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Quantifying Economic Value of Coastal Ecosystem Services: A Review

Seyedabdolhossein Mehvar [1,2,*], Tatiana Filatova [3,4], Ali Dastgheib [2], Erik de Ruyter van Steveninck [2] and Roshanka Ranasinghe [1,2,5,6]

1 Department of Water Engineering and Management, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands; r.ranasinghe@un-ihe.org
2 Department of Water Science and Engineering, IHE Delft Institute for Water Education, P.O. Box 3015, 2601 DA Delft, The Netherlands; a.dastgheib@un-ihe.org (A.D.); e.deruijtervansteveninck@un-ihe.org (E.d.R.v.S.)
3 Department of Governance and Technology for Sustainability, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands; t.filatova@utwente.nl
4 School of Systems, Management and Leadership, Faculty of Engineering and Information Technology, University of Technology Sydney, Sydney, NSW 2007, Australia
5 Harbour, Coastal and Offshore Engineering, Deltares, P.O. Box 177, 2600 MH Delft, The Netherlands
6 School of Civil Engineering, University of Queensland, St. Lucia, Brisbane, QLD 4072, Australia
* Correspondence: s.mehvar@utwente.nl; Tel.: +31-068-442-6320

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Abstract: The complexity of quantifying ecosystem services in monetary terms has long been a challenging issue for economists and ecologists. Many case specific valuation studies have been carried out in various parts of the World. Yet, a coherent review on the valuation of coastal ecosystem services (CES), which systematically describes fundamental concepts, analyzes reported applications, and addresses the issue of climate change (CC) impacts on the monetary value of CES is still lacking. Here, we take a step towards addressing this knowledge gap by pursuing a coherent review that aims to provide policy makers and researchers in multidisciplinary teams with a summary of the state-of-the-art and a guideline on the process of economic valuation of CES and potential changes in these values due to CC impacts. The article highlights the main concepts of CES valuation studies and offers a systematic analysis of the best practices by analyzing two global scale and 30 selected local and regional case studies, in which different CES have been valued. Our analysis shows that coral reefs and mangroves are among the most frequently valued ecosystems, while sea-grass beds are the least considered ones. Currently, tourism and recreation services as well as storm protection are two of the most considered services representing higher estimated value than other CES. In terms of the valuation techniques used, avoided damage, replacement and substitute cost method as well as stated preference method are among the most commonly used valuation techniques. Following the above analysis, we propose a methodological framework that provides step-wise guidance and better insight into the linkages between climate change impacts and the monetary value of CES. This highlights two main types of CC impacts on CES: one being the climate regulation services of coastal ecosystems, and the other being the monetary value of services, which is subject to substantial uncertainty. Finally, a systematic four-step approach is proposed to effectively monetize potential CC driven variations in the value of CES.

Keywords: coastal ecosystems; ecosystem services; economic valuation; climate change

1. Introduction

For centuries people have lived in coastal zones (CZ) and benefited from the ecosystem services that these areas provide. CZ have always been popular due to their accessibility to resources, in particular due to the abundant supply of subsistence resources, and recreational and cultural activities [1]. While coastal areas cover only 4% of the earth's total land area and are equivalent to only 11% of the World's ocean area [2], they host one third of the World's population and are twice as densely populated as inland areas [3]. The population density grows in the CZ annually due to migration driven by global demographic and socio-economic changes [1]. Growing population and accompanying infrastructure build-up provoke agglomeration economies that attract even more people and capital to the CZ, which has resulted in 15 out of the 20 present-day megacities of the World being located in low elevation CZ [4].

Worldwide, the economies of coastal communities and their resilience highly depend on the ecosystem services that CZ provide. It is well known that coastal ecosystems undergo major changes triggered by direct and indirect drivers. Direct drivers include natural forcing drivers such as coastal hazards (e.g., flooding, erosion), the probability and severity of which is expected to increase with climate change (CC). CC impacts which are primarily due to the anthropogenic greenhouse gas effect can alter the atmospheric composition and thereby change the intricate dynamics of the marine area resulting in variations in coastal ecosystems. The potential CC impacts relevant to coastal ecosystems include variations in mean sea level (i.e., sea level rise), wave conditions, storm surge [5], ocean circulation, ocean acidification (due to higher levels of CO_2), water temperature and changes in precipitation [6].

However, there is very little known about how CC may affect the value of ecosystem services in the CZ. Other examples of direct drivers of ecosystem change include land conversion, which changes the local land use and land cover [7]. The two most important indirect drivers of the environmental changes in coastal areas are population growth and economic development. Both direct and indirect drivers lead to a loss of coastal ecosystem services (CES), which will damage ecosystems and will undermine further development in CZ. Ironically, it is often the monetary valuation of this loss in CES that attracts the attention of policy makers and stakeholders.

Interest in ecosystem services in both research and policy-making communities has grown rapidly [8]. Many studies have estimated the value of ecosystem services for different wetland types, most of which have been limited to a particular local-scale case study (e.g., [9–13]).

On a larger spatial scale, Chaikumbung et al. [14] reviewed 1432 valuation studies of wetlands worldwide with a goal to provide a meta-regression analysis of their economic value and factors that influence it. In addition, Rao et al. [15] estimated the global value of CES for specific coastal ecosystems ranging from 0.4–1998 US $/ha/year in 2003 corresponding to 0.5–2530 US $/ha/year in 2013. Other studies have indicated that CZ and the oceans together contribute more than 60% of the total economic value of the biosphere [16,17]. A more recent study [18] indicates that global land use has changed between 1997 and 2011 resulting in an ecosystem services loss of between US $4 and US $20 trillion per year, implying that CES may have experienced a proportional loss. However, studies estimating the monetary effects of CC impacts on CES are scarce. Such an endeavor often requires a multidisciplinary effort—even more than in traditional ecosystem valuation exercises that do not consider CC effects.

Despite the above mentioned local scale and global studies, a coherent review on the valuation of CES with a systematic description of fundamental concepts, key reported applications, and potential CC impacts on the monetary value of CES has not been undertaken to date. This review article takes a step towards addressing this large knowledge gap and is aimed at assisting researchers and policy makers in multidisciplinary fields to gain a better appreciation of the economic value of CES and potential CC impacts on CES.

Specifically, here we discuss a number of salient questions that one has to consider when seeking to estimate the value of certain coastal ecosystems. In particular, (1) What type of wetlands and ecosystems are being assessed? (2) What type of ecosystem services, goods and values need to be considered? (3) Which drivers of ecosystem change are applicable to the study? (4) What kind of valuation methods should be used for valuing a particular ecosystem service? (5) What type of data are needed given the limitations and costly process of its collection? (6) How CES have been valued in previous global and local case studies, and what are the highest and lowest valued services and the most frequently used valuation methods therein? (7) How important are CC impacts on CES, and to what extent can they potentially affect the value of services? (8) What are the gaps and challenges in assessing potential CC-driven changes in the value of CES? These questions are sequentially addressed in the subsequent sections of this article, following the sequential structure shown in Figure 1.

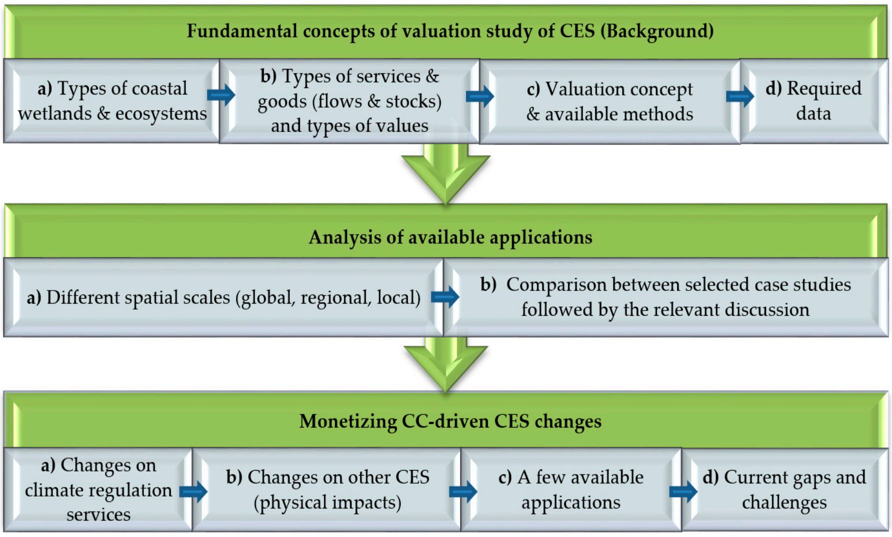

Figure 1. Schematic depiction of the sequential structure of this article.

As shown in Figure 1, this article first presents a background on coastal wetlands, ecosystems and their services/goods (Section 2.1), followed by a summary description of the concepts underlying ecosystem services valuation studies, current economic valuation methods and required data for conducting such studies (Section 2.2). This is followed by Section 3 which presents and analyses 30 selected local and regional-scale valuation studies of CES and two global-scale cases where they are clustered based on type of ecosystem to highlight the current status of valuation studies of CES. Section 4 presents the important and less known issue of monetizing climate change impacts on CES. Here, the link between CC impacts and monetary value of CES is discussed via a methodological framework.

2. Background

2.1. Coastal Wetlands, Ecosystems, Services and Goods

Wetlands are classified into three types: inland, coastal and marine, and human-made wetlands [3]. In general, the coastal and marine environment can extend up to 100 km inland and up to 50 m water depth in the ocean [19]. Coastal and marine wetlands include estuaries, lagoons, coastal peatlands and beaches. Nearshore areas with a maximum depth of 6 m at low tide are also considered part of coastal and marine wetlands as defined by the Ramsar Convention in 1971 [3,20]. Associated with coastal and marine wetlands (referred in this article as coastal wetlands), coastal ecosystems include mangrove forests, coral reefs, sea-grass beds, marshes, beach and dune systems as well as pelagic systems. In general, ecosystem services are defined as the immaterial services that are of benefit to humans with a monetary value which are generated by wetlands [7]. Thus, ecosystem services are the benefits (sometimes referred to as flows of the benefits) that people obtain from ecosystems, while ecosystem goods consist of food provision (such as fish, fiber), and raw materials (such as wood), sometimes also called stocks of natural ecosystems. From an ecological point of view, stocks and flows refer to the structural components and environmental functions respectively [21].

Tinch and Mathieu [22] stated that the ecosystem services framework focuses on the flows of valuable goods and services that are provided by the stock of natural resources. According to this study, these two terms should be differentiated since flow values are the ones that can be derived over a defined time interval, while stock values are the net present value sum of all flow values that may be derived from an ecosystem over a future period.

A variety of benefits can be explicitly classified as ecosystem services such as use and non-use values including existence and bequest values [3,20,23]. Table 1 indicates the classification of the main coastal and marine ecosystem services modified from [20,23].

Table 1. Values provided by coastal and marine ecosystem services.

Use Values		Non-Use Values
Direct Values	**Indirect Values**	**Existence and Bequest Values**
Food, fiber and raw materials provision	Flood control	Cultural heritage and spiritual benefits
Transport	Storm protection, wave attenuation	Resources for future generations
Water supply	CC impacts mitigation	Biodiversity
Recreation and tourism	Contaminant storage, detoxification	
Wild resources	Shoreline stabilization/erosion control	
Genetic material	Nursery and habitat for fishes and other marine species	
Educational opportunity	Nutrient retention and cycling	
Aesthetic	Regulation of water flow, water filtration	
Art	Source of food for sea organisms	
	Climate regulation, primary productivity as Oxygen production and CO_2 absorption, Carbon sequestration etc.	

Direct use values refer to the ecosystem services that can be directly used and associated with human well-being. Indirect use values include services that provide benefits outside the ecosystem. These latter values refer to ecosystem services with values that can be only measured indirectly, since they are only derived from supporting and protecting activities that have directly measurable values [24].

It should be noted that some of the cultural services (referred to as non-use values in Table 1) can also be included in other typologies of ecosystem services [25]. For example, recreation and tourism services offer non-consumptive values such as the enjoyment of recreational and cultural amenities (e.g., wildlife, bird watching and water sports) [26]. Recreational services can also be classified as a direct use value [27], which is how they are considered in this review (see Table 1).

Non-use or passive use values represent the value of ecosystem services which exist even if they are not used. These include existence and bequest values which refer to the public awareness of ecosystem services that exist and will persist for future generations to enjoy. Table 2 provides an overview of the coastal ecosystems and some of their attributed use-value services modified from [3].

Table 2. Overview of coastal ecosystems and their attributed use-value services.

Coastal Ecosystem	Direct Use Value	Indirect Use Value
Mangrove forests	Raw material (wood production), aesthetic, educational opportunities, artistic value	CC impact mitigation, storm protection and wave attenuation, shoreline stabilization and erosion control, flood control, nursery and habitat for fishes and other marine species, regulation of water flow and filtration, carbon sequestration, oxygen production and CO_2 absorption, contaminant storage and detoxification

Table 2. *Cont.*

Coastal Ecosystem	Direct Use Value	Indirect Use Value
Coral reefs	Aesthetic, recreation and tourism (snorkeling), educational opportunities, artistic value, raw material for building, jewelry and aquarium trade	Nursery and habitat for fishes and other marine species, wave attenuation and shoreline stabilization, nitrogen fixation
Sea-grass beds	Aesthetic, contribution to recreation and tourism (snorkeling)	Nursery and habitat for fishes and other marine species, source of food for sea organisms, shoreline stabilization and erosion control, primary productivity as oxygen production and CO_2 absorption, water filtration
Beach and dune systems	Recreation and tourism, fiber and raw material (wood source) provided by the dune vegetation, aesthetic value, artistic value	Flood control, erosion control, nursery for some marine species (turtles)
Pelagic systems	Food source, aesthetic value, tourism services, artistic value	Source of food for sea organisms, nursery and habitat for fishes and other marine species

2.2. Valuation of Ecosystem Services

In principle, economic valuation of ecosystem services is based on "people preference" and their choices. Therefore, it is quantified by the highest monetary value that a person is willing to pay in order to obtain the benefit of that particular service. The "willingness to accept" approach determines how much someone is willing to give up for a change in obtaining a certain ecosystem good or service [3]. Thus, the key outcome of valuation studies is to illustrate the importance of a healthy ecosystem for socio-economic prosperity and to monetize the gains that one may achieve or lose due to a change in ecosystem services [28].

The value of ecosystem services can be measured in three different forms [22]: (1) Total economic value (TEV) that refers to the value of a particular ecosystem service over the entire area covered by an ecosystem during a defined time period; (2) average value of an ecosystem service per unit, which is often indicated for a unit of area or time; (3) marginal value which is the additional value gained or lost by an incremental change in a provision of a particular service.

The valuation starts from estimating a TEV of an ecosystem, which is in fact a sum of consumer surplus and producer surplus. This is done by applying different valuation techniques. For example, in the case of tourism, producer surplus is the direct or indirect benefit from the local ecosystems for the tourism sector by considering the revenue made from tourists minus the costs of providing these services to them [29]. In addition, consumer surplus conveys the maximum amount that tourists are willing to pay for visiting the specific recreational area.

2.2.1. Valuation Methods

There are different ways of classifying economic methods used for valuing ecosystem services and goods: Revealed preference methods, stated preference methods, market price, and benefit transfer method. Table 3 shows an overview of these techniques including their attributed CES and goods adapted from [2,16,24,30–32].

Table 3. Overview of the valuation methods and their attributed coastal ecosystem services and goods.

Valuation Method		Description	Coastal Ecosystem Services and Goods
Revealed preference methods (use-value)	Production-based (net factor income)	Often used to value the ecosystem services that contribute to the production of commercially marketed goods	Regulating services such as oxygen production, CO_2 absorption, nitrogen fixation and carbon storage, providing fish nurseries, water purification, coastal protection
	Hedonic pricing	Commonly used to value the environmental services contributing to amenities. Property's price often represents the amenity value of ecosystems	Tourism and recreation, aesthetic, improving air quality
	Travel cost	Basically considers the travel costs paid by tourists and visitors to the environmental value of a recreation site	Tourism and recreation, recreational fishery and water sports
	Damage avoided cost, replacement cost	Based on either the cost that people are willing to pay to avoid damages or lost services, the cost of replacing services or the cost paid for substitute services providing the same functions and benefits	Buffering CC impacts such as wave attenuation, providing coastal protection against storms and erosion, flood impact reduction, water purification, carbon storage
Stated preference methods (both use and non-use value)	Contingent valuation (CVM)	The most applied method for both use and non-use values, based on surveys asking people their willingness to pay (WTP) to obtain an ecosystem service	Tourism and recreation, recreational fishery and water sports, aesthetic value, cultural and spiritual value, art value, educational value
	Contingent choice (CCM)	WTP is stated based on choices between different hypothetical scenarios of ecosystem conditions	
Market price		Often used for the ecosystem products that are explicitly traded in the market	Fiber, wood and sea food provision, raw material for building, and aquarium
Benefit transfer		It transfers available data from previous valuation studies for a similar application	Mostly applied for gross value of coastal ecosystems associated with recreation

2.2.2. Required Data

The data required for valuation of ecosystem services are collected by different means. Primary data are obtained via field observations and surveys, participatory approaches and stakeholder involvement which is often in the form of questionnaires and interviews. This is costly and time consuming, but the flexibility of the approach allows researchers to collect data on specific averting behaviors, attitudes, perceptions, and on the prices of averting behaviors stated by people [33]. This type of data is mostly obtained when using stated preference methods. For example, for valuation of recreation service, information is obtained from beach visitors stating their willingness to pay to obtain the benefit of recreational services of coastal ecosystems.

In absence of such primary data, one may use secondary data that are obtained from existing sources, such as global and national databases or available literature. Using secondary data is becoming more common given that in many studies the time and budget constraints apply. A widely used method in valuation studies relying on secondary data is the benefit transfer method, which derives information and estimates of values from previous studies [33]. Richardson et al. [34] described a coherent analysis of the benefit transfer method summarizing advancements, databases and analysis tools provided to simplify the application of this method.

3. Analysis of the Available Valuation Studies—Selected Sample

Valuation of CES can be done at different spatial scales, ranging from local and regional to global scale. In general, the spatial variability of ecological services might be of importance, affecting the net ecological benefits that they provide [35–37]. For example, Barbier et al. [36] showed that the magnitude of wave attenuation by coral reefs, salt marshes, sea-grass beds, and sand dunes varies spatially across ecosystems. This geographical influence was also observed by de Groot et al. [38].

3.1. Local and Regional Scale Applications

In this review, 30 local and regional valuation studies have been selected to represent a sample of current valuation studies. This sample has been chosen by searching the scientific database of google scholar considering applications in which the value of coastal ecosystem services has been estimated with a reported value. These selected references have been considered in such way to be able to distinguish them based on specific characteristics such as ecosystems and services considered, valuation methods used and estimated value. Here we have clustered these studies based on the type of coastal ecosystems that have been valued and Tables 4–7 show the ecosystem services provided, valuation methods used, and estimated results for each case.

Table 4. Selected applications of valuation of coral reef ecosystem services.

Reference	Valuation Method/s	Ecosystem Service/Good	Estimated Value
[39]	Stated preference	Tourism and recreation (marine national park in Seychelles)	US $88,000 (whole area)
[40]	Hedonic property price	Aesthetic (Indian ocean)	US $174 (per hectare)
[41]	Travel cost, stated preference	Recreation (Andaman sea of Thailand)	US $205.41 million (per year)
[29]	Production-based, avoided damage cost, travel cost, stated preference	Fishery, tourism, biodiversity, amenity, coastal protection (Guam)	US $141 million (per year)
[42]	Market price, net factor income, stated preference	Recreational and commercial fishing (Caribbean Netherlands, Bonaire)	US $400,000 and US $700,000 (per year)
[43]	Avoided damage cost	Protection to coastal erosion (Sri Lanka)	US $160–172,000 (per km of reef, per year)
[44]	Avoided damage cost	Habitat support for fisheries (Caribbean sea)	US $95–140 million (projected by 2015)
[44]	Avoided damage cost	Tourism (Caribbean sea)	US $300 million (projected by 2015)
[45]	Avoided damage cost	Coastal protection by wave dissipation (Bonaire Island, Caribbean, Netherlands)	US $33,000–70,000 (within 10 years–beyond 10 years)
[46]	Avoided damage cost	Coastal protection (Tobago, St. Lucia, (Caribbean)	US $18–33 million, US $28–50 million (annual values)
[44]	Replacement, substitute cost	Coastal protection in Caribbean coastline	US $750 million–2.2 billion (annually)

The economic value of ecosystem services provided by coral reefs: Table 4 shows studies in which coral reef services have been valued at local and regional spatial scales. These services vary from recreational and tourism services to fishery, erosion control and coastal protection services. Depending on the service, different valuation methods have been used. Geographically, the selected case studies are mostly located in the Caribbean region highlighting this area as one of the important and large habitats of coral reefs. According to Table 4, coral reef services are valued at different estimations ranging from US $33,000–70,000 [45] to a very high value between US $750 million and US $2.2 billion [44]. This Table also shows that compared to other services, the coastal protection service provided by coral reefs is among the highest value estimated for this type of ecosystems.

Table 5. Selected applications of valuation of mangrove ecosystem services.

Reference	Valuation Methods	Ecosystem Service/Good	Estimated Value
[13]	Market price, replacement cost	Fishery, timber, carbon sequestration and storm protection (Vietnam)	US $3000 (per hectare, per year)
[47]	Avoided damage cost	Coastal protection, wood, habitat support for fishery (Thailand)	US $10,158–12,392 (per hectare)
[48]	Avoided damage cost	Storm (wind) protection (Odisha region, India)	US $177 (per hectare) (1999 price level)
[49]	Benefit transfer (from 48 selected studies)	Fisheries, fuel wood, coastal protection, water quality (Southeast Asia)	(mean) US $4185 (per hectare, per year) (2007 price level)
[12]	Replacement cost	Nutrient retention value (India)	US $232 (per hectare)

The economic value of ecosystem services provided by mangroves: Table 5 shows selected applications of CES valuations for mangroves indicating a range of estimations which is mostly considered per hectare of the study area. According to Table 5, fishery and storm protection are among the most frequently valued services reflecting the importance of these two services provided by mangroves. With respect to the estimated values, depending on the number of services considered, low values of US $177/ha [48] and US $232/ha [12] were estimated in the coastal area in India, while higher values between US $10,158/ha and US $12,392/ha were estimated in Thailand [47].

The economic value of other coastal ecosystems: Table 6 shows 7 selected case studies in which the value of other coastal ecosystems such as marshes, beaches and pelagic systems have been estimated using a variety of methods. These studies highlight the difference between types of values affecting estimated results. For example, Emerton and Kekulandala [11] estimated the total value of flood control services provided by marshes in Sri Lanka at USD 5 million per year, while Bell [50] estimated average values of USD 6471 and USD 981 respectively with respect to habitat support for fishery provided per acre of marsh on the East and West coasts of Florida in 1984 dollars. Among these selected applications, a high value of USD 23–44 billion was estimated by Molnar et al. [51] for food provision service of the marine area (referred to as pelagic system in this review) in British Colombia in 2004.

Table 6. Selected applications of valuations of other coastal ecosystems.

Reference	Ecosystem	Valuation Methods	Ecosystem Service/Good	Estimated Value
[11]	Marsh	Avoided damage cost	Flood attenuation (Colombo, Sri Lanka)	US $5 million (per year)
[50]	Marsh	Production-based	Habitat support for fisheries (Florida coast)	a. US $6471 (East) b. US $981 (West) (per acre)
[10]	Beach and dune system	Stated preference	Tourism (San Andres Island, Colombia)	US $997,468 (annual consumer surplus)
[52]	Pelagic system	Avoided damage cost, market price	Food provision (fish) (UK)	£513 million (in 2004)
[51]	Pelagic system	Benefit transfer (literature data)	Aesthetic and recreation (British Colombia)	US $23-44 billion (per year)
[53]	Pelagic system	Travel cost	Recreation (Baltic Sea)	€15 billion (total annual)
[9]	Pelagic system	Stated preference	Food provision (fish) (coast of Southeast Alaska)	US $248–313 Mean value for single-day private boat fishing trips

The economic value of combined coastal ecosystems: There are some available valuation studies in which coastal ecosystems have been valued as a whole system. These cases, which are shown in Table 7, indicate that one may value a combination of services [54] and goods grouped as coastal nature or a combination of two ecosystems such as coral reefs and mangroves as presented by Cooper et al. [54], and van Beukering and Wolfs [55]. Most of the selected cases in Table 7 were derived from studies that approximated the value of coastal nature in Caribbean Islands. Among the used methods, the net factor income has been applied for estimating research and artistic value of coastal nature as presented by van Beukering and Wolfs [55]. Selected applications show that direct-use value of the coastal environment was mostly considered in these studies indicating the highest value for providing erosion protection service at US $231–347 million in Belize in 2007 [54]. On the contrary, art value of the coastal environment was estimated at a relatively low annual value of US $290,000 in Bonaire Island [55]. Notably, all estimated values of services provided by the coastal environment are presented in annual value.

Table 7. Selected applications of valuation of combined coastal ecosystems.

Reference	Ecosystem	Valuation Methods	Ecosystem Service/Good	Estimated Value
[55]	Coastal nature	Net factor income	Research opportunity (Bonaire Island, Caribbean)	US $1,240,000–1,485,000 (in 2011)
[55]	Coastal nature	Net factor income	Pharmaceutic (Bonaire Island, Caribbean)	US $688,788 (annual)
[55]	Coastal nature	Net factor income	Art (Bonaire Island, Caribbean)	US $460,000 (annual)
[42]	Coastal nature	Stated preference	Tourism (Bonaire Island, Caribbean)	US $50 million (annual)
[56]	Coastal nature	Hedonic property price	Amenity (analysis of 1 million housing transactions) from 1996 to 2008 (UK)	£3700 (moving the bottom 1% postcode to the best 1% postcode (per year)
[54]	Coral reef and mangrove	Net factor income, avoided damage cost	a. Tourism b. Fisheries c. Erosion protection (Belize, Caribbean)	a. US $150–196 mil. b. US $14–16 mil. c. US $231–347 mil. (in 2007)
[55]	Coral reef and mangrove	Market price	Carbon sequestration (Bonaire Island, Caribbean)	US $290,000 (annual)

3.2. Global Scale Applications

The few reported global scale ecosystem service valuation studies have used the benefit transfer method, where global assessments have been derived based on the results of different local and regional case studies. For example, Costanza et al. [18] estimated the value of global ecosystem services at US $125 trillion per year (assuming updated unit values and changes to biome areas) and US $145 trillion per year (assuming only unit values changed) both in US $2007.

In contrast, the global valuation of coastal ecosystems done by de Groot et al. [38] estimated the total monetary value of a bundle of ecosystem services. Table 8 indicates the results of this study in standardized units (Int. $/ha/yr–2007 price level) for the coastal area categorized as open ocean, coral reefs, coastal systems and coastal wetlands. According to de Groot et al. [38], the open ocean (referred to as *pelagic system* in our review) represents the largest area of the marine ecosystem including deep sea (water and sea floor below 200 m). The coastal systems studies include several distinct ecosystems such as sea-grass fields, shallow seas of continental shelves, rocky shores and beaches, which are found in the terrestrial near-shore as well as the intertidal zones—i.e., until the 200 m depth contour. Moreover, de Groot et al. [38] separately studied coral reefs and coastal wetlands (mangroves and tidal marshes) because of the important and unique ecosystem services these systems provide.

Table 8. Global valuation of coastal ecosystem services (total monetary value per biome).

Coastal Wetlands/Ecosystems	No. of Estimates	Total of Service Mean Value	Total of Median Value	Total of Minimum Value	Total of Maximum Value
Open ocean	14	491	135	85	1664
Coastal systems	28	28,917	26,760	26,167	42,063
Coastal wetlands	139	193,845	12,163	300	887,828
Coral reefs	94	352,915	197,900	36,794	2,129,122

Source: de Groot et al. [38] (values in Int. $/ha/year, 2007 price level).

3.3. Discussion

The local and regional applications reviewed in this article indicate that *tourism and recreation* as well as storm protection services are among the most commonly valued services. This is in agreement with the conclusions made by [10,41,45]. In addition, these two types of services are often valued higher than other services. For example, Cooper et al. [54] conducted a valuation study in which tourism and erosion protection services of coral reefs and mangroves were valued at US $150–196 million and US $231–347 million, while providing fishery habitat value was estimated much lower at US $14–16 million. On the contrary, very little appears to be known about the value of cultural services of coastal ecosystems such as aesthetic and artistic values. Van Beukering and Wolfs [55] presented one of the few examples of valuing these less considered services in Caribbean Islands with an associated call for conducting similar studies in other coastal areas.

With respect to valuation methods used in the selected applications, avoided damage, replacement, and substitute cost methods are the most frequently used techniques for valuing storm/flood protection service provided by mangroves. In addition, stated preference and production-based methods (net factor income) are the second and third commonly used methods for the valuation of services, respectively.

The selected 30 studies also highlighted one of the main limitations in valuation of CES presenting a mostly incomplete measure of the ecosystem's value. The reason for this incomplete estimation might be the complexity of covering and valuing all the services provided by ecosystems in a particular area. Therefore, there are often missing services in the valuation studies. Data scarcity in some coastal areas together with the time consuming and high cost associated with data collection are also other important factors that discourage investigators from considering and valuing all services provided by a particular coastal ecosystem.

Tables 4–7 also illustrate that the range of estimated values quantitatively vary due to the many inconsistencies and irregularities in their characteristics. These discrepancies might be in temporal scale of studies, the way that data has been collected, number of services valued, type of the estimated values, location of the case studies, probability of the hazard occurrence and importance of the hinterlands (relevant for the replacement, substitute and avoided damage cost method) and other factors that make the estimated results not easily comparable. For instance, the high estimated value for the food provision service provided by marine areas in the study of Molnar et al. [51] may not be directly comparable with the results of Boero and Briand [52] for the same coastal ecosystem, due to the fact that location, type of valuation method and the services considered are different in these two studies. Also, in some of the selected applications, estimated value is presented per year (total value), while in some others (e.g., [44]), the marginal values have been projected for the future.

Apart from the mentioned irregularities, in some methods such as stated preference, socio demographic data such as age, level of education, mean salary etc. may affect the WTP stated by the visitors. This can affects the estimated value and consequently results in a totally different estimation for a certain CES. Therefore, all the aforementioned factors, discrepancies and inconsistencies add another challenge in comparing the results of different valuation studies.

4. Coastal Ecosystems and Climate Change Impacts: Monetizing Changes in the Value of Ecosystem Services

As mentioned in Section 1, the consequences of coastal hazards as direct drivers of change, not only affect the inhabitants of CZ, but also pose a considerable threat to the coastal environment. A remarkable proportion of coastal ecosystems is already under threat, with 50% of marshes, 35% of mangroves, 30% of coral reefs and 29% of the known global coverage of sea-grasses either lost or degraded already [24]. Climate change is likely to have a considerable impact on the threat levels faced by CES in future.

The World's coastlines are shaped by mean sea level, wave conditions, storm surge, and river flows, while CC driven variations in these forcing factors pose a considerable effect on the coastal area [5]. As a result, CC will significantly affect the direct or indirect benefits that humans obtain from these ecosystems [57]. Thus, CC will substantially alter or eliminate certain ecosystem services in the future. To better understand the impacts of CC on CES and to develop effective adaptation measures where possible, it is essential to improve our knowledge on the links between CC and ecosystem services and the corresponding economic impacts [58].

Academic literature discusses two types of links between CC and CES; climate regulation service provided by CES and CC impacts on CES (see Figure 2).

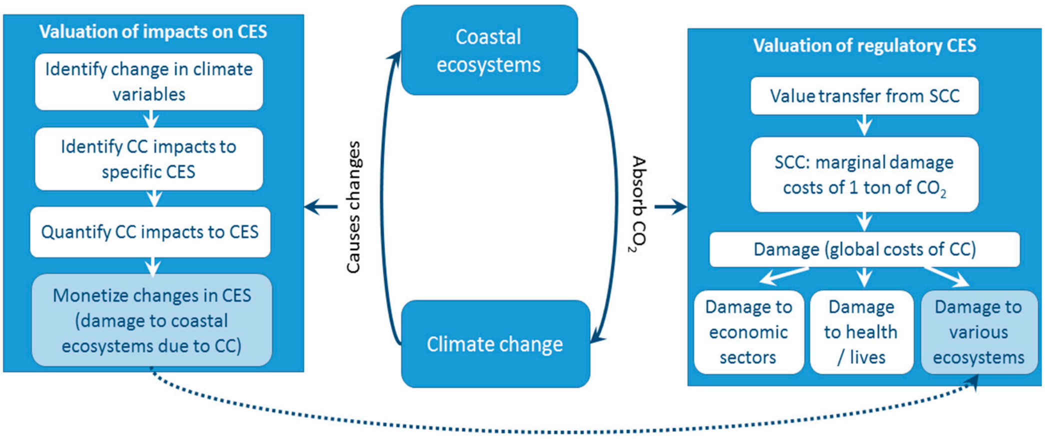

Figure 2. Links between climate change (CC), coastal ecosystem services (CES) and their valuation.

4.1. CC Link with Climate Regulation Service

Coastal ecosystems provide many services as indicated in Table 1; one of them being climate regulation through their ability to absorb CO_2 (right hand side of Figure 2). Blue carbon (CO_2) sequestered by mangroves, sea-grass beds, tidal marshes and vegetation present in other coastal ecosystems [59] attracts considerable attention in CC mitigation discussions. For example, Jerath et al. [60] performed a valuation study of regulatory climate service of mangrove forests of the Everglades National Park in Florida, USA.

The benefits of this regulatory service are compared to the average abatement costs of carbon that the mangroves provide. The valuation exercise of the regulatory climate service in this case is rather simple. Since CC has adverse effects globally, the common practice is to apply the value transfer method based on the social costs of carbon (SCC) to derive a single value of 1 ton of carbon absorbed. SCC indicates the marginal damage costs of 1 ton of CO_2 emitted, based on the global estimates of damages caused by CC [6].

Global CC induced damage in general comprises the monetary assessments of climate-induced damage to various economic sectors, health and human lives as well as ecosystems across the entire planet using global Integrated Assessment Models [61]. However, the monetary damage to various ecosystems including coastal are very rudimental [62,63]. In the Florida study, [60] used the IPCC value of SCC equal to $36/t$CO_2$ in US $2007 price level, which translated into US $2015 per ton of carbon amounts to $167/t$CO_2$. Furthermore, the total carbon absorption of coastal mangroves was potentially estimated and multiplied on this monetization rate. While this connection between CES and CC is an important research direction, it is the other link between CC and CES that is most relevant to this article.

4.2. CC Driven Changes on CES

CC will result in changes in temperature and hydrology, which will alter ecosystems. As coastal ecosystems evolve under CC, the benefits that they provide in the form of ecosystem services are likely to decline [57] and therefore, impact the socio-economic wellbeing of people. Any attempt to monetize CC driven variations in CES (left hand side of Figure 2) should necessarily follow a number of steps, as summarized below.

First, the results of global climate models have to be downscaled to a case study area to identify likely changes in climate variables and resulting physical changes in the coastal environment under different CC scenarios. Potentially, different CC mitigation [64,65] or adaptation [66] scenarios can be considered. When exploring CC impacts on the East coast of England, Turner et al. [65] used 17 climate model patterns till 2080 and a range of local weather data to estimate the key climate variables for coastal ecosystems. They included increases in average monthly and average monthly maximum temperatures, changes in monthly precipitation patterns, sea level rise (SLR) and changes in extreme events which are expected to be more frequent and severe in the future. CC-driven changes in temperature significantly influence the coastal and marine areas as they alter ocean conditions such as water temperature and biogeochemistry [67–69]. As a result, oceans become warmer and more stratified. In addition, higher levels of CO_2 lead to higher acidity of oceans [70]. Both will influence ocean flora and fauna. Increase in precipitation may cause growing nutrient fluxes due to heavy runoff from land leading to eutrophication risks in coastal wetlands [69].

Potential CC physical impacts on coasts—SLR and extreme events in particular—lead to episodic coastal inundation and permanent submersion of low lying land, episodic storm erosion of beaches and dunes, episodic formation and closure of small tidal inlets, and/or chronic coastal recession [5]. Coastal recession will result in less opportunity for beach recreational use. In general, less attractive beaches for recreation might be due to any of the CC driven impacts on sandy coasts listed in [5].

Secondly, these CC driven physical impacts need to be linked to specific ecosystem services that are currently provided by coastal wetlands in a particular location. This should ideally start with a qualitative assessment of changes in the provision of CES. In particular, it is necessary to assess whether changes in temperature, precipitation and other climatic variables will affect different use and non-use values of services provided by coastal ecosystems. Each of these two groups of CES should be specified and translated into measurable physical units. For instance, CC driven changes in temperature may be linked to changes in regulation services (categorized as indirect use value in this paper) measured through eutrophication, changes to food provision services measured in fishing stock, and changes to cultural and recreational ecosystem services measured through impacts on tourism and visitor numbers [65]. Similarly, SLR can be linked to regulation services measured through a need for flood protection to avoid land inundation [66] or to food provision services measured through increasing salinity of coastal soils [65].

Sumaila et al. [69] discussed the potential CC driven changes on food (fish) provision aspect of CES through change in primary fish productivity [71] caused by changes in physiology [72]. These CC driven changes on fish production affect economics of fisheries through a change in fishing costs due to adaptation to CC, a change in the relation between fish supply and ex-vessel revenue ultimately leading to changes in the price of fish and gross revenue. CC may also alter fish abundance by shifting their habitat and spatial distribution through changes in salinity, water temperature, vertical mixing rate, wind driven circulation etc. [68].

It should also be noted that the impacts of CC might alter CES differently depending on the ecosystem type and provided services. For example, changes in sea temperature may not always negatively affect the health condition of mangroves [73], since mangrove swamps can expand due to increases in temperature. Thus, it is important to note that ecosystems are not always damaged due to climate change impacts and in fact these ecosystems can extend under a warmer climate. Changes in precipitation patterns caused by CC may also positively affect the growth of mangroves and their areal extent [74,75]. However, decreases in the value of some CES may have a positive impact on other ecosystem services such as educational and research value, where damage due to CC impacts on coastal wetlands and their ecosystems might attract scientists and researchers to allocate higher academic budgets for undertaking research into these destructive impacts.

It should be noted that in quantification of CC-driven ecosystem changes, adaptation of some ecosystems to the physical changes can positively affect the services they provide. Moreover, it is very important to consider whether there is room for coastal ecosystems to migrate inland (mostly applicable for mangroves). For example, if SLR-induced inundation occurs causing inland salt intrusion, and if a landward migration is possible, then a favored habitat could be created for mangroves farther inland, resulting in inland expansion of such ecosystems. Therefore, these CC-driven changes can result in providing more mangrove services, and adding value rather than losing value.

Thirdly, the qualitative trends in CES provision need to be specified in quantitative terms. This often involves domain-specific modelling and data, for example, on fisheries or on land submersion. While research on the previous two steps is rather extensive, only a few studies have performed detailed quantitative analysis of physical impacts of CC on CES. One exception is the work of Cheung et al. [76] who estimated that ocean acidification in the North Atlantic will result in the reduction of fish growth, leading to a 20–30% decrease in harvests.

Finally, the CC driven variations in CES have to be monetized. Until recently, monetary valuation of potential losses of ecosystem services under different CC scenarios (left hand side of Figure 2) have been scarce leading to rudimental assessments of CC damages to ecosystems [63], which are part of global SCC (right hand side of Figure 2). Currently there is a fast growing body of literature with individual case studies as well as attempts for large-scale valuations. As the first estimate of the potential cost of adapting the World's fishing sector to climate change, Sumaila and Cheung [77] estimated that globally, the fishing sector may suffer from a $17 to $41 billion annual loss in landed value. Kragt et al. [78] presented another example in the Great Barrier Reef Marine Park in Australia, where reef trips by divers and snorkelers could decrease by 80% given a hypothetical decrease in coral and fish biodiversity, corresponding to a loss of AUD 103 million per year in tourism revenues.

Kuhfuss et al. [66] presented an example of a thorough valuation of CC driven changes in CES in coastal wetlands in France. Given a 1 m SLR scenario by 2100, regional coastal wetlands are expected to gain additional territory due to a retreat of agricultural and urban areas, and thus result in a value ranging between 10,790,000 to 16,188,000 of 2010 €. Fanning [79] also estimated that the annual value of CC driven impacts on ecosystem services at a coastal lagoon in Uruguay is US $178,487–290,540 and US $300,000 for regulatory (indirect use), and provisional (direct use) combined with cultural ecosystem services, respectively. Large-scale valuations have also indicated that annual damage to CES in Europe due to CC driven SLR could be about €2.9 billion by 2050 [80].

5. Concluding Remarks

This article aims to provide a coherent review on the valuation of coastal ecosystem services by systematically describing the main valuation concepts, and addressing the issue of climate change impacts on the monetary value of CES. To this end, it offers a systematic overview of the state-of-the-art and a CES assessment guideline for practitioners and researchers in interdisciplinary teams. To achieve this objective, firstly we present a summary of coastal wetlands, ecosystems and the services they provide, drivers of ecosystem change, valuation methods, and required data for performing valuation studies.

Secondly, we analyze two global scale and 30 local and regional scale case studies of coastal ecosystem valuation. This analysis has resulted in the following main observations: Valuation studies reviewed in this article consider coral reefs and mangroves as the most important coastal ecosystems, while sea-grass beds are the least investigated coastal ecosystems in terms of the monetary value provided by their services; With respect to ecosystem services provided, tourism and recreation as well as storm protection are the most common CES that have been monetized. These two services are often valued higher than other services provided by coastal ecosystems. On the contrary, cultural services such as aesthetic and artistic values have been hardly valued so far, indicating the necessity for further research regarding these services; With respect to the valuation methods, avoided damage, replacement and substitute cost methods are the most commonly used techniques for valuing storm or flood protection services. In addition, stated preference and production-based methods (net factor income) are also frequently used for valuation of many different ecosystem services; The most common limitation of the reviewed studies is the incomplete measure of ecosystem value they provided. The reason for this incomplete estimation can be associated with the complexity of considering and valuing all the services provided by ecosystems as well as data scarcity in the study areas.

Finally, this article addresses the important but poorly understood aspect of how foreshadowed climate change may affect coastal ecosystem services. Here, we present a framework that illustrates the two different ways in which CC and CES are linked. The first link represents how CC affects the climate regulation service of the coastal ecosystems. The second link, represents how CC may tangibly affect CES. Furthermore, the monetization of CC driven variations in the value of CES, which is subject to substantial uncertainty, is identified as a major challenge. To address this challenge, we propose a systematic approach involving the following steps: (1) Identification of changes in climate variables and resulting physical impacts on coastal ecosystem; (2) qualitative determination of the effects that CC-driven physical impacts identified in (1) may have on CES; (3) translation of the qualitative trends of CC driven impacts into quantitative estimates; and (4) monetization of quantitative CC impacts on CES. The fourth step represents the main contemporary knowledge gap in CES valuation studies due to uncertainties in quantifying future physical climate impacts on CES, and changes in WTP due to shifts across socio-demographic groups. Hence, quantifying potential CC driven losses or gains in CES value is an important future research direction that will ultimately enable much needed quantitative assessments of climate change associated environmental risk in coastal areas.

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