Economic Benefit of Coastal 'Blue Carbon' Stocks in Moroccan Lagoon Ecosystem: A Case Study From Moulay Bouselham lagoon

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Abstract

Land degradation is a problem that increasingly affects large areas of territories and affects various ecosystem services provided by coastal wetlands. These marine ecosystems provide valuable benefits to the environment and to humans, including services such as coastal blue carbon sequestration (CBCS) the economic value of which is still poorly understood. This paper investigated land use/cover (LULC) changes in Moulay Bouselham lagoon (MBL) from 1971 to 2020 and their effects on CBCS variation. The transformation of LULC and their cumulative conversions in coastal wetlands were studied during the 1971-2010 and 2010-2020 periods based on LULC data. Then the InVEST model was used to quantify the carbon storage provided by coastal ecosystems in response to LULC changes. The results show that the overall area of strictly wetland habitats in the MBL has decreased by 8.83% since 1971. There were 94 types of LULC transformation over 1971-2020, with significant wetland losses marked by the conversion of wet lawn and juncus meadow to cropland. Using recent estimates of social cost of carbon (SCC) and CO₂ European Emission Allowances (EUA), the monetary value of CBCS service was calculated over the entire lagoon during the study period to reach gains between 371,053 and 3,803,295US\$/y and losses between -10,127 and -103,806US\$/y. If current trends of habitat loss continue, the capacity of coastal habitats to sequester and store CO₂ will be significantly reduced. The study shows that revenues from CBCS service can accelerate the implementation of wetland rehabilitation strategies that have a positive impact on climate regulation.

1. Introduction

Coastal ecosystems are essential for maintaining human well-being and global biodiversity. These ecosystems provide many benefits and services that contribute to climate regulation, such as erosion protection, hydrological regimes, flood risk reduction, and water purification (Saintilan et al., 2018; Sutton-Grier & Sandifer, 2019). In addition to these ecosystem services, coastal wetlands also provide an ecosystem service, often ignored or poorly considered for in ecological analyses, namely sequestration and storage of carbon dioxide (CO₂) captured from the atmosphere and ocean (Chmura, 2013; Herr et al., 2017; Howard et al., 2014), aka coastal blue carbon.

"Blue carbon" is the carbon stored in the biomass and sediments of tidal marshes, mangroves and seagrass beds. These coastal ecosystems sequester greater amounts of carbon than those stored in terrestrial ecosystems (McLeod et al., 2011). Despite their important role in carbon sequestration, coastal ecosystems are increasingly affected by climate change factors, such as rainfall and temperature and human activities including population growth, environmental pollution, and land use/cover change (Lovelock & Reef, 2020; Ward, 2020). The loss of area in these ecosystems means that stored carbon is being released and that LULC changes or other disturbances to these systems are causing them to lose the future potential to store more carbon (Pendleton et al., 2012). In Morocco, the main estuarine wetlands have been protected by the Ramsar Convention on Wetlands of International Importance. But LULC changes are threatening coastal ecosystems, which are becoming sources of carbon emissions.

Where these wetlands are pressured from land-use, the sediments are exposed to the atmosphere or water, causing carbon stored in the sediments to bind with oxygen from the air to form CO₂ and other greenhouse gas (GHGs) that are released into the atmosphere and ocean (Donato et al., 2011; Fourqurean et al., 2012; Howard et al., 2014). These activities lead not only to CO₂ emissions, but also to losses of biodiversity and essential ecosystem services.

In this research, we used the InVEST model, an open-source tool available at www.naturalcapitalproject.org, among others (Arkema et al., 2013; Clerici et al., 2019; Sathiyabama et al., 2020; Sharp et al., 2014) to quantify the value of CBCS service provided by coastal ecosystems by analysing changes in carbon storage over time in response to LULC changes. We conducted the case study in MBL located in northwest Morocco, to make a detailed accounting of blue carbon over the period (1971-2020) and to assess the potential LULC changes effects on the spatial and temporal dynamics of the CBCS. The InVEST model was used to analyse disturbances of coastal ecosystems caused by climate change and anthropogenic activities (Harley et al., 2006). Analysing these disturbances was important for prioritizing strategies to mitigate and adapt to climate change based on conservation and management of these ecosystem services. On a global scale, several coastal management strategies (Duarte, Losada, et al., 2013; Sutton-Grier & Sandifer, 2019; Wu et al., 2020) have been designed for the conservation (restoration and protection) of coastal ecosystems just as the United Nations Framework Convention on Climate Change (*United Nations Framework Convention*, 1992), in its article 4.1(d). Integrating these strategies into policies and funding mechanisms, which are still under development, can be a powerful tool for effective coastal management.

Therefore, the aims of this paper are: (1) to determine the historical extent of coastal ecosystems with accurate mapping, (2) to monitor carbon stock changes over five decades (49 years), (3) to quantify carbon stored and sequestered by coastal wetlands based on LULC changes, and (4) to estimate the monetary value of the CBCS provided by coastal ecosystems. The results of our valuation analysis highlight the economic importance of the CBCS service which offers an opportunity to mobilize additional funds and revenue by respecting

the 2030 Agenda for Sustainable Development Goals (SDGs). The SDGs directly concerned are, respectively, climate action (goal 13) and life on land (goal 15) (www.unfoundation.org) which aim to: take urgent action to combat climate change and its impacts, halt and reverse land degradation, and halt biodiversity loss.

2. Study Area And Data Used

Moulay Bousselham lagoon, also known as Merja Zerga is a Ramsar wetland (Ayadi et al., 2014) located on the northern Moroccan coast at the north-western of the Gharb plain, to the south of the coastal town Moulay Bousselham (longitude: 6°16'32" W and latitude: 34°50'57" N; Figure 1). The total area of MBL is approximately 6.1 ha, and its elevation varies between -6 to 20 m. The population of Moulay Bousselham reached 26600 inhabitants (RGPH., 2014). The general climate is sub-humid Mediterranean with temperate winters influenced by the Atlantic Ocean. Temperature ranges between 9° and 30°C, and precipitation varies between 300 and 1000 mm depending on the year. At the level of the lagoon depression, the overall texture of the soil is sandy; however, at the foot of the hills, the soil becomes a clay-conglomerate (Bureau de la Convention de Ramsar, 2004). The hydrological regime of the MBL is mainly subject to the tidal rhythm. At low neap tide, only the channels and the downstream parts of the Nador canal and the Drader Wadi are submerged; on the other hand, at high spring tide, the entire mudflat is submerged (Qninba et al., 2006).

The wetland habitats identified on the site represent currently only 52% of the overall surface area, with a predominance of mudflats and sandpits, halophilic meadows, wet lawns, and estuarine aquatic beds, while cultivated land, coastal dunes, shrubs and forest occupy the non-wetland area (Olengoba Ibara et al., 2015). The main types of activities in the study area are agriculture, fishing and animal breeding.

3. Methods And Modelling Coastal Blue Carbon Storage

3.1. LULC changes and cumulative transformation

To prepare for land use/cover mapping, three mosaics of orthophotos dated 1971, 2010, and 2020 with a respective spatial resolution of 1.5 x 1.5m, 1.3 x 1.3m, and 0.6 x 0.6m were obtained from the National Agency of Land Conservation of the Cadastre and Cartography (ANCFCC). These mosaics are composed of 10, 17, and 6 orthophotos respectively. Figure 1 shows a georeferenced mosaic of orthophotos of the MBL in 2020. Based on these mosaics of orthophotos, detailed cartography of the lagoon has been produced in each year. Then LULC was classified into eleven major types (Figure 3) and validated by previous studies (Qninba et al., 2006). We utilized LULC maps in 1971, 2010 and 2020 with ArcGIS software to analyse the LULC transformation in the MBL in two periods (i.e. 1971-2010, 2010-2020) and their cumulative conversions within the coastal wetland. To facilitate visual analysis of the cumulative transformation between LULC types, we used a chord diagram. In addition, the InVEST model was used to assess the quantity of CBCS and to estimate its economic value over the 49 years.

3.2. InVEST model:

The InVEST model was used to quantify the carbon storage provided by coastal ecosystems in response to LULC changes over the two time periods. It models the carbon cycle through a bookkeeping-type approach (Houghton, 2003), summing the carbon stores in four carbon reservoirs: aboveground and belowground biomass (AGB and BGB respectively), litter biomass (LB), and soil organic carbon (SOC) (Figure 4); it also models the rate of annual carbon accumulation in sediment and biomass (Liang et al., 2017). The InVEST model has two steps: the CBC pre-processor, then the main CBC model. The pre-processor tool creates a transition matrix that is the result of LULC changes in the studied periods (Figure 2). The main CBC model calculates carbon stock and sequestration based on the transition and carbon input data.

3.3. Carbon Data:

The InVEST model requires biophysical data including carbon storage and accumulation rates, soil and biomass disturbance rates, and carbon decay rates. The Carbon storage (Figure 4; Table 1) and accumulation rates (Table 2) of each LULC type are defined by the Intergovernmental Panel on Climate Change's (IPCC) database and local values from recent blue carbon studies (Table 1; Table 2). The specific data from these studies are used because they are comparable to our study area based on the same habitat types. The biomass and soil disturbance rates are the percentage of carbon lost as a result of LULC changes. These percentages are specific to vegetation types and are classified into three categories of impact: high, medium and low (Table 3). In our case, we used the percentages of disturbance provided by the Natural Capital Project (Sharp et al., 2014). The carbon decay rate parameter is based on vegetation disturbance-specific to a 7.5 years carbon release rate and is based on a global literature review (Sharp et al., 2014).

Table 1
Carbon model input for above-ground and below-ground biomass, litter biomass and soil organic carbon by LULC types

No	LULC types	(AGB & BGB) (Mg ha ⁻¹)	LB (Mg ha ⁻¹)	SOC (Mg ha ⁻¹)	References
1	Cultivated land (High activity)	7,3	1	110	IPCC
2	Cultivated land (Low activity)	7,3	1	70	IPCC
3	Cultivated land (Sandy soils)	7,3	1	25	IPCC
4	Estuarine aquatic bed	0,62	0	87,93	(Röhr et al., 2018)
5	Juncus Meadow	32	1,1	15,69	(Sousa et al., 2017)
6	mudflat and sandpit	-	0	143	(Phang et al., 2015)
7	Salicornia meadow	15,3 ^(a)	1	97,5 ^(b)	^(a) (Laffoley & Grimsditch, 2009) ^(b) (Schile et al., 2017)
8	Shrub and Forest	41	1	88	IPCC
9	Spartina Meadow	8,66	1	85	(Curado et al., 2013)
10	Wet lawn	13,5	1	88	IPCC

Table 2: Carbon accumulation rates (CAR) in coastal ecosystems

LULC-class	biomass-half-life	biomass-low-impact-disturb	biomass-med-impact-disturb	biomass-high-impact-disturb	biomass-yearly-accumulation	soil-half-life	soil-low-impact-disturb	soil-med-impact-disturb	soil-high-impact-disturb	soil-yearly-accumulation
cultivated land***	0.5	50%	50%	100%	210 ^(a)	7.5	10%	10%	50%	178 ^(a)
cultivated land**	0.5	50%	50%	100%	210	7.5	10%	10%	50%	178
cultivated land*	0.5	50%	50%	100%	210	7.5	10%	10%	50%	178
estuarine aquatic bed	0.5	50%	50%	100%	279 ^(b)	7.5	10%	10%	50%	52 ^(c)
juncus meadow	0.5	50%	50%	100%	1384 ^(d)	7.5	10%	10%	50%	133 ^(d)
mudflat and sandpit	0.5	50%	50%	100%	0	7.5	10%	10%	50%	359 ^(e)
salicornia meadow	0.5	50%	50%	100%	1540 ^(f)	7.5	10%	10%	50%	385 ^(g)
shrub and forest	0.5	50%	50%	100%	300 ^(a)	7.5	10%	10%	50%	510 ^(d)
spartina meadow	0.5	50%	50%	100%	332 ^(h)	7.5	10%	10%	50%	228 ^(h)
wet lawn	0.5	50%	50%	100%	120 ⁽ⁱ⁾	7.5	10%	10%	50%	44 ⁽ⁱ⁾

^(a) IPCC, ^(b) (Lavery et al., 2013), ^(c) (Duarte, Kennedy, et al., 2013), ^(d) Supplementary information of (Sousa et al., 2017), ^(e) (He et al., 2016), ^(f) (Singh et al., 2014), ^(g) (Ouyang & Lee, 2014), ^(h) (Curado et al., 2013), ⁽ⁱ⁾ (Abberton, M. ; Conant, R. ; Batello, 2010).

Table 3: LULC transition matrix for Moulay Bousseham lagoon, 1971 versus 2020

3.4. CBC pre-processor tool

The CBC pre-processor tool compares the LULC input maps (1971, 2010 and 2020) pixel by pixel to identify the set of transitions produced between LULC classes. The cells of the "Accumulation" matrix indicate that a LULC class with carbon storage potential persisted between 1971 and 2020. The "Disturbance" matrix indicates that a LULC class with carbon storage potential was changed from a vegetated LULC class to a non-vegetated LULC class. The "None" matrix indicates that the transition between LULC types did not occur on any of the LULC maps. It also generates an initial carbon pool table for LULC classes and a carbon pool transition table with disturbance and accumulation impact information quantifying the carbon storage due to LULC transitions. These three tables are used as input to the main CBC model.

3.5. Main CBC tool

After running the model using the previous data, the main CBC tool produces an output folder that contains raster carbon maps, namely the carbon stock in 1971, 2010 and 2020, as well as carbon accumulation, emission and sequestration over the period 1971 to 2020. The net sequestration of carbon $N_{p,t}$ during the year t in the pool p , whether positive in case of accumulation of carbon or negative in case of emission equals:

$$N_{p,t} = S_{p,t} + S_{p,t-1} \quad (1)$$

Where $S_{p,t}$ refers to the carbon stocks in the pool p for the year t which is calculated by :

$$S_{p,t} = S_{p_{SOC},t} + S_{p_{AGB},t} + S_{p_{BGB},t} + S_{p_{LB},t} \quad (2)$$

The carbon stock maps show the total stock of the four reservoirs combined for each year. The accumulation map shows the areas that gained carbon for the period 1971 to 2020, while the emission map shows the areas that experienced a decrease in carbon storage. The sequestration maps show the net value (+/-) between the accumulation and emission maps.

3.6. Economic valuation of CBCS

To encourage economic decision-makers to invest more in clean energy or low-carbon technologies and less in GHG-emitting technologies, some countries have decided to give an economic value to the emission of a tonne of CO₂ (I4CE, 2019). In anticipation of future carbon pricing in Morocco and to estimate the current economic value of CBCS service provided by the MBL wetland, 2020 market prices for carbon were taken into consideration according to two scales: the social cost of carbon (SCC) adopted by the United States and Canada which prices ranging from \$12 to more than \$123 per tonne of CO₂ (Government US, 2015) and the system of CO₂ European Emission Allowances (EUA) with a value of €25 ([www.markets.businessinsider.com/commodities/CO₂-european-emission-allowances](http://www.markets.businessinsider.com/commodities/CO2-european-emission-allowances) , 2020).

4. Results

4.1. LULC changes and cumulative transformation analysis

According to (Figure 5) and (Table 4), the mudflat/sandpit zone and cultivated land were identified as the largest areas of LULC habitats in the MBL in 1971-2020.

Table 4
LULC change area and CBCS statistics

InVEST types	Area (ha)			Total CBC stocks en (Mg C)			Total CBC sequestration (Mg C)
	1971	2010	2020	1971	2010	2020	1971_2020
Cultivated land	1 610	1 905	1 935	165 500	480 875	584 451	418 951
Estuarine aquatic bed	286	256	262	25 555	63 506	74 574	49 019
Juncus meadow	587	604	627	18 795	393 162	435 643	416 847
Mudflat and Sandpit	1 642	1 712	1 366	234 776	455 936	442 665	207 889
Salicornia meadow	417	129	346	47 157	113 180	232 569	185 412
Shrub and Forest	309	338	317	40 112	146 517	154 558	114 446
Spartina meadow	60	215	282	5 654	97 284	128 225	122 570
Wet lawn	625	134	124	63 716	21 856	22 362	-41 354
Total (ha)	5 535	5 292	5 259				
Total (Mt C)				0.60	1.77	2.07	1.47

The area of wet lawn was decreased by 80% during 1971–2020, showing a dramatic decline during the first period (1971-2010) and remained mostly stable during the second period (2010-2020). The area of Salicornia meadow decreased during 1971–2010, but increased during the subsequent period. The built-up area continuously expanded during 1971–2020.

To facilitate visual analysis of the cumulative transformation between LULC types in each period, we used a chord diagram. The eleven colors of the diagram (Figure 5) correspond to eleven LULC types. The chords within the circle indicate how the flow area converted from the initial LULC types to the final ones. The essential transition in the first period was the movement of 420 ha from wet lawn to cultivated land, followed by a transfer of 290 ha from Salicornia meadow to mudflat/sandpit. In the second period, most of the loss, (about 460 ha) of mudflat/sandpit was transformed mainly into Salicornia meadow, estuarine aquatic bed, juncus meadow and spartina meadow. To summarize, 94 types of LULC transformation occurred during 1971-2020. The large wetland losses were marked by the conversion of about 394ha and 175ha respectively from wet lawn and juncus meadow to cultivated land.

4.2. Estimated carbon stocks in different land use/cover

The results of this study, carried out on coastal habitats that store carbon (Table 4), show that the amount of carbon stock in 1971 recorded a total of 0.60 Mt C (Megatons of Carbon) for an area of 5,535 ha. In 2010, this quantity reached a value of 1.77 Mt C, for a continually decreasing area (Table 4). This increase of carbon stock is due in particular to the development of the cultivated area. Despite the presence of changes in land use/cover, carbon continues to be sequestered naturally. In 2020, there was 2.07 Mt C sequestered in an area of 5 259 ha.

The results showed that in 2020, cultivated land had the highest amount of sequestered carbon with 0.58 Mt C, followed by mudflat and sandpit with 0.44 Mt C and juncus meadow with 0.43 Mt C, while wet lawn had the lowest amount with 0.02 Mt C. This increase in carbon stock at the cropland level compared to other coastal habitats (Table 4) is due to the intensity of cropland use, the nature of the soil (black soils rich in organic matter), and developed irrigation systems affecting carbon storage in the form of soil organic carbon (M. Maanan et al., 2019). For carbon emissions, the large estimated loss of -0.04 Mt C (Table 4) was released mainly by wet lawn, which converted to built-

up area, followed by the conversion of cultivated land, juncus meadow, Salicornia meadow and shrub and forest to built-up area and coastal dunes (Table 3 ; Table 5). The majority of these LULC changes occurred in the coastal dunes and in the expanding built-up areas of Moulay Bousselham town and some rural villages (Figure 3). Carbon sequestration is estimated at a total of 1.47 Mt C between the years 1971 and 2020, with a spatial distribution quite similar to the carbon stock in 2020 (Figure 6), with carbon gains of 0.42 Mt C, 0.41 Mt C and 0.21 Mt C respectively for cultivated land, juncus meadow and mudflat and sandpit (Table 4).

Table 5

Present value (US\$) of the CBCS service in MBL over 49 years (1971–2020) at SCC prices and EUA prices. Conversion rate: € 1 = US\$1.21

	CBCS service loss in tonnes of C (1971-2020)		CBCS service gain in tonnes of C (1971-2020)	
	-41 354 ↗		1 515 134 ↘ ↘ ↘	
Carbon Cost	Economic value of total loss by (US\$)	Economic value of annual loss by (US\$/y)	Economic value of total gain by (US\$)	Economic value of annual gain by (US\$/y)
(a) SCC prices/tCO₂ eq				
5%: US\$12	-496 248	-10 127,51	18 181 608	371 053,22
3%: US\$42	-1 736 868	-35 446,29	63 635 628	1 298 686,29
2,5%: US\$62	-2 563 948	-52 325,47	93 938 308	1 917 108,33
3% (95th %): US\$123	-5 086 542	-103 806,98	186 361 482	3 803 295,55
(b) CO₂ European Emission Allowances/tCO₂ eq				
€ 25	-1 250 959	-25 529,77	45 832 804	935 363,34
(a) Current US social cost of carbon estimates, for 2020 in \$ per tonne of CO ₂ . The US defines four values for the SCC. These are a high-impact figure (95th percentile value for a 3% discount rate) and average values for three discount rates of 2.5%, 3% and 5%. (Government US, 2015);				
(b) The market price per tonne of carbon in European countries. (www.markets.businessinsider.com/commodities/CO₂-european-emission-allowances , 2020).				

4.3. Economic valuation of carbon stocks

Given the wide range that exists between different estimates of the market price of carbon, five value estimates of carbon are used in this study: US\$12, 25, 42, 62 and 123 per tonne of C to account values of CBCS service in MBL coastal ecosystems (1,515,134 Tonnes C, over approximately 5,300 ha) (Table 4).

According to (Table 5), the approximated value of revenues from CBCS during the period (1971-2020) was estimated to be an equivalent gain of US\$18,181,608 (US\$ 371,053.22/y) for a discount rate of 5% and US\$186,361,482 (US\$ 3,803,295.55/y) for a discount rate of 3% (95th %) both by the SCC price and of US\$ 45,832,804 (US\$ 935,363.34/y) by the EUA price. The estimated economic loss from CBCS ranged from a minimum of US\$ -496,248 (US\$ -10,127.51/y) to a maximum of US\$ -5,086,542 (US\$ -103,806.98/y) by SCC prices, and US\$ -1,250,959 (US\$ -25,529.77/y) by the EUA price.

5. Discussion

This paper has focused on presenting the methodology and the results associated with the economic valuation of the carbon sequestration service provided by the MBL for Morocco.

The first section of study showed that the non-wetland area, especially cultivated lands and built-up areas, increased over the studied period (1971-2020). This is coherent with numerous LULC studies conducted in Morocco (Mehdi Maanan et al., 2014; Simonneaux et al., 2015) and other global studies (Scharsich et al., 2017; Zhang et al., 2017). However, some wetland areas have declined since 1971, as demonstrated by the regression of wet lawns, natural habitats and the external margins of mudflats. This regression is also motivated by hydrological and/or anthropogenic factors. Hydrological factors include: the decrease of fresh water in the MBL due to the multiplication of collection and pumping points in the Wad Drader and the Nador Canal for agricultural needs, and the over-exploitation of groundwater

which gradually causes the outer margins of wetland habitats, particularly the wet lawn, to transform into bare land. Anthropogenic factors include: the impact of cutting vegetation and overgrazing on wet lawns and meadows as well as the pollution of the water and sediments of the site by hydrocarbons and certain heavy metals discharged by the highway sanitation system directly into the MBL (Mehdi Maanan et al., 2013).

This study also explored that any disturbance of wetland LULC caused a negative impact on blue carbon storage. This is consistent with previous evaluations (Clerici et al., 2019; Li et al., 2018; Xiong et al., 2014; Yim et al., 2018) of the modifications of carbon stocks by the LULC changes. The expansion of cropland and urban areas had a slight influence on carbon storage in our study area, as this change in LULC has mainly affected wet lawns and the edges of unused land (which store less carbon). However, the overuse of plant protection products in agriculture, which contributes to the contamination of the water and sediments of the lagoon, has slowed down the development of some natural vegetation that live in fresh water, reducing in the process the dynamics of carbon storage, especially for juncus and spartina meadows. The continued overuse of plant protection products risks destroying a much greater quantity of these natural habitats.

As for the third and last section of this study, it's been revealed that the economic value of blue carbon sequestration and storage in wetland such as MBL is very attractive. Indeed, countries with wetlands, especially developing ones, can benefit from even greater revenues if other ecosystem services provided by wetlands, such as recreation and tourism, food production, genetic resources, biological control, and nutrient cycling, are taken into account (Badamfirooz & Mousazadeh, 2019). These revenues could be used for projects dedicated to the rehabilitation and protection of wetlands as these coastal ecosystems are increasingly at risk of degradation.

Globally, the number of marine or coastal wetlands of international importance has increased continuously since the entry into force of the Ramsar Convention in 1975, recording a total of 992 sites for a total area of about 75 million hectares in 2021. Morocco has also used the designation of marine protected areas as a tool to conserve marine and coastal ecosystems. Currently, in country, there are 21 protected marine or coastal wetlands covering approximately 174,267 hectares <https://rsis.ramsar.org/>. With international climate finance from developed countries to encourage developing countries to reduce their greenhouse gas (GHG) emissions, Morocco can increase the efficiency of conservation of protected wetlands and even increase their number. In addition, the country's investment in wetland development projects can strengthen its position on the "Climate Change Performance Index" (CCPI) to meet the commitments required by the 2030 Agenda for Sustainable Development Goals (SDGs).

Finally, it is useful to recall from this study that these kinds of projects would, not only preserve the coastal ecosystems of the area, but also generate interesting monetary returns on investment.

6. Conclusion

This paper investigated the value of "blue" carbon in the Atlantic coast of Morocco based on the LULC analysis. The results indicate that LULC changes in the MBL have reduced the potential capacity of the CBCS over the period 1971-2020. This reduction is demonstrated by the conversion of LULC types with greater carbon storage capacity to those with lower carbon storage capacity. The total CBCS experienced a deficit of -41,354 Mg C, due to the loss of 80% (501 ha) of wet lawn to the built-up area, while the CBCS experienced a total gain of 1,515,134 Mg C related to the natural development of coastal habitats, despite the fact that the area of some wetland species has started to decrease in recent years, due to non-compliance with the conservation measures listed in the Ramsar Convention on Wetland Management and Protection. This study shows also the economic value importance of CBCS service and the opportunity for countries to benefit from climate change funding and to strengthen their efforts in coastal ecosystem management. Considering its extremely important role in carbon stocks and sequestration rates, blue carbon ecosystems have been included in the Nationally Determined Contributions (NDCs) (Herr et al., 2017; Lovelock & Reef, 2020) for climate change mitigation, and in the United Nations Sustainable Development Goals (SDGs) specifically goal 13, Climate Action, through carbon sequestration and storage, and goal 15, Life on Land, through halting and reversing land degradation, and halting biodiversity loss.

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Authors' contributions All authors contributed to the study conception. Material preparation, data collection and analysis, were performed by HAK, YB, MeM, YK and SE. HAK, HR, MM and MeM verified the analytical methods. The first draft of the manuscript was written by HAK and all authors commented on previous versions of the manuscript. All authors discussed the results and approved the final manuscript.

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Figures

Figure 1

Geographical location of Moulay Bouselham lagoon

Figure 2

Hierarchical Structure of the InVEST coastal blue carbon model

Figure 3

Land use/cover mapping for Moulay Bouselham lagoon

Figure 4

Coastal blue carbon ecosystems storage graph (1) Cultivated land (high activity), (2) cultivated land (low activity), (3) cultivated land (sandy soils), (4) estuarine aquatic bed, (5) juncus meadow, (6) mudflat and sandpit, (7) salicornia meadow, (8) shrub and forest, (9) spartina meadow, (10) wet lawn.

Figure 6

(A) carbon stock at 1971, (B) carbon stock at 2010, (C) carbon stock at 2020, (D) Carbon accumulation between 1971 and 2020, (E) Carbon emissions between 1971 and 2020, (F) Total net carbon sequestration.