Valuation of coastal ecosystem services in the Large Marine Ecosystems of Africa

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Abstract

The African coastline is bordered by highly valuable marine ecosystems, but the environmental degradation due to anthropogenic pressure alter the benefits that they render to people. Our paper aims at assessing the value of ecosystem services provided by mangroves, seagrass beds, coral reefs, and kelp forests present in the Large Marine Ecosystems (LMEs) of Africa. After the mapping of coastal marine habitats, our valuation relies on the transfer of value of all ecosystem services from reference monetary unit values, extracted from the literature. A habitat functionality index based on the assumption that a higher population density and a higher demographic growth rate lead to a decrease in the functionality and services of marine habitats was then defined and incorporated into the valuation. The surveyed coastal habitats cover about 117,000 km², with seagrass beds being by far the most extensive habitat. Present all along the coasts of Africa, their surface area represents about 62% of surveyed coastal habitats, followed by the mangroves (23%), coral reefs (15%). Kelp forests are only present in the southern Benguela Current LME. We estimated the annual value of the LME's coastal ecosystem services at 814 billion USD. Coral reefs have the highest value (588 billion USD/year), followed by seagrass beds (135 billion USD/year), mangroves (91 billion USD/year), and kelp forests (0.4 billion USD/year). The results show that ecosystem services from the four coastal habitat types had the highest value in the Agulhas Current LME, representing 38 % of the total value, followed by the Red Sea LME (28 %) and the Somali Coastal Current LME (10 %). The three LMEs of the Atlantic side represent 15 % of the total estimated value. Our paper highlighted many gaps that remain to be filled in terms of mapping and ecosystem services assessment in Africa. Nonetheless, our estimated values can facilitate dialogue between decision-makers and managers, and between countries sharing the same habitats and marine resources, toward better management of these ecosystems.

Keywords

Coastal marine habitats; Nature's contributions to people; Habitat functionality; Large Marine Ecosystems; Blue Economy

1. Introduction

The African coastline, which is over 30,000 kilometers long, is subject to many pressures (UNEP-WCMC, 2016a). Its natural habitats are damaged due to direct anthropogenic actions (resource extraction, environmental modification, pollution) and indirect actions such as climate change (UNEP-WCMC, 2016b; CBD, 2018). Thus, the surface area of natural coastal habitats such as mangroves, coral reefs, and seagrass beds has globally decreased in recent decades (with an annual loss of mangrove surface area of 2%, for example) (IPBES, 2018). At the same time, the ecological condition of these habitats has deteriorated, leading to a loss of more than 50% of the live coral cover in coral reefs of the southwest Indian Ocean following the 1998 and 2016 bleaching events due to surface waters warming (UNEP-WCMC, 2016b; IPBES, 2018). Therefore, African coastal habitats' optimal functioning is hampered even though their functions are essential to maintain a suitable living environment for African and World populations.

In order to counteract this phenomenon, national and international institutions have mobilized to organize and harmonize public policies in favor of the coastal environment in Africa (Abidjan Convention, Nairobi Convention, Jeddha Convention, Convention on Biological Diversity, etc.). In this context, ecosystem-based approaches on a multi-national scale are becoming increasingly common. This is particularly true within Large Marine Ecosystem (LME) programs that often establish multi-national diagnostics and strategic documents to optimize resources and natural spaces management within large-scale geographical areas, but also to guarantee a stable regional base in terms of human, institutional and scientific capacities and progress towards sustainable development (Satia, 2016). While public policies formerly focused on maintaining natural spaces and related biodiversity, they are now increasingly included in the process of reclaiming and enhancing degraded natural areas (Palmer and Filoso, 2009; Prober et al., 2019; Smith-Hall, 2009), in line with the United Nations' Sustainable Development Goals – SDG 15 (United Nations, 2015) and Aichi Targets 14 and 15 (CBD, 2010). In the current framework of the Intended Nationally Determined Contribution for the implementation of the Paris Agreement with particular consideration for blue carbon (UNECA, 2016; CMAE et al., 2019), or more conventionally in the achievement of Aichi Targets (Tittensor et al., 2014; Failler et al., 2019) and the implementation of Global Environment Facility (GEF)-funded programs related to LMEs (Sherman, 2019), the enhancement of coastal habitats has a leading role. In this regard, a monetary valuation is a relevant tool for integrating the environment into the economic, political, and social spheres (Binet et al., 2012; UNEP and GRID-Arendal, 2016). Quantifying ecosystem services in monetary terms allows us to compare different types of habitats and compare them with income-generating economic activities (Bacon et al., 2019; Bonnin et al., 2015). It also makes it possible to estimate the costs of political inaction (Trégarot et al., 2017), following the degradation of natural habitats. While the natural capital is often overlooked due to a lack of data compared to the human, social and economic capital (Failler et al., 2015; Pascal et al., 2018), this approach offers the advantage of emphasizing ecosystems in the planning of public policies. Choices in terms of investment for protection or conservation would be better informed if, for example, undervalued and previously overlooked habitats, such as seagrass beds, are taken into account. Monetary valuation of ecosystems further allows for greater balance in decision-making regarding the use of spaces: economic activities to the detriment of ecosystems versus risk-averse management of these ecosystems due to their high economic value.

This article's objective is to present an economic valuation of the services provided by African coastal ecosystems. The economic value of these ecosystems is calculated from the surface area of the main African coastal habitats, namely mangroves, coral reefs, seagrass beds, and kelp forests, and considers their functionality in relation to anthropogenic stressors. We used Large Marine Ecosystems (LMEs) as a spatial unit for conservation purposes. Developed by Sherman and Alexander (1986), "*LMEs are relatively large areas of ocean space (>200,000 km²) located along the margins of the continents. They are defined based on four ecological criteria: bathymetry (bottom depth); hydrography (water column structure); productivity; and trophic linkages*" (Sherman, 2019). The LME concept enables ecosystem-based management to provide a collaborative approach to managing resources within ecologically bounded transnational areas. The method used is innovative since it incorporates the level of anthropogenic pressure to adjust the monetary valuation calculated using benefit transfer, where monetary assessments are usually limited to surface area data. The adjustment of the production function, which characterizes relationships between habitat condition and the delivery of economically valuable ecosystem services, by the ecological condition or the vulnerability of habitats was tested in the evaluation of ecosystem services for coral reefs and associated habitats (mangroves and seagrass beds), within the French Initiative for the Protection of Coral Reefs in French Overseas - IFRECOR (Failler et al., 2015; Trégarot et al., 2017). It was more recently applied to assess ecosystem services in the Banc d'Arguin National Park (PNBA), the largest marine protected area in West Africa (Trégarot et al., 2018). In the context of chronic lack of data and studies relating to African coastal and marine ecosystem services (Wangai et al., 2016; Willcock et al., 2016), this article presents, to our knowledge, the first exhaustive monetary study at the scale of the whole African continent for four essential coastal habitats. The geographic scale is unprecedented, considering that none of the monetary assessments that have already been conducted in Africa does exceed the regional level (Interwies, 2011; Interwies and Görlitz, 2013 in UNEP and GRID-Arendal, 2016), or individual LME level (Chukwuone et al., 2009). Moreover, they focused on few topics such as fishery resources (Sumaila, 2016), West African marine protected areas (Binet et al., 2012) and carbon sequestration (Bryan et al., 2020). Our approach can be re-used for similar work at other spatial scales (regional, national and local), particularly within the framework of the implementation of the African strategy relating to the blue economy, within which the enhancement of coastal ecosystems is a central concern.

The article is structured in three parts to present 1) the methods used for mapping and assessing ecosystem services considering the anthropogenic pressures; 2) a section giving the estimated value of coastal habitats per LME; 3) a discussion that integrates the main results into a broader reflection on the development challenges of the continent with its coastal environment.

2. Method

2.1. Estimated surface area of coastal marine habitats

The files digitizing the surface areas of coastal marine habitats targeted in this study (coral reefs, mangroves, and seagrass beds) are available on the Ocean Data Viewer database (available online at data.unep-wcmc.org). At the same time, we retrieved the distribution of kelp forests from Blamey and Bolton (2018). We determined coral reefs' surface area (UNEP-WCMC et al., 2018) considering only the surface areas that correspond to the African waters with the function "cutting" of the QGIS software (QGIS Development Team, 2020). Mangroves' surface area, then, was determined following

the same process as coral reefs from the digitizing work of the Global Mangrove Watch project (Bunting et al., 2018), also available on Ocean Data Viewer. In this case, it was also necessary to use the automatic calculation function of QGIS to determine the surface area of the polygons digitized by Global Mangrove Watch. On the other hand, there is a lack of data on seagrass beds (Nordlund et al., 2018). The datasets present on Ocean Data Viewer are more likely to illustrate favorable distribution zones rather than existing contours (Bryan et al., 2020) even in the own view of some of their authors (Jayathilake and Costello, 2018). However, in the absence of suitable alternatives, our estimation of seagrass beds' surface area was based on UNEP's dataset (UNEP-WCMC and Short, 2017) made available through this platform.

In a second step, these habitats' surface areas were measured for each Large Marine Ecosystem bordering the African continent. The files digitizing the surface areas of mangroves, coral reefs, and seagrass beds were crossed with the digitized contours of these LMEs using the "cutting" function of QGIS.

The widely recognized NOAA classification of LMEs (IOC-UNESCO and UNEP, 2016) served as a reference. Thus, eight LMEs are bordering Africa: Agulhas Current LME (ACLME), Arabian Sea LME (ASLME), Benguela Current LME (BCLME), Canary Current LME (CCLME), Guinea Current LME (GCLME), Mediterranean Sea LME (MEDLME), Red Sea LME (RSLME) and Somali Coastal Current (SCCLME). One additional region was included because it occurs near the African continent and shares similar coastal marine habitats: the African islands of the Indian Ocean. The region of Cabo Verde was not included due to the 'absence' of habitats from the dataset of UNEP, despite the confirmed observation of coral reefs (Monteiro et al., 2008), seagrass beds (Creed et al., 2016), and kelp forests (Bolton, 2010). The spatial scale of Cape Verde Islands is also much smaller than the other LMEs and therefore requires a more refined evaluation. Furthermore, for the African Islands of the Indian Ocean, the Arabian Sea LME, the Mediterranean Sea LME and the Red Sea LME, we considered only the extent of each entity that was within the exclusive economic zones of the related African countries for our analyses. These LMEs and the additional region are illustrated in Figure 1, while the surface areas of coastal marine habitats within each LME and additional regions are presented in section 3.1.

2.2. Anthropogenic pressures and loss of functionality

The ecological condition of habitats is often overlooked in the valuation of ecosystem services. However, the degradation of habitats condition alters the provisioning of their services and should, therefore, be accounted for (Culhane et al., 2020; Failler et al., 2010; Trégarot et al., 2017). In the absence of reliable data to assess marine habitats' ecological conditions in Africa, our paper examined the potential anthropogenic pressures as a proxy. Marine habitats exposed to stress are less resilient, i.e., more sensitive to disturbances, have reduced adaptive capacities, and have therefore an increased vulnerability (Folke et al., 2004; Moe et al., 2013). We assumed, then, that an increase in anthropogenic pressures is likely to decrease the ecological condition (i.e., increase the vulnerability) and the functionality of the habitat, and the supply of its services (Folke et al., 2004; Schröter et al., 2005). Indeed, human development is one of the main drivers of habitat degradation and loss of biodiversity (Cardinale et al., 2012) and a relatively good indicator of anthropogenic pressures. For instance, human population density has been previously related to water pollution levels (Nixon et al., 2003), forage fish declines (Greene et al., 2015), and sharks' distribution (Ward-Paige et al., 2010), while population growth rate has been previously related to species geographic

range size (Di Marco and Santini, 2015) and ecosystems shifts (Tam et al., 2017). Therefore, we decided to consider both the population density and growth rate at the national scale in the absence of reliable information at the coastal level. The two parameters provide different information about the potential anthropogenic pressures and their effects on marine ecosystems.

On the one hand, population density indicates of the strength or magnitude of the anthropogenic pressures the ecosystems are likely to face. The higher the population density, the stronger the potential anthropogenic pressures (Creel, 2003; Nixon et al., 2003). The population growth rate, then, is more indicative of the temporality or trend of anthropogenic pressures. Indeed, while a relatively low growth rate reflects relatively stable stressors (or 'chronic pressures') to which ecosystems are more likely to be able to adapt, a relatively high rate reflects an increasing anthropogenic pressure to which ecosystems would be less likely to adapt, considering there would not be enough time for adaptive processes to occur (Dawson et al., 2010; Whitney et al., 2017). Consequently, we derived from these two parameters an index of habitat functionality as follows:

- We assumed that marine habitats in LMEs that were among the top 25% of LMEs globally for both parameters were facing acute and increasing anthropogenic pressures and, thus, only functioning at 25% of their optimal functional capacity, i.e., an index of functionality of 0.25.
- In comparison, marine habitats in LMEs in the top 25% for one of the parameters but in the lower 75% for the other were considered as functioning at 50% of their optimal functional capacity (i.e., an index of functionality of 0.50), reflecting intermediate anthropogenic pressures (either strong but stable or low to moderate but increasing rapidly).
- Finally, we considered that marine habitats in LMEs in the lower 75% for both parameters were functioning at 75% of their optimal functional capacity (i.e., an index of functionality of 0.75), reflecting relatively low and stable anthropogenic pressures. In this last instance, we didn't consider an optimal functional capacity (i.e., 100%) because both parameters, especially the population growth rate, were still above the average world values (United Nations, 2019).

2.3. Economic Valuation

We used Google Scholar to search for papers on the valuation of ecosystem services for the targeted habitats and selected recent reviews of economic values when they were available in the literature. We then classified the services following the Common International Classification of Ecosystem Services (CICES v5.1; Haines-Young and Potschin, 2018), avoiding as much as possible the risk of double counting, which may occur when assessing multiple ecosystem services using different nomenclatures or classifications, such as the Millennium Ecosystem Assessment (MA, 2005) and The Economics of Ecosystems and Biodiversity (TEEB, 2010). From the full list of ecosystem services, we selected the ones relevant to the marine environment (MARINE CICES Relevance = 1) and selected the services applicable to the targeted habitats (expert knowledge). The literature review provided us with reference values (average value of several studies for a particular service) compiled in Table 1, and which were standardized to 2018 USD using the world average inflation rate (consumer prices, annual %) retrieved from The World Bank (2020).

The available reference values were then adjusted by multiplying them with the habitat functionality index (0.25, 0.50, or 0.75), and then multiplied by the surface area of coastal marine habitat for each LME. We considered the valuation of ecosystem services of kelp forests in South Africa (Blamey and

212 Bolton, 2018) to reflect of the current habitat's functionality and did not require further adjustment.
213 However, to calculate the value of kelp forests in an optimal state, we divided the reference value
214 with the habitat functionality index. Our valuation method can be characterized by a benefit transfer
215 approach (without adjusting the value with the Gross Domestic Product of the countries because of
216 the spatial scale) fitted with a production function approach to account for the potential loss of
217 functionality (and ecosystem services) of habitats as a result of anthropogenic pressures.
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Table 1. Reference values of ecosystem services in 2018 USD provided by marine coastal habitats following the CICES classification, for the assessment of the economic value of marine ecosystem services per African Large Marine Ecosystem.

	Code	CICES Class	Mangroves [USD/ha/year]	Coral reefs [USD/ha/year]	Seagrass beds [USD/ha/year]	Kelp forests [USD/km/year]
Provisioning	1.1.5.1	Wild plant used for nutrition	na	na	na	nd
	1.1.5.2	Fibres and other materials from wild plants for direct use or processing	3,417 ^d	na	11,580 ^e	2,428 ^a
	1.1.5.3	Wild plant used as a source of energy		na	nd	nd
	1.1.6.1	Wild animals used for nutritional purposes	10,574 ^d	965 ^b	1,481 ^e	179,230 ^a
	1.1.6.2	Fibres and other materials from wild animals for direct use or processing	nd	31,359 ^b	nd	nd
	1.2.1.1	Seeds, spores and other plant materials collected for maintaining or establishing population	nd	na	nd	nd
	1.2.2.1	Animal material collected for maintaining or establishing population	nd	47,107 ^b	nd	nd
Regulation & Maintenance	2.1.1.1	Bio-remediation by micro-organisms, algae, plants, and animals	3,593 ^d	121 ^b	23,237 ^e	Part of 2.2.6.1
	2.1.1.2	Filtration/Sequestration/storage/accumulation by micro-organisms, algae, plants, and animals			nd	na
	2.2.1.1	Control of erosion rates	1,182 ^d	218,391 ^b	4,803 ^c	nd
	2.2.1.3	Hydrological cycle and water flow regulation (including flood control, and coastal protection)	2,143 ^d	24,219 ^b	nd	nd
	2.2.2.1	Pollination (Gamete dispersal)	nd	23,106 ^b	nd	nd
	2.2.2.2	Seed dispersal	nd	nd	nd	nd
	2.2.2.3	Maintaining nursery populations and habitats (including gene pool protection)	1,975 ^d	nd	136 ^e	nd
	2.2.3.1	Pest control	1,013 ^d	nd	nd	nd
	2.2.3.2	Disease control		nd	nd	nd
	2.2.4.2	Decomposition and fixing processes and their effect on soil quality	544 ^d	na	nd	na
	2.2.5.2	Regulation of the chemical condition of salt waters by living processes	1,016 ^d	nd	nd	nd
	2.2.6.1	Regulation of chemical composition of atmosphere and oceans		1,693 ^b	413 ^c	147,540 ^a
	2.2.6.2	Regulation of temperature and humidity including ventilation and transpiration	44,178 ^d	na	na	na
	3.1.1	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	4,482 ^d	137,269 ^b	nd	115,839 ^a
Cultural	3.1.2.1	... that enable scientific investigation or the creation of traditional knowledge	351 ^d	1,632 ^b	nd	72 ^a
	3.1.2.2	...that enable education and training			nd	
	3.1.2.3	...that are resonant in terms of culture or heritage	325 ^d	nd	nd	nd
	3.1.2.4	... that enable aesthetic experiences		16,235 ^b	nd	nd
	3.2.1.1	Elements of living systems that have symbolic meaning	nd	nd	nd	nd
	3.2.1.2	Elements of living systems that have sacred or religious meaning	nd	nd	nd	nd
	3.2.1.3	...used for entertainment or representation	nd	nd	nd	nd
	3.2.2.1	...that have an existence value	nd	nd	nd	nd
	3.2.2.2	... that have an option or bequest value	nd	nd	nd	nd

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Sources: ^aBlamey and Bolton (2018), ^bDe Groot et al. (2012), ^cDewsbury et al. (2016), ^dHimes-Cornell et al. (2018a), ^eVegh and Potouroglou (2018).

na: this service has never been associated with this habitat; nd: this service has been associated with this habitat but there are no data available.

223 Values between doted lines means that the valuation covered both services indistinctively.

3. Results

3.1. Surface areas of coastal marine habitats

Based on our mapping, the combined extent of coral reefs, mangroves, and seagrass beds was estimated at approximately 117,000 km², following a heterogeneous distribution. Seagrass beds, which are present all along the coasts of Africa, are the most extensive ecosystem with an estimated surface area of more than 72,000 km² (Table 2). The mangroves come next, with a surface area of 27,465 km², distributed between Mauritania in the north and Angola in the south for the Atlantic coast, while they are present on the entire eastern coast from the north of South Africa (Figure 1). Coral reefs, then, represent a total surface area of 17,121 km². No surface area was given for kelp forests, which dominate the nearshore environment in the southern region of the Benguela Current LME, covering approximately 1,000 km of the coastline (Blamey and Bolton, 2018).

Figure 1. Distribution of the main coastal marine habitats along African waters, and their divisions into the Large Marine Ecosystems and the additional region.

Seagrass beds are particularly abundant along the Guinea Current LME (Table 2). More importantly, they are present in 8 out of 9 LMEs and additional regions of Africa. Mangroves are mainly located along West Africa in the Guinea Current LME (over 16,000 km², representing almost 60% of the total area). However, a significant area is also present in the Agulhas Current LME (5,792 km², equivalent

to 21% of the total area). The Agulhas Current LME is also the LME within which the coral surface area is the largest (more than 6,400 km²), followed by the Red Sea LME (more than 5,400 km²).

Table 2. Surface areas (or linear coastal length - kelp forests) of the main coastal marine habitats along African waters, and their divisions into the Large Marine Ecosystems and additional region.

Large Marine Ecosystems (LME) and the additional region	Coral reefs [km ²]	Mangroves [km ²]	Seagrass beds [km ²]	Combined [km ²]	Kelp forests [km]
African Islands of the Indian Ocean	2,285	8	134	2,427	0
Agulhas Current LME	6,442	5,792	9,714	21,948	0
Arabian Sea LME	408	11	0	419	0
Benguela Current LME	0	617	601	1,217	1,000
Canary Current LME	0	3,212	6,195	9,407	0
Guinea Current LME	0	16,195	43,582	59,777	0
Mediterranean Sea LME	0	0	5,065	5,065	0
Red Sea LME	5,481	76	6,963	12,521	0
Somali Coastal Current LME	2,844	1,555	160	4,559	0
Total	17,460	27,465	72,415	117,339	1,000

The LME with the greatest combined surface areas of coral reefs, mangroves, and seagrass beds is by far the Guinea Current LME with ~ 60,000 km², followed by the Agulhas Current LME with ~ 22,000 km² (Table 2). Among the other large LMEs, the Arabian Sea LME and the Benguela Current LME are less luxuriant.

3.2. Anthropogenic pressures over Large Marine Ecosystems in Africa

With the third highest population density and the second highest population growth rate, the marine habitats of the Guinea Current LME are facing the most substantial anthropogenic pressures of African LMEs (see Table A1 in Annex). They are the only ones to be considered to function at only 25% of their capacity. Then, the marine habitats of the African Islands of the Indian Ocean, the Arabian Sea LME, and the Somali Coastal Current LME face more moderate anthropogenic pressures of different intensity and temporal changes and are thus considered functional at 50% of their optimal capacity. Indeed, on the one hand, the African Islands of the Indian Ocean are presenting the highest population density, about ten times higher than the average population density in the African LMEs. They also present the lowest population growth rates, meaning their marine habitats face strong but relatively stable anthropogenic pressures. On the other hand, the Arabian Sea and the Somali Coastal Current LMEs have two of the highest population growth rates (more than twice the average world value), but relatively low population densities, meaning their marine habitats face relatively low but quickly increasing anthropogenic pressures. Finally, the Agulhas Current, the Benguela Current, the Canary Current, the Mediterranean Sea, and the Red Sea LMEs present relatively low population densities and moderate population growth rates above the average world value. Accordingly, we considered their marine habitats to have higher functionality (75%) since they were experiencing low to moderate and relatively stable anthropogenic pressures.

Figure 2. African LMEs habitat functionality index according to their population density and growth rate. Solid lines represent the 75% quantile while dotted lines represent the average World value over the 2015-2020 according to the United Nations (2019).

3.3. Economic valuation of African Large Marine Ecosystems

Table 1 shows that many services remain to be valued for all habitats, especially cultural services. It also shows the overlap of different services, when valuations are based on previous classifications, confirmed by Czúcz et al. (2018). Also, the risk of double-counting can arise when valuing different services and is particularly high for cultural services (LUC, 2015). Some of the supporting and regulating services, such as maintaining nursery populations and habitats (including gene pool protection), are inputs for provisioning services. However, we found few reference values for the cultural services, and given the numerous services that could not be valued, our approach remains most likely conservative. Based on the available reference values, the sum of ecosystem services values reaches 352,250 USD/ha/year for coral reefs, 58,842 USD/ha/year for mangroves, and 41,413 USD/ha/year for seagrass beds. For kelp forests, the average value per km of coastline in South Africa was estimated at 445,109 USD/km/year, considering the current habitat functionality and productivity. Note that those values do not represent the Total Economic Value, as developed by Ledoux and Turner (2002).

To estimate the economic value of coastal marine habitats in each LME and additional regions of Africa (Table 3), we applied the habitat functionality index (Figure 2) to the average values of marine habitats to adjust the production function. By doing this, we estimated the value of marine ecosystem services in Africa from the four coastal habitat types at 814 billion USD annually, with coral reefs having the highest value (588 billion USD/year), followed by seagrass beds (135 billion

USD/year), mangroves (91 billion USD/year) and kelp forests (0.4 billion USD/year). The results show that of the African LMEs, the value of ecosystem services from coastal habitats was highest for the Agulhas Current LME, representing 38 % of the total value in Africa, followed by the Red Sea LME (28 %). The Somali Coastal Current LME, the Guinea Current LME, and African Islands of the Indian Ocean each represent between 10 and 7 % of our estimated value in Africa (9.5 %, 9.3 %, and 7.1 %, respectively) while the other LMEs represent less than 5 % each (Canary Current LME: 4.6 %; Mediterranean Sea LME: 1.9 %; Arabian Sea LME: 1.3 %; Benguela Current LME: 0.7 %).

Table 3. Economic value of marine ecosystem services per African Large Marine Ecosystem, expressed in million USD/year, adjusted by the habitat functionality index for each LME (estimated values), and comparison with reference values.

Large Marine Ecosystems (LME) and the additional region of Africa	Mangroves	Seagrass beds	Coral reefs	Kelp forests	Total
African Islands of the Indian Ocean	31	279	57,352	-	57,662
Agulhas Current LME	32,491	30,345	242,573	-	305,408
Arabian Sea LME	41	-	10,245	-	10,286
Benguela Current LME	3,459	1,876	-	445	5,780
Canary Current LME	18,017	19,351	-	-	37,368
Guinea Current LME	30,282	45,379	-	-	75,661
Mediterranean Sea LME	-	15,822	-	-	15,822
Red Sea LME	426	21,752	206,411	-	228,589
Somali Coastal Current LME	5,813	334	71,388	-	77,535
Total (reference values)	205,422	301,602	876,615	593	1,384,233
Total (estimated values)	90,561	135,137	587,967	445	814,111
%	44 %	45 %	67 %	75 %	59 %

Using the reference values only, the value of marine ecosystem services in Africa would reach 1,384 billion USD/year (Table 3). By considering the potential loss of services due to the demographic pressure (derived habitat's functionality index), results showed a monetary value that is only 59 % of this 'maximal' value. It also indicates that mangroves might be the habitat suffering the most from the demographic pressure (44 % of the 'maximal' value).

4. Discussion

Assessing the value of ecosystem services is essential to facilitate the dialogue with and between decision-makers and make choices about public investment. It helps to formulate sound policies for both economic development and nature conservation.

The first key outcome of the valuation is that coral reef is the most important habitat, with 72% of the value generated (17% from seagrass beds, 11% from mangroves, and 0.06% from kelp forests). Despite a surface area fourfold smaller than seagrass beds, coral reefs' unit value is much higher thanks to their highly valued control in erosion rates and their support to activities promoting health, recuperation or enjoyment through active or immersive interactions. Cold-water corals, that were omitted in this valuation, are also largely represented in West Africa (Hebbeln et al., 2019; Ramos et al., 2017; Yesson et al., 2012), and provide habitat and refuge for many fish of commercial value and invertebrates.

Support of commercial fisheries probably represents the most important services offered by cold-water corals (Foley and Armstrong, 2010). Scientific knowledge for this habitat (i.e., distribution, depth range, biodiversity, functionality, ecosystem services), in Africa and other regions of the world, is still at its infancy due to the limited accessibility (Freiwald et al., 2004). Mangroves have a higher unit value than seagrass beds, by 40 %, but seagrass beds' extent is much larger, distributed from the Mediterranean Sea to Southern Africa. Despite the broad distribution of seagrass beds in Africa, this habitat remains poorly characterized, at the image of the uncertainty behind their distribution. Seagrass beds are probably one of the most unknown habitats in West Africa due to the difficulty of detecting them using remote sensing because of coastal waters' turbidity. Even emblematic region such as the National Park of Banc d'Arguin in Mauritania, created in 1976, and well known for its vast extents of seagrass beds, estimated at 674 km² (Trégarot et al., 2018) is not represented and were still not considered in the revision of seagrass distribution by McKenzie et al. (2020). Seagrass has, however, faced an increasing interest in the past few years with the growth of Blue Carbon (Lavery et al., 2013) and their potential contribution as a carbon sink. The distribution of seagrass beds in West Africa is currently being revised through the project ResilienSea (resiliensea.org). Their presence in most LMEs and the additional region merits special attention from policymakers to strengthen the conservation and restoration efforts at larger scales.

The second key outcome is that the potential value of the ecosystem services, not considering their ecological condition, is about 1,384 billion USD compared to 814 billion USD when considering the effect of the population growth and the associated habitat perturbation and degradation (derived habitat functionality index). If demographic pressures without appropriate management measures reduced the functionality of the four coastal habitat types to the degrees supposed in this study, the estimated annual loss of about 570 billion USD corresponds to the absence of additional policy or policy revision to prevent environmental damages, also referred as the cost of policy inaction (Braat et al., 2008; Failler et al., 2010). The value of ecosystem services will likely continue to decline in the future without appropriate policies to address the increasing pressure due to population growth along the African coasts. The recent African Union Blue Economy Strategy seeks to address this issue by providing means of intervention for regions and countries (AU-IBAR, 2019). The Indian Ocean Commission is also addressing this issue with its Blue Economy Regional Action Plan, where a specific focus is made on the enhancement of coastal urban ecosystems for the improvement of the public health and people's well-being in general.

Compared to other valuation studies on African LMEs, Chukwuone et al. (2009) estimated the Direct Output Value at 49,914 million USD for the Guinea Current LME, considering marine fishery, offshore oil production, Non-Timber Forest Product (periwinkle), and mining. In our study, our evaluation reaches 75,661 million USD, which is in the same order of magnitude despite a different approach and different habitats and services. Environmental goods and services from African LMEs were also estimated at 139 billion USD per year (Hamukuaya, 2011) with 22 billion USD for Agulhas and Somali Current LMEs, 54.3 billion USD for the Benguela Current LME, 11.7 billion USD for the Canary Current LME, and 51 billion USD for the Guinea Current LME (Hamukuaya, 2011 in Satia 2016). In our study, the total value reaches 502 billion USD for those LMEs. The most significant difference is for the Agulhas and Somali Current LMEs, with a 383 billion USD value. However, we could not find the reference within Satia (2016), making the comparison difficult. The average value of the LMEs and the

additional region in Africa was estimated at 90 billion USD per year, which, compared to the Bay of Bengal LME, is in the same order of magnitude, estimated at 72 billion USD (BOBLME, 2014).

4.1. Intended use of ecosystem services valuation

Over the last decades, ecosystem valuation has become a convincing way of demonstrating the economic gains and value-added associated with marine and coastal conservation. As useful as this kind of information on benefits is for advocacy and awareness purposes, it is, nevertheless, important to underline that economic valuation is not an end in itself. Instead, it should be seen as a means to an end – better and more informed decision-making (Emerton, 2013). Therefore, our main concern is incorporating valuation results into the implementation of African LMEs projects and their respective Strategic Action Programmes. Indeed, although there have been great achievements and advances made by African LME Programmes to constitute a solid foundation on which to build and move forward (Satia, 2016), about 90% of all the Transboundary Diagnostic Analysis-Strategic Action Programme (TDA-SAP) processes undertaken so far include the need for a cost-benefit analysis or value chain analysis to justify political support for the ecosystem-based management approach and to strengthen protection for ecosystem resilience (UNDP, 2017). Fisheries is one good example for which the desire to maximize added value often results in the overexploitation of the resources shared between several countries (Munro, 1979; Clark, 1990). The three BCLME countries have already established the Benguela Current Commission (BCC) as a fully-fledged regional cooperative management body for the Benguela Current Large Marine Ecosystem (Sumaila, 2016). Similar management initiatives in Africa's other LMEs would be an important addition to the marine environment's current management framework. Given the urgency to upscale restoration efforts, LMEs provide a suitable framework and management tool to reversing the degradation and general loss of biodiversity and introduce an ecosystem approach to managing the living marine resources to sustain the good and services of LMEs for the well-being of livelihoods in Africa.

At a more regional or local scale, this evaluation could be a starting point for some regions that do not have ecosystem services valuations to rely on. The simple transfer of value of ecosystem services from reference monetary unit values is an approximation at best and must be interpreted with the utmost care. But this method has the advantage of being easily implemented in data-scarce regions. The unit reference values of habitats can be used locally, with little adjustments, considering the Gross Domestic Product and the socio-economic and environmental contexts. Valuation estimates can support arguments for establishing Marine Protected Areas when the benefits of such designations outweigh the costs and, more generally, can inform the "preservation versus development" debate in coastal areas. In return, the creation of Marine Protected Areas contributes to achieving the Aichi target 11 and SDG 14 – target 14.5, which is to effectively conserve 10% of coastal and marine areas by 2020 (CBD 2010; United Nations 2015). Our results may also support market solutions such as Payment for Ecosystem Services schemes (Palmer and Filoso, 2009). PES schemes, such as 'Reducing Emissions from Deforestation and Degradation' (REDD+), incentivize conservation through 'avoided deforestation', with a service buyer paying a service provider to store carbon that would otherwise be emitted due to land cover change. Payments for avoided deforestation are rapidly gaining traction in the marine environment, mainly through mangrove research and policymaking under the term 'blue carbon' (McLeod et al., 2011; Sutton-Grier and Moore, 2016). In fact, many countries are including Blue Carbon in their revised Nationally

Determined Contributions (Herr and Landis, 2016) with carbon market makers such as Verra (formerly Verified Carbon Standard; VCS; <https://verra.org>) creating methodologies and standards for seagrass carbon sequestration as well as regional bodies such as IORA (Indian Ocean Rim Association) initiating regional Blue Carbon Think Tanks, among other efforts (<https://www.iora.int>).

4.2. Limitations and Future research

The valuation of ecosystem services using benefit transfer presents many drawbacks, namely the tendency to overestimate, the inaccuracy that arises when the original value was calculated in very different biophysical, ecological and socio-economic characteristics, or the risk of recycling old values (see Himes-Cornell et al. (2018b) and references within). Furthermore, there are substantial risks and uncertainties associated with our assessment. First, the use of a single monetary value in this study may suggest a false precision, whilst decision-makers should interpret the values having the uncertainties and limitations in mind. The current state of knowledge requires that we simplify complex ecological systems into single economic goods that we are able to value (Cole and Moksnes, 2016). Our valuation aims not to provide precise estimates of ecosystem services at this scale but to highlight the benefits and goods coastal marine habitats offer to people in Africa. As Costanza et al. (2017) mentioned: “there is not one right way to assess and value ecosystem services. There is however a wrong way, that is, not to do it at all”. Furthermore, the monetary value should be considered within the local environmental context (ecological and social). For instance, the service of coastal protection and its value could also be calculated with the damage avoided cost (Pascal et al., 2016). Although some habitats do not protect human infrastructure and hence should have a lower monetary value, their natural importance to protect terrestrial habitats, for instance, breeding colonies of seabirds at risk of flooding on low elevated islands in Mauritania (Veen et al., 2018), should nonetheless be recognized. On the other hand, the service of coastal protection is vital in regions at risks of extreme climatic events (i.e., cyclone), such as South-East Africa (Cabral et al., 2017; Devi, 2019) or in West Africa, where coastal erosion rates have been substantial over the past decades (Ndour et al., 2018).

Secondly, the mapping of coastal marine habitats is an obvious source of uncertainty, especially seagrass beds, for which the surface area is still a gross approximation. Also, kelp forests are probably not limited to the Benguela Current LME, according to the distribution of laminarian globally (Wernberg et al., 2019), but might also be present in the Canary Current LME and the southern Agulhas Current LME. The distribution of coral reefs and mangroves are considered reasonably representative of the reality at this spatial resolution. Indeed, the surface areas of coral reefs from UNEP-WCMC et al. (2018) is consistent with the ones from The Nature Conservancy in the Red Sea (<http://maps.tnc.org/globalmaps.html>), and the work from Fatoyinbo and Simard (2013) and Tang et al. (2018) confirms the surface for mangroves. Finally, other habitats present in Africa that provide valuable ecosystem services and were omitted include salt marshes, mudflats, estuaries, sand beaches, and dunes (Barbier et al., 2011; Trégarot et al., 2018). Then, ecosystem services are not uniform across a seascape, and considering the surface area alone puts aside any spatial and temporal differences that should be accounted for, such as reef flat width, for their ability to attenuate wave’s height (Ferrario et al., 2014), or seasonal fluctuations in the density and biomass of seagrass (Oreska et al., 2017). The assessment of habitats’ vulnerability is one way to account for spatial variability, and has been developed before at a smaller scale (e.g., Ellison, 2015; Ventura and

da Cunha Lana, 2014), with data on environmental and anthropogenic drivers, the adaptive capacity and sensitivity of marine habitats that could not be assessed here. Our approach is much more simplistic by considering only the demographic pressure but can be easily implemented in other regions. Such an indicator has never been used to adjust the assessment of ecosystem services to our knowledge. Further studies are needed to understand the response of marine habitat functioning (and services) to environmental and anthropogenic pressures. In the context of climate change, implementing effective long-term monitoring is fundamental as habitats should benefit from actions reinforcing their resilience capacity. It requires identifying tipping points and thresholds of foundation species (Moore, 2018) against the cumulative impact of environmental and anthropogenic drivers (Furlan et al., 2019) and developing models to predict coastal marine habitats' trajectories and the benefits that they render to people.

5. Conclusion

As human populations continue to increase, particularly in Africa, future population growth and expansion of human settlements in the coastal areas will increase the challenges for conserving species-rich LMEs and maximizing the benefits that humans can gain from nature (Luck, 2007). With an annual loss estimated at 570 billion USD, it questions the effectiveness of policies at national, regional, and continental levels. Therefore, it is crucial to identify economic policy instruments for LMEs' Strategic Action Programme to reverse the degradation of habitats and sustain the goods and services coastal marine habitats provide. The recent set-up of Blue Economy strategies at the African Union, Regional Economics Committees, and country levels (Seychelles and South Africa, for instance) should fill the current science-policy gap, or at least narrow it, as they are addressing, in an integrative manner, the development and the conservation of blue ecosystems.

Acknowledgements

We are grateful to the anonymous reviewers for critical and constructive feedback.

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Annex 1

Table A1. Demographic parameters associated with Large Marine Ecosystems from adjacent countries and derived habitat functionality index.

Large Marine Ecosystems (LMEs) and the additional region of Africa	Population ^a	Population Density ^{a*} [inhabitants/km ²]	Population Growth Rate ^a [%/year]	Habitat Functionality Index
African Islands of the Indian Ocean	2,264,560	502.23***	0.41	50%
Agulhas Current LME	95,896,747	43.64**	2.23	75%
Arabian Sea LME	6,217,608	29.00	2.69	50%
Benguela Current LME	58,574,052	23.46	2.42	75%
Canary Current LME	51,167,231	47.92	1.82	75%
Guinea Current LME	436,506,189	83.94	2.67	25%
Mediterranean Sea LME	109,474,334	44.86	1.71	75%
Red Sea LME	112,454,878	64.47	2.11	75%
Somali Coastal Current LME	123,843,160	48.08	2.67	50%

^a Source: United Nations, 2019.

* these calculations are based on population density data on a national level. However, coastal populations in each country are assumed to be more concentrated.

** Madagascar wasn't used to calculate the population density here, but its density is close to the calculated average (48 inhabitants per km²). Comoros and Mayotte, whose density are higher, weren't integrated into the calculation because of their very small surface area.

*** in this case, considering that all entities were small islands, population was used to weight population density.