions. Most other services were only valued in one or two regions. In addition, four services were never valued for mangroves in any region: ornamental resources, pollination, and inspiration for culture, art, and design (**Table 3**).

TABLE 2 | Count of studies published between 2007 and 2016 that used each valuation method by region of the case study.

Valuation method	Africa	Asia	Australia and South Pacific	Central and South America	Middle East	North America
Avoided cost	1	3				
Benefit transfer	5	12	5	1	1	1
Choice modeling					1	
Contingent valuation	1	2				
Damage cost			1			
Production function	1	7	2			2
Marginal abatement price						2
Market price	7	14	2	2		2
Net price method		1				
Opportunity cost		1				
Participatory valuation		1				
Replacement cost	1	4		2		1
Social cost of carbon						2
Substitute goods		1				
Travel cost method		2				

TABLE 3 | Count of studies published between 2007 and 2016 that valued each ecosystem service category by region of the case study.

Ecosystem service	Africa	Asia	Australia and South Pacific	Central and South America	Middle East	North America
Food	8	21	6	3	2	3
Water	1	5				
Ornamental resources						
Genetic resources	1					
Medicinal resources	1	1				
Raw material	9	20	4		1	1
Waste treatment	1	8	1	2	1	2
Air quality regulation		1				
Moderation of extreme events	4	18	5	2	1	
Regulation of water flows		4				
Erosion prevention	2	9	2			
Climate regulation	5	13	1	1		6
Maintenance of soil fertility and nutrient cycling	1	5				
Pollination						
Biological control		1	1			
Maintenance of life cycles of migratory species	1	17	2	1		
Maintenance of genetic diversity	2	5				
Spiritual experience	2					
aesthetic information		5				
Opportunities for recreation and tourism	5	14	3	3	2	1
Inspiration for culture, art, and design						
Information for cognitive development	3	5		1		

Trends Over Time in the Use of Benefit Transfer

Although there is a broad use of valuation methodologies in the mangrove valuation literature, across all ecosystem services, there is a relatively high use of benefit transfer to calculate values (**Table 1**). The relative proportion of studies using benefit transfer varied significantly between 2007 and 2016 ($\chi^2 = 9.447$, $df = 9$, $p < 0.05$), with the most studies being published in 2012, 2013, and 2015 (**Figure 2**). The time between publication of the benefit transfer study and the original date of the studies referenced has remained relatively stable between 8 and 12 years old, with a dip to 3 and 5 years, respectively, in 2014 and 2015 and a spike of 17 in 2016. By comparison, for studies that relied on primary data collection, the average time between publication and data collection is only 4.4 years. Twelve of the studies using benefit transfer (37.5%) relied on valuation studies that also relied on benefit transfer to calculate values, meaning the final published values are even older than the papers indicated (Costanza et al., 1997; Brander et al., 2012; Salem and Mercer, 2012).

Value estimates from benefit transfer studies do not often reflect the overall value estimates from primary studies. For example, **Table 4** shows that the average value of food and climate regulation estimated by benefit transfer studies is significantly less than the average value from primary studies. The benefit transfer estimates for raw material, medicinal resources, and information for cognitive development are also less than primary value estimates. On the other hand, benefit transfer estimates of the value of waste treatment, moderation of extreme events, maintenance of soil fertility and nutrient cycling, aesthetic information, and opportunities for recreation and tourism are higher than those of primary studies. Erosion prevention and maintenance of life cycles of migratory species are the only two ecosystem service categories where benefit transfer studies do not appear to affect average values.

We also compared the studies compiled through this review to the results published in Costanza et al. (1997) and de Groot et al. (2012), who use benefit transfer to estimate the global value of ecosystem services by ecosystem type. These studies have been cited more than 8,239 and 398 times, respectively (based on the Web of Science database) and form the bases of many benefit transfer valuation studies, both in the gray and peer-reviewed literature. Costanza and de Groot's teams used values from multiple studies to calculate an average, unit value (per unit area) and then multiplied that average by the estimated global area of a set of biomes based on global land use maps. For the purpose of comparison, here, we compare the 1994 (Costanza et al., 1997) and 2007 (de Groot et al., 2012) values from these two papers for "tidal marsh and mangroves" and "Coastal wetlands (tidal marsh, mangroves, and salt water wetlands)," respectively, to the average values identified in the present literature review (**Table 4**). Costanza et al. (2014) compared the change in ecosystem service value between 1994 and 2007 and found that the total ecosystem service value for these coastal habitats had increased significantly, particularly for waste treatment, maintenance of life cycles of migratory species, and opportunities for recreation and tourism.

To compare the published values from these global studies with case study values in our literature review, we calculated the average value of ecosystem services published in between 2007 and 2016 for: (1) all mangrove studies, (2) studies employing all methods except benefit transfer, and (3) only benefit transfer studies (**Table 4**). There are a number of notable differences between these average values published for case studies and those presented in Costanza et al. (1997) and de Groot et al. (2012). The values for waste treatment, maintenance of genetic diversity, and maintenance of life cycles of migratory species across all three categories are much less than those reported in

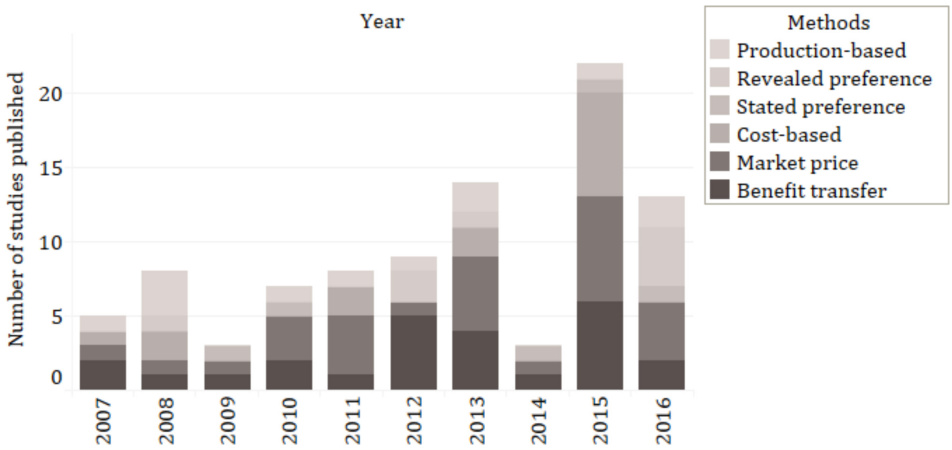

FIGURE 2 | Use of valuation methods between 2007 and 2016. Methods are categorized as follows: cost-based methods include avoided cost, conversion cost, damage cost, mitigation cost, opportunity cost, replacement cost, and restoration cost. Stated preference methods include choice modeling, contingent ranking, contingent valuation, and participatory valuation. Revealed preference methods include consumer surplus, hedonic pricing, marginal abatement price for carbon, net price method, public investments, social cost of carbon, substitute goods, and travel cost method. Production-based methods include bio-economic modeling, analysis, and production function.

TABLE 4 | Values and methods from papers in the mangrove valuation literature.

	Costanza et al. (1997)	de Groot et al. (2012), Costanza et al. (2014)	Literature review conducted for this study		
	Tidal marsh and mangroves	Coastal wetlands (tidal marsh, mangroves, and salt water wetlands)	Mangroves		
	Units: 1994 US$/ha/year	Units: 2007 US$/ha/year	Units: US$/ha/year (values have not been standardized – average year of values is 2009)		
Ecosystem service category	**Value**	**Value**	**Avg. value across all studies**	**Avg. value excluding benefit transfer studies**	**Avg. value of benefit transfer studies**
Food	466	1,111	8,319	24,312	3,609
Water	–	1,217	799		799
Raw material	162	358	2,591	3,074	86
Genetic resources	–	10	–	–	–
Medicinal resources	–	301	97	173	20
Ornamental resources	–	–	–	–	–
Waste treatment	6,696	162,125	2,827	72	3,286
Climate regulation		65	34,756	138,233	313
Erosion prevention	–	3,929	930	858	744
Moderation of extreme events		5,351	1,086	455	1,316
Maintenance of soil fertility and nutrient cycling	–	45	428	3	640
Regulation of water flows	–	–	600	–	600
Biological control	–	–	797	–	797
Pollination	–	–	–	–	–
Maintenance of genetic diversity	–	6,490	82	–	82
Maintenance of life cycles of migratory species	169	10,648	1,472	1,475	1,456
Aesthetic information	–	–	256	11	500
Information for cognitive development	–	–	276	477	75
Opportunities for recreation and tourism	658	2,193	3,526	1,024	6,627
Spiritual experience	–	–	–	–	–

The ecosystem service categories were adopted from TEEB (2010). Units: US$/ha/year (values have not been adjusted to a constant year, average year for values considered is 2009).

de Groot et al. (2012). The values for water, medicinal resources, erosion prevention, and moderation of extreme events are also less across the three categories compared to de Groot et al. (2012), although to a lesser extent. On the contrary, the values published for food, raw material, climate regulation, maintenance of soil fertility and nutrient cycling, and opportunities for recreation and tourism are more than those published in de Groot et al. (2012).

Published Values of Mangrove Ecosystem Services

Authors published mangrove ecosystem service values consistently over time between 2007 and 2016. Some ecosystem services were valued multiple times between 2007 and 2016 (**Table 5**). Food, raw materials, moderating extreme events, erosion prevention, and maintaining the life cycles of migratory species receive the bulk of the attention in the mangrove valuation literature. However, many other ecosystem services (e.g., pollination and ornamental resources and the "cultural" category of ecosystem services) were never or rarely valued. **Table 6** provides example values for each ecosystem service that show the range of values in US$ per hectare per year that were published in the literature using each valuation methodology.

Cultural Ecosystem Services

Of the 70 papers reviewed for this study, 28 papers included values for CES, representing 40% of all the mangrove valuation studies in this literature review. This included 20 peer-reviewed studies, 6 published in the gray literature, and 2 master's theses. Of these 28 papers, 27 included or valued exclusively ecotourism/recreation. Twelve papers, or 17.1% of the 70 original papers addressed CES outside of recreation and ecotourism. Two of these papers, Khaleel and Jaleel (2009) and Khaleel (2012), are the same study published twice, the later publication providing more details. Nine of these 11 papers (including both studies by Khaleel) were published in the peer-reviewed literature. The remaining two were published in the gray literature. Four of these

TABLE 5 | Frequency of how often mangrove ecosystem service values were published each year between 2007 and 2016.

Ecosystem service	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Food	1	3	3	5	3	4	4	2	12	6
Water			1	1		1		1	2	
Ornamental resources										
Genetic resources									1	
Medicinal resources							1		1	
Raw material		3	2	3	2	4	6	2	9	4
Waste treatment		2	2	1	1	2	1	2	4	
Air quality regulation								1		
Moderation of extreme events	3	2	2	2	1	3	6	2	7	2
Regulation of water flows			1	1		1			1	
Erosion prevention	1		1	2		2	4		3	
Climate regulation		1	2	2	3	4	4	2	6	3
Maintenance of soil fertility and nutrient cycling		1	1	1		1		1	1	
Pollination										
Biological control			1				1			
Maintenance of life cycles of migratory species	3	1	1	2		3	5	1	3	2
Maintenance of genetic diversity				1	1	1	1	1	1	1
Spiritual experience									2	
Aesthetic information			1	1		1	1	1		
Opportunities for recreation and tourism			4	3	2	3	5	3	6	2
Inspiration for culture, art, and design										
Information for cognitive development		1	2	1	1	1		1	2	

11 papers studied CES in Africa (Nigeria and Kenya), 3, including both Khaleel studies, were done in the Indian Subcontinent (Kerala and Bangladesh), 3 in Asia (Philippines, Thailand, and Asia in General), and 1 in the Caribbean (Martinique).

Only three studies (Padilla, 2008; Wiwatthanapornchai et al., 2014; Failler et al., 2015) defined the CES they valued, the latter two used the Millennium Ecosystem Assessment (2005) definitions, while Failler et al. (2015) used definitions generated by surveying the local stakeholders. The remaining studies either did not provide explicit definitions of the cultural service being valued or referred the reader to previous studies. The methods used to value non-ecotourism/recreation CES include: participatory valuation in the form of surveys and interviews (five studies), benefit transfer (four studies), market price (four studies), and willingness to pay (one study). Two studies did not state how their value data were obtained.

DISCUSSION

There is wide recognition of the importance of healthy coastal ecosystems, the services they provide to humans for overall economic and social well-being, and the role they play in securing livelihoods and sustaining populations dependent upon them for survival (Millennium Ecosystem Assessment, 2005; Haines-Young and Potschin, 2009; Pascual et al., 2017). Ecosystem service valuation can play a key role in communicating arguments for coastal conservation projects and for highlighting spatial and social patterns of ecosystem service use across the coastal zone (Lele et al., 2013; Shackleton et al., 2017). Valuation can also provide needed insight into the role that ecosystem services play in social and economic well-being of coastal communities (Van Riper et al., 2017).

Here, we summarize the relative use of valuation methods to value mangrove ecosystem services, of which benefit transfer and market price stand out as the most widely used. We then review the use of various valuation methods by geographic region of the world and provide insight into the use of benefit transfer and valuation of CES. This literature review sheds light on two principle issues affecting the mangrove valuation literature: over- and mis-use of benefit transfer in valuing mangrove ecosystem services and a lack of attention paid to the CES that mangroves provide.

Risks and Recommendations With Using Benefit Transfer

This literature review shows that although the use of valuation methods has evolved over time, many studies are focused on just a small number of ecosystem services (five) and use few methods. Many valuation studies rely heavily on benefits transfer to calculate ecosystem service values; however, often authors do not adequately consider the source and context of the benefit transfer values. Values themselves are very context specific and can change greatly from one community or context to another depending on how the ecosystem is used and the unique ecological, economic, and social context (Satterfield et al., 2013; Himes-Cornell et al., 2018). Therefore, they are not inherently transferrable. These problems are exacerbated when global value estimates from some of the most cited studies (i.e., Costanza et al., 1997, 2014; de Groot et al., 2012) are used for benefits transfer, as those studies rely on published studies to extrapolate

TABLE 6 | Use of valuation methods and range values in United State dollars per ha for ecosystem services provided by mangroves as reported by studies published between 2007 and 2016.

Ecosystem service	Methods used and value range	Min (US$/ha)	Max (US$/ha)	Number of published values
Food	Benefit transfer	5.75	23,613	10
	Production function	52	126,444	3
	Market price	37	560.55	9
Water	Benefit transfer	212	6,716	2
Raw material	Benefit transfer	1.45	212	8
	Production function	151	39,233	4
	Market price	12	2,040	6
Waste treatment	Benefit transfer	30.80	11,000	6
	Replacement cost	72	72	1
Climate regulation	Benefit transfer	2.20	1,100	5
	Market price	30.50	1,100	5
	Production function	414,411	414,411	1
Erosion prevention	Benefit transfer	38.25	1,340.60	7
	Market price	395	3,896	3
Moderation of extreme events	Benefit transfer	16	3,116	9
	Replacement cost	35	1,879	6
	Avoided cost	91.70	91.70	1
Maintenance of soil fertility and nutrient cycling	Benefit transfer	640	640	2
Regulation of water flows	Benefit transfer	540	660	2
Maintenance of genetic diversity	Benefit transfer	2.43	200	7
Maintenance of life cycles of migratory species	Benefit transfer	117.14	4,200	7
	Production function	995	4,887	2
aesthetic information	Benefit transfer	500	500	2
Information for cognitive development	Benefit transfer	50	100	2
	Market price	184.40	770.23	2
Opportunities for recreation and tourism	Benefit transfer	20	37,927	6
	Market price	9.30	2,352.15	3
	Contingent valuation	97	97	1
	Travel cost method	2,960.44	4,597.71	1

The minimum and maximum published values are provided for each ecosystem service by valuation method. Due to the inherent challenges associated with standardizing values across currencies, time, and whether they are reported per geographical acre or per unit (e.g., person, household), only those values that were published in US$/ha are being compared in this table.

local ecosystem service values to biomes on the global scale. In a global context, this is extremely valuable in terms of bringing attention to the importance of ecosystem services for a wide range of habitats; the drawback being that local and regional differences are effaced (Troy and Wilson, 2006). If an ecosystem service is not valuable to those that use or could use it in a given location or context, then applying a value calculated for another region will likely overinflate the calculated value (Emerton, 2014). Thus, using values from these studies in benefit transfer exercises presents significant problems for the validity of valuation studies.

We found examples of these problems within the literature reviewed for this study. First, **Table 4** shows extreme values for waste treatment and climate regulation. de Groot et al. (2012) reported a value for waste treatment of $162,125/ha/year. This value is significantly inflated through the inclusion of ecosystem system values from a 1978 study. With regards to the climate regulation values, the average was heavily affected by those reported by Pascal and Bulu (2013), who developed a production function to quantify the amount of carbon being sequestered on two islands in Vanuatu. Second, **Tables 5**, **6**, along with data presented in the **Supplementary Appendix**, show the wide variance primary valuation data can have from one case study to the next, despite the ecosystem being held constant.

Another concern is the age of valuation estimates that is published in the literature. As valuation methods are improved upon and societal values and preferences change over time, it is important to use data that are as current as possible in order to most accurately reflect societal values for the ecosystem services of a specific ecosystem. Even recently published studies often rely on value estimates that were calculated years prior, which can promote a false sense of security in the current relevance of the published values (Himes-Cornell et al., 2018). Given this, we argue that authors are doing themselves a disservice by recycling benefit transfer values and consistently under or overvaluing ecosystem services (Pendleton et al., 2016). Instead, studies should put more weight on collecting primary data for use in valuation studies to improve their accuracy and relevance

(O'Higgins et al., 2010). At a minimum, care should be taken to convert older values to recent currency values to account for inflation or weight the values to account for interannual discrepancies.

Lastly, we noted that there are many benefit transfer studies that rely on value estimates from studies that also did a benefit transfer. Ultimately, every time benefit transfer is used to value ecosystem services, we lose resolution in the data. This problem is rarely addressed in the literature despite the fact that so many studies rely on this valuation method. It is imperative that any future authors relying on benefit transfer studies critically look at where the values they are using come from and how they are calculated. The researchers' goal should be to use the most accurate values possible in discussions on how coastal ecosystems are being managed. These issues need to be explicitly recognized and addressed in order for valuation to have a global impact on coastal ecosystem management and sustainability.

Ignoring Cultural Ecosystem Services

Based on our sample of studies, understanding how to value CES represents a large gap in our knowledge. The notable exception is the tourism and recreation service category, which was valued in all but one study. This is not surprising, ecotourism and recreation fit neatly within our economic framework; we have the tools readily available to value it. Despite being less frequently valued, the "research and education" service is likewise straightforward to value, using monetary values from grants, salaries, and field and research costs. Therefore, these two CES subcategories will not be considered in the rest of the discussion.

The gap in our knowledge comes with the other CES, such as spiritual, aesthetic, and existence values. These services were only addressed in 11% of the papers in our review and were only clearly defined in three of the papers. The other papers mentioned relevant CES peripherally either in one sentence in the body of the text or as a line in a table. For example, Ayanlade and Proske's (2015) study of CES provided by the mangroves of the Niger delta, mentioned "cultural values" in the text, then in a table, identified cultural services as including "spiritual, recreational, and medicinal benefits." Another study (Pernetta et al., 2013) quantified "aesthetic value" in a table, but cited no source for the data. Khaleel (2012), Khaleel and Jaleel (2009), Ullah et al. (2010), and Hoberg (2011) are additional examples. Furthermore, each of these studies used benefit transfer, a method we have already drawn attention to. The appropriateness of benefit transfer is even more questionable when it comes to transferring values from one culture to another that does not necessarily share the same worldview.

In contrast, the studies that did value CES provide clear definitions to identify what CES they measured. Failler et al. (2015) used the results of survey data collected in Martinique to define the "bequest" value as "passing on the [fishing] lifestyle to future generations." Wiwatthanapornchai et al. (2014) used household survey data from a mangrove ecosystem in Thailand to assess aesthetic and national heritage value. These studies provide a good model from which to start. The researchers chose to use surveys to get the primary stakeholders to directly identify, define, and value CES important to them. This is consequential, particularly when indigenous cultures are involved, the stakeholders interact directly with the ecosystem and are better able to identify the services they receive, and how they value them than outside researchers (Kaplowitz, 2000; Abunge et al., 2013; Gould et al., 2015; Blicharska et al., 2017). These surveys also provided the researchers the opportunity to value the services using the techniques of choice experiments, willingness to pay, and participatory valuation. Because the data are coming from the primary stakeholders themselves to obtain values for the services the results are more realistic than the benefit transfer or other monetary-based methods. The remaining two studies (Kairo et al., 2009; Huxham et al., 2015) looked primarily at education and ecotourism, with the former grouping "ritual consultation" (without further clarification) within education. It is clear that researchers recognize the value of CES as a part of the overall ecosystem services of mangroves, but when approaching the analysis from the economic valuation viewpoint rarely are CES consistently identified. Even when they are identified, researchers often attempt to value CES using methods that are at best marginally appropriate.

Cultural ecosystem services are often interwoven with other environmental services (Chan et al., 2012b; Pert et al., 2015). For example, Chan et al. (2012b) notes that fishing, in addition to being a source of nourishment and income (provisioning services), frequently provides spiritual, activity, and aesthetic benefits derived from the act of fishing, as well as materials to create art and in ceremonies. Pert et al. (2015), who worked with aboriginal Australians, point out that in the Aboriginal worldview culture cannot be separated from nature, and are necessarily interlinked. Similar findings have been found in work with the First Nations of the Pacific Northwest, especially with regards to whales and salmon (Erikson, 1999; Klain et al., 2014; Deutsch, 2017). The cultural interactions (e.g., spiritual, aesthetic, inspiration for art, etc.) people have with the ecosystems in which they live are psychological in nature and thus referred to as "intangible" (Satterfield et al., 2013). They are not traded, and have no commercial value, thus they cannot be valued using our standard economic methods (Daniel et al., 2012; Milcu et al., 2013; Satterfield et al., 2013; Pert et al., 2015). These observations have led various research teams to develop frameworks and toolkits to more satisfactorily value CES (Berbés-Blázquez, 2011; Chan et al., 2012a; Felipe-Lucia et al., 2014; Baulcomb et al., 2015; Díaz et al., 2015; Ruckelshaus et al., 2015; Vazquez-Gonzalez et al., 2015; Fish et al., 2016). These frameworks invariably combine ecological and economic aspects of ecosystem service valuation with the social aspect, using non-economic methods to determine the CES values to primary stakeholders. These non-monetary methods include, but are not limited to: Delphi surveys, Q-methodology, rapid rural appraisal, Citizens juries, focus groups, and questionnaires (Christie et al., 2012; Satterfield et al., 2013; Poe et al., 2014).

Besides the questionnaires used in a few of the studies in our literature review, none of the non-monetary methods

described above were used. The starting point of the present literature review came out of the economic valuation methods described in TEEB (2010), thus the non-traditional and non-economic valuation methods did not make it into the search terms used for the previous blue forests valuation study from which the present analysis came from (Himes-Cornell et al., 2018). Therefore, the findings of this review are biased toward economic valuation terminology and methods, and many relevant CES studies were surely missed. Although this represents a shortcoming of this study, this is also an issue for the majority of studies approaching ecosystem service valuation from the economic valuation perspective. Future literature analyses need to include non-traditional and non-monetary valuation methods in order to have a more complete picture of the services provided by mangroves specifically and all ecosystems in general. The 20 studies identified in this review that valued mangrove CES also valued provisioning, regulating, and support services, which are more easily valued using the economic valuation toolkit. Effectively exploiting the non-traditional and non-monetary techniques entails an interdisciplinary approach, drawing on theory and approaches used in the study of socio-ecological systems (Berkes et al., 2003), and requires involving colleagues from fields such as anthropology, applied ethics, and sociology (Kaplowitz, 2000), and the local stakeholders as collaborators (Pert et al., 2015).

Cultural ecosystem services are inextricably intertwined with a community's interactions with its environment (Berkes, 2012; Satterfield et al., 2013; Poe et al., 2014; Pert et al., 2015) and form the basis of all other interactions of a group of local stakeholders with their environment (Berkes, 2012; Chan et al., 2012b; Poe et al., 2014; Pert et al., 2015). Consequently, accounting for these cultural dimensions is arguably the foundation upon which values can be determined for the provisioning, regulating, or supporting ecological services and is essential for maximizing stakeholder engagement and commitment to any potential policy decisions (Chan et al., 2012a; Abunge et al., 2013; Felipe-Lucia et al., 2014; Mangora and Shalli, 2014; Poe et al., 2014; O'Neill and Graham, 2016).

CONCLUSION

As coastal ecosystems face new threats and multiple uses, careful consideration needs to be taken with regards to societal uses of those ecosystems, where and to what extent those uses occur, and how important or valuable to those uses are to coastal communities. Here, we consider research questions: (1) Is the current literature robust enough to give us an accurate understanding of mangrove value? (2) Where do we stand on evaluating mangrove CES?

In considering relevance of the body of mangrove valuation literature published in recent years, we find that, in fact, there are substantial gaps in both the valuation methods employed and the ecosystem services that have been valued. Estimates of the ecosystem service values of food, raw materials, and climate regulation have been subject to the widest variety of valuation methods. However, mangroves are known to provide many more ecosystem services from erosion prevention to water provision, maintaining genetic diversity, and CES (Salem and Mercer, 2012). Few attempts have been made to value these other services, and when they are valued, there is a high reliance on benefit transfer. This study shows that there is a need to substantially diversify the valuation methods used in all regions and for all types of ecosystem services.

We have a long way to go before the mangrove valuation literature is robust and includes estimates of all categories of ecosystem services that mangroves provide, including CES such as spiritual and aesthetic value. In fact, there are significant gaps in the current literature on mangrove valuation and many ecosystem services that are very important to coastal communities are rarely valued. Most studies focus on a small selection of ecosystem services based on the availability of benefit transfer values and the ability to easily measure values with market prices. This ignores the importance of many ecosystem services that cannot be valued monetarily, but that are often equally important to local communities.

We are doing ourselves an injustice by ignoring or not appropriately valuing CES. CES are of fundamental importance to local stakeholders, especially so to indigenous peoples. The cultural aspects of the environment are tightly woven with all aspects of stakeholders' lives. Including stakeholders in the service identification and valuation process is integral to garnering their buy-in and collaboration for future policy changes. We must use a bottom up approach when valuing at least the intangible services, and we need to resist the temptation to transfer cultural values from one place or group of stakeholders to another.

Therefore, if we want to thoroughly understand the role CES play in the culture of their local stakeholders, and appropriately value them, we need to collect more primary data that explicitly accounts for the primary stakeholders' identification and value of the cultural services from which they benefit. Direct interaction with the people concerned is imperative; not only does it provide better data, but it develops rapport and trust in the researcher, especially if they are from outside the culture. Interactions must be done with sensitivity and respect. We need to collaborate with our colleagues in the social sciences, anthropology, and applied ethics to apply an interdisciplinary approach so as to achieve a more wholistic understanding of the value of CES.

Understanding that resource managers and researchers often need rapid assessment methods that can help them make a quick assessment of ecosystem service value, we recommend that explicit consideration be given to the types of methods that researchers should use in lieu of benefit transfer. As human uses of the coastal environment, and mangroves in particular, continue into the future, the development of appropriate best practices, guidelines, and suggestions for ecosystem service valuation methods needs to be prioritized. It is with this type of guidance and assistance that new researchers will be able to effectively take up the cause for sustainable use of ecosystems and their services.

DATA AVAILABILITY

The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

AUTHOR CONTRIBUTIONS

AH-C led the conceptual design of the paper, conducted the literature review and analysis, and drafted the first version of the paper. SG collected background material and contributed text to all sections of the paper. LP contributed to the conceptual design and improvements to various drafts.

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SUPPLEMENTARY MATERIAL

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