



Blue carbon conservation in West Africa: a first assessment of feasibility

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Abstract

The loss of blue carbon ecosystems results in significant levels of carbon emissions and decreased supply of other ecosystem services. West Africa contains approximately 14% of the world's mangrove area but despite 25% of coverage loss between 1980 and 2006, the region's mangroves have not been well studied. This study aims to provide a first step toward increasing the knowledge of the region's blue carbon stocks, with a focus on mangroves, and of their financial value based on their carbon storage benefit alone. The best available data suggest that the region contains 1.97 million hectares of mangroves storing 854 million metric tons of carbon in above- and below-ground biomass and the top meter of soil; 4.8 million hectares of seagrass storing 673 million metric tons of carbon; and 1.2 million hectares of salt marshes storing 303 million metric tons of carbon. Even without including values for other benefits of intact mangroves, the conservation of mangroves in the region appears viable. Specifically, the discounted value of 20-year emission reductions under a conservation scenario is estimated to be between \$341.2–569.0 million at an 8% discount rate and carbon prices of \$3 and \$5 per metric ton respectively.

Keywords Mangrove · Ecosystem service · Sequestration · Biomass · Protected area

Introduction

Coastal vegetated ecosystems, such as mangrove forests, seagrass meadows and salt marshes, have long provided benefits to human communities and fisheries, and in recent years have been recognized for the significant amounts of carbon (C) that they store and hence their contributions to mitigating climate change (Nellemann and Corcoran 2009; Barbier 2011). At the same time, these ecosystems are being converted rapidly, with current trends projected to lead to 30 to 40% loss of tidal marshes and sea grasses over the next 100 years, and a loss of nearly all unprotected mangroves (Pendleton et al. 2012). The C stored in these habitats is collectively known as 'blue carbon' (BC). Efforts to conserve coastal vegetated habitats and reduce C emissions from their conversion have

increased over the last 5 to 6 years, notably in the case of mangrove forests, as the international community has developed mechanisms to pay tropical countries to reduce greenhouse gas (GHG) emissions from deforestation. These sources of international finance could potentially help tropical countries, where most of the world's mangroves are found, to leverage global capital to fund the economic and financial costs of mangrove conservation, while capturing local benefits such as flood protection and fisheries support, among others.

The global value of mangroves

Mangrove ecosystems have social, cultural, aesthetic, economic, and financial values. Of the previously identified social and cultural values, the most studied are those for food and food processing, medicinal values and values associated with culture and tradition. With regard to economic values, the most studied is the C sequestration and storage capacity of these ecosystems because of the aforementioned climate connection. In the last decade, a number of assessments have shown the capacity of intact mangrove forests and other coastal vegetated habitats to store C at rates that surpass tropical forests with high burial rates on the order of 108 Tg (teragram; 1 Tg equals 1,000,000 metric tons) C per year (Duarte, Middleburg et al. 2004; Nellemann and Corcoran 2009;

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Murray et al. 2011, Murray 2012, Alongi 2014). Though mangroves and other marine vegetated habitats occupy only some 0.2% of the global ocean surface, they contribute half of oceanic C burial (Duarte, Losada et al. 2013).

Given this large storage capacity, globally significant levels of C emissions result from mangrove deforestation due to coastal population growth and urbanization (Nellemann and Corcoran 2009; Pendleton et al. 2012). From the estimated 49 million hectares of mangroves and other coastal vegetated habitats worldwide, over 1850 Mg (megagram; 1 Mg equals 1 metric ton) CO₂ (C dioxide) per hectare are susceptible to release (Pendleton et al. 2012). The global economic damages resulting from global BC emissions are estimated at the high end on the order of some US\$41 billion annually (Table 1), using a social cost of C value of US\$40 per ton of CO₂ emissions (EPA 2015).

To put BC emissions into more familiar terms, currently an estimated 1.9% of mangroves are lost each year globally, resulting in 240 Tg of CO₂ emissions – equivalent to emissions from the use of 588 million barrels of oil or from 50.5 million passenger vehicles for example (Pendleton et al. 2012; Herr et al. 2015). Given this benefit of BC sequestration and storage that mangroves and other coastal vegetated habitats provide to the international community, numerous governments, communities, companies and civil society around the world are increasingly supporting their conservation as a climate change mitigation strategy (Herr et al. 2015).

These efforts crystallized in late 2015 with the adoption by the United Nations General Assembly of a new set of Sustainable Development Goals (SDGs), including SDG 13 to take urgent action to combat climate change and its impacts, and SDG 14 to conserve and sustainably use the oceans, seas and marine resources for sustainable development. Mangrove conservation would support the SDG 13 target to “strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries” and SDG 14 target to “by 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their

restoration in order to achieve healthy and productive oceans (United Nations 2015a).” Additionally, the United Nations Conference on Climate Change (COP) 21 Paris Agreement in December 2015 to hold the increase in global average temperature to well below 2 degrees Celsius above pre-industrial levels, could lead to an increase in the urgency of mangrove conservation.

The importance of West Africa’s mangroves

From the southern border of Mauritania down to the northern border of Angola, West Africa’s extensive mangrove forests (Fig. 1) provide a wide range of sustainable benefits to coastal communities and countries, including supporting fisheries, protecting towns and structures from flooding and erosion, as well as a range of cultural and spiritual benefits. This region contains approximately 11% of the world’s mangrove area (Corcoran et al. 2007). Mangroves in the region are believed to be in decline, with estimates suggesting some 25% lost in the region between 1980 and 2006 (Corcoran et al. 2007), or at an average annual rate of 2–7% in terms of C sink (USAID et al. 2014).

The intense human pressure on the mangroves of West Africa are partly due to coastal population densities in some of the top mangrove countries. Mangroves in the ecological zone termed the Afro-tropical realm (which includes West-Africa) are facing the highest mean human influence index scores of any biome in the region and rank 6th highest out of 50 biomes (Sanderson, Jaiteh et al. 2002). Population densities translate to pressures on a coastal ecosystem by ways of conversion due to urban development and sprawl, infrastructure and related pollution on land (roads and houses) and on the coast (ports). These pressures in West Africa also tend to be concentrated near areas of large BC stocks.

Beyond these immediate pressures of increasing coastal population densities, West Africa is also heavily dependent on the region’s ocean economy which includes fisheries, shipping, offshore oil, and subsistence among others. For example, in terms of fisheries some of the world’s richest fishing grounds can be found in the large marine ecosystems off of the coast of West Africa, due to highly productive waters fed by nutrient-rich upwelling currents in certain areas. Many of the region’s fisheries depend on mangroves to provide nursery areas and food sources for key species. In the case of mangrove forests, 39% of capture fish harvest has a life cycle dependent on mangroves (Huxham et al. 2015). Rönnbäck (1999) estimates that annual market value of fisheries supported by mangroves ranges from \$750–16,750 / ha, with a significant share of this coming from subsistence (e.g., 10–20% in Sarawak, 56% in Fiji, and 90% in Kosrae). Fishing intensity—both commercial and subsistence—is highest along the coasts of Mauritania, Senegal, and Guinea, as

Table 1 Global BC emissions and resulting economic damages

Ecosystem	C emissions (Pg CO ₂ yr ⁻¹)		Economic damages (Billion USD yr ⁻¹)		
	90% confidence interval	Median	Low	High	Median
Salt marsh	0.02	0.24	0.06	0.8	2.4
Mangroves	0.09	0.45	0.24	3.6	9.6
Seagrasses	0.05	0.33	0.15	2.0	6.0
Total	0.15	1.02	0.45	6.0	18.0

Source: Pendleton et al. 2012, EPA 2015

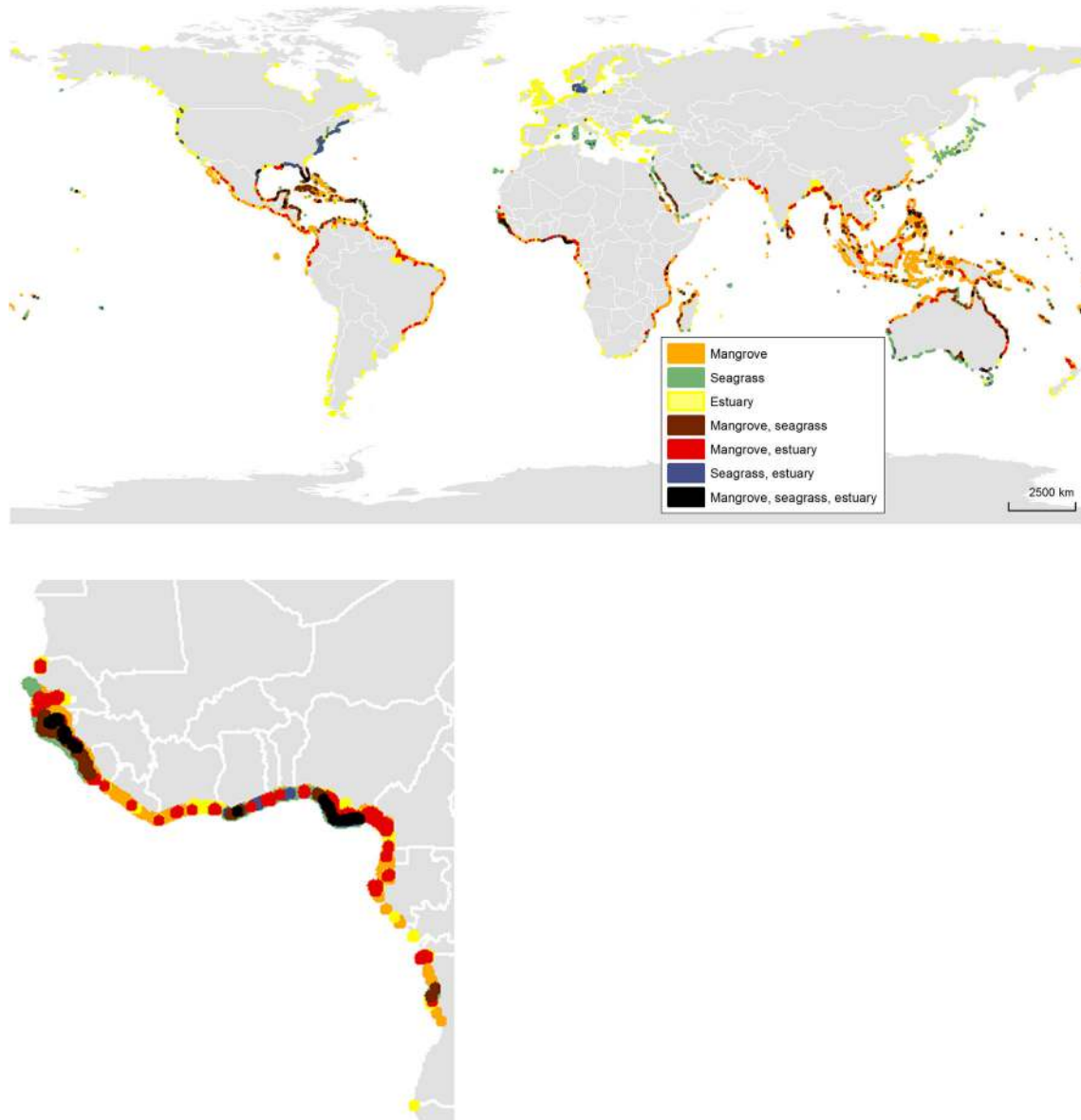


Fig. 1 Global (top) and West African (bottom) distribution of sea grasses, salt marshes, and mangroves, or ‘BC’. Note: Estuary coverage is used as an approximation for salt march coverage. Source: USGS Global Distribution of Mangroves (Giri et al. 2011), UNEP WCMC Global

Distribution of Seagrasses (UNEP-WCMC and Short 2005), Sea Around Us Global Estuary Database (Alder 2003). Overlaps were determined using ESRI ArcMap 10.3

well as from Cote d’Ivoire east to Cameroon. These areas also coincide with major shipping routes, potentially adding more pressure on the BC habitats due to increased pollution.

To ensure that benefits such as fishery support from mangrove forests, and to a lesser extent from seagrasses and salt marshes, are better considered in decision-making, countries in the West Africa region have prioritized conservation at a number of different scales. For example, at the regional scale, the Convention for Cooperation in the Protection, Management and Development of the Marine and Coastal Environment of the Atlantic Coast of the West, Central and Southern Africa Region (the Abidjan Convention) provides

the overarching legal framework for mangrove use and conservation. The Convention was agreed upon in 1981 based on an action plan developed by the United Nations Environment Program (UNEP) in 1976 to address negative impacts on the region’s coastal and marine environment. Building upon the Abidjan Convention, a number of countries have adopted policies and laws to promote mangrove conservation in support of coastal communities, including a range of protected areas throughout the region. The growing recognition of the overall suite of benefits that West Africa’s mangrove forests supply to the international community could provide a new source of support to conservation efforts in the region. However, capturing this opportunity will require a minimum level of key

information and knowledge on the global benefits from the region's mangroves.

Knowledge gaps on the global benefits of West Africa's mangroves

Relatively little is known about West Africa's BC stocks. Available data sets on West African mangrove coverage reflect different methodologies and are difficult to compare, while information on C storage is often lacking (Hutchison et al. 2014; Jardine and Siikamäki 2014). Notably, much of the literature that has emerged in the last decade on BC has omitted the region, despite the presence of significant mangrove forests in many countries (Fig. 2). Furthermore, although the continent is home to 22% of the world's mangroves, it is the subject of only 7% of the literature that has attempted to estimate values for the services such as BC that ecosystems provide (Vegh, Jungwiwattanaporn et al. 2014).

Research over the last 5 years has indicated the potential for a large economic benefit from conservation of BC in mangrove forests (Siikamäki et al. 2012; Murray et al. 2011). The capability to estimate BC stocks has grown in recent years, including improved global predictive models of storage in soil and biomass, progress on remote sensing and GIS application in mangroves (Jardine and Siikamäki 2014; Patil et al. 2015; Hutchison et al. 2014). This has led to the development of databases with sufficient relevant data upon which to base estimates of potential payments for BC.

In addition to having a more in-depth and wider coverage of raw BC data to support C payment opportunities, a growing body of literature on habitat and C loss due to conversion

pressures has enhanced understanding of the trends and drivers of coastal habitat conversion and BC loss (Hamilton 2013; Hamilton and Lovette 2015; Polidoro et al. 2010; Barbier and Sathirathai 2004; Barbier and Cox 2003; Valiela et al. 2001). These analyses have led to a similarly-themed growing literature on the valuation of additional benefits from mangrove forests, e.g. supporting fisheries, providing coastal protection, etc. (Kauffman and Bhomia 2014; UNEP 2014; Barbier 2015; Salem and Mercer 2012). For example, a recent study estimated that global mangrove losses have resulted in up to \$42 billion in economic damages annually due to greenhouse gas emissions losses (UNEP 2014).

As a result of the growing amount of information available on BC storage capacity, international financing mechanisms are increasingly ready to be deployed to pay for this service as part of the effort to reduce GHG emissions through the creation of C markets (Herr et al. 2015). Furthermore, improved valuation of other benefits provided by mangrove forests and coastal vegetated ecosystems may lead to additional markets to pay for these ecosystem services (PES) – potentially incorporating BC sequestration and storage.

In terms of markets for C and accompanying financing mechanisms, BC has recently become a valid candidate for inclusion under the Reducing Emissions from Deforestation and Forest Degradation (REDD+) market mechanism which prices GHG reductions from forest conservation. Additional international finance mechanisms that could be relevant for BC include several U.N. Framework Convention on Climate Change (UNFCCC) specific funds, bi- and multilateral, as well as national climate funds, among others (Herr et al. 2015). Additionally, novel financing options such as debt-

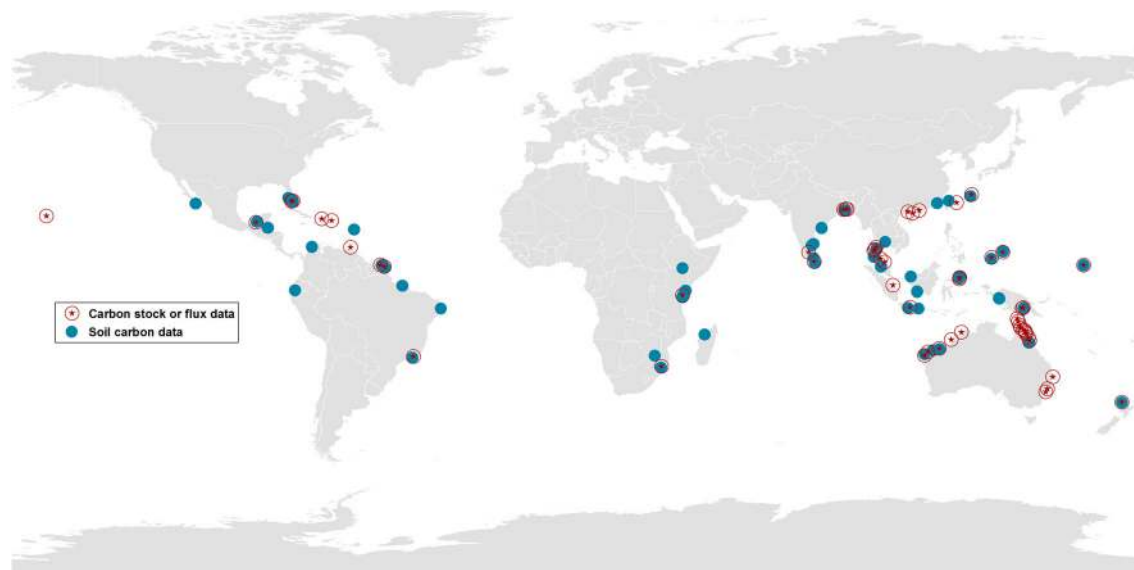


Fig. 2 Global biophysical mangrove data coverage. Note: Red marks show locations reported in (Hutchison et al. 2014) where C stock or flux data is available; blue marks show locations reported in (Jardine and

Siikamäki 2014) where soil C data is available from meta-analyses by (Chmura et al. 2003; Kristensen et al. 2008; Donato et al. 2011)

for-nature swaps or payments for biodiversity have also been considered recently for BC conservation (Ministerio del Ambiente 2015). All of these mechanisms have developed within the last decade and may provide a new opportunity to support West African countries in their goals for conserving mangrove ecosystems, through payments for BC storage. However, there are few examples or significant literature to date on their use for BC, so there is not yet a body of experience from which to refer.

Given the significant benefits of BC storage that mangroves provide to the international community, and its growing willingness to pay for this service, it is surprising that so little is known about West Africa's BC stocks and the steps that communities and countries in the region would need to take in order to capture this opportunity. To help fill that knowledge gap, this study aims to 1) synthesize the current state of information on the size and distribution of BC stocks in West Africa's mangrove forests, 2) estimate the size of payments that could be secured for maintaining BC stocks in mangroves, and 3) discuss the potential for communities and countries to secure BC payments from the international community in order to help implement the region's mangrove conservation policy objectives as well as relevant targets of the Sustainable Development Goals.

Methods

Biophysical data

Quantifying mangrove and other BC loss has been difficult due to a lack of comparable time series data sets that use consistent methodology. In terms of the data available for mangrove coverage and C, the project identified the following sources: (Corcoran et al. 2007), (Spalding et al. 2010), (Giri et al. 2011), (Fatoyinbo and Simard 2013), (Hutchison et al. 2014), (Jardine and Siikamäki 2014), and Hamilton and Casey 2016.

For seagrasses, datasets by (UNEP-WCMC and Short 2005; Green and Short 2003) have been used to provide coarse data collected over the period 1934–2004. Relative salt marsh abundances within ecoregions is currently available (Hoekstra et al. 2010) and an effort to develop a complete global dataset for salt marsh distribution is still underway at UNEP-WCMC. (Halpern et al. 2008) developed a dataset delineating salt marshes within 1 km of the shore collected over the period 1975–2007. A global lakes and wetlands database is also available, though the resolution is relatively coarse (30 s) (Lehner and Döll 2004). Finally, a global estuary database is currently available, which may be used as a proxy for salt marsh distribution (Alder 2003).

In this study, the following datasets were used: mangrove coverage data for 1999–2000 from (Fatoyinbo and Simard

2013); salt marsh coverage from (Halpern et al. 2008); and seagrass coverage from (UNEP-WCMC and Short 2005, Green and Short 2003). Coverage is estimated from Green and Short (2003)'s distribution maps, though his work shows a range of seagrass distribution in the region rather than seagrass coverage, therefore, seagrass coverage is likely overestimated. BC areas were estimated for each country (GADM 2015) using ESRI ArcMap 10.3 Spatial Analyst Intersect Tool for vector data and Zonal Statistics as Table Tool for raster data. C stored was calculated as the sum of (1) mean above-ground biomass (Hutchison et al. 2014), (2) mean belowground biomass (Hutchison et al. 2014), and (3) mean soil C (Jardine and Siikamäki 2014), multiplied by coverage of each BC resource. For mangroves, mean C content in biomass in (1) and (2) were calculated using biomass-to-C ratios of 1-to-0.46 and 1-to-0.39, respectively, after Howard, Hoyt et al. (2014), page 78 and 90, respectively. For seagrasses and salt marshes, C per hectare values of 139.2 and 258.7 tC/ha for biomass and top meter of soil carbon were used based on Pendleton et al. (2014). This analysis used a single generalized value for seagrass ecosystems, though ecosystem associated carbon values range multiple orders of magnitude (Fourqurean et al. 2012) being influenced by species (Lavery et al. 2013) and environmental setting (Armitage and Fourqurean 2016; Serrano et al. 2016).

Economic analysis

Decisions on the use of mangrove forests often do not factor in the economic value of the services provided by these forests when kept intact, such as potential payments for BC (Alongi 2014; Hutchison et al. 2014; Siikamäki et al. 2012; Jardine and Siikamäki 2014). A preliminary net present value (NPV) analysis of the benefits from mangrove conservation in West Africa is performed in this study, considering the potential payments for BC storage in the below- and above-ground biomass, and top meter of soil, as well as the opportunity costs of conservation, i.e. the benefits of conversion to agriculture. Placing a value on the carbon sequestration and storage ecosystem service is straightforward using defensible values for carbon credits or offsets from the literature, or market analyses (Goldstein and Gonzalez 2014).

This analysis calculated the future values of upfront and annual costs and benefits in present value, using 5 and 8% discount rates and a 20-year time horizon, the midpoint recommended by (UNEP and CIFOR 2014). Following the methodology of (Pendleton et al. 2014) the NPV analysis includes BC payments (i.e. C credit revenue), mangrove conservation project establishment costs, and opportunity costs of conservation (i.e., value per hectare of alternative use), but not C project transaction costs necessary to access buyers for the credits generated (Galik et al. 2012). The alternative use was assumed to be agriculture, for which returns per hectare

were collected from (IFAD 2001) and adjusted to current dollar years using the CPI (BLS 2015). Returns reported per hectare averaged \$221 (in 2015\$) with a range of \$38–460. For countries without data, adjacent countries were used to estimate agriculture returns.

The analysis explicitly gives the estimated financial flows from BC payments, based on avoided C emissions due to mangrove conservation, two reasonable C offset prices of \$3 and 5 per Mg CO₂e (Goldstein and Gonzalez 2014) and use the low-end estimate of global mangrove loss rates. Assuming the low-end global conversion rate of 0.7% per year across the region (Pendleton et al. 2012), we estimate the value of avoided emission reductions from BC conservation using the two C prices.

Specifically, at the time of conversion we assumed that all biomass (above and below ground) C is lost in the year a given area of mangroves is converted. Soil C is emitted with a half-life of 10 years (Pendleton et al. 2012). Mean C stocks per hectare in the region ranged from 314.4 to 456.1 Mg C / ha. For comparison, according to measurements on mangroves in the Central Africa region, undisturbed and heavily exploited mangroves store 967, and 741 tons of C per ha, respectively (Ajonina et al. 2014). We also accounted for continued C sequestration of intact mangroves at a conservative rate of 1.89 tons C / ha / yr (Nellemann and Corcoran 2009) which is lower than the 16.52 tons C / ha / yr reported for intact mangroves in Central Africa (Ajonina et al. 2014). In this study we do not account for methane, and nitrous oxide emissions associated with loss of mangroves.

We use the following model to estimate the financial value of BC:

$$BC \text{ Financial Value}_i = \sum_{t=0}^{20} \frac{(CS_{it} + AvCE_{it}) \times PriceC_t}{(1 + d)^t} - PAEstab_1 - PAMgmt_i - OppCost_i$$

Where CS is carbon sequestration in Mg C/ha/yr, AvCE is avoided above-, below-ground, and soil (top meter) carbon emissions in Mg C/ha/yr assuming no net loss of carbon in the business-as-usual scenario, PriceC is carbon market price, PAEstab1 is the one-time cost, in year 1, of establishing protected areas where mangroves are conserved, PAMgmt is the annual cost of managing protected areas where mangroves are conserved, OppCost is the opportunity cost of conservation (i.e. returns from the alternative use of agriculture) and d is the discount rate. All other terms are as defined above. Viable conservation means that the net benefit of conservation is larger than the sum of blue carbon protection cost and the opportunity cost in alternative use (e.g. agriculture). Other significant benefits that intact mangrove forests provide to the region's fisheries e.g. (Barbier 2000; Rönnbäck 1999), or coastal areas in terms of protection services, are not included in our analysis due to the absence of locally estimated values for West Africa.

The analysis uses two sets of protected area establishment and maintenance costs. According to the global analysis by Pendleton et al. (2014) and economic analysis of BC in Belize by (Chang et al. 2015), we assume protection costs (to start a BC project) to be \$232 / ha (McCrea-Strub et al. 2011) or a lower estimate of \$25 / ha based on (Vasconcelos et al. 2014). Ongoing management costs were assumed to be \$1 (Vasconcelos et al. 2014) based on published region-specific values from Guinea-Bissau, or \$7 / ha / year (Balmford et al. 2003) representing a higher estimate from the literature. Regarding biophysical data quality, data on BC loss rates over time, C burial rates, and C stock in soil and biomass numbers are the best published scientific estimates. These data are based on global, rather than regional or local estimates and conditions, because data from West Africa is currently very limited e.g. (Hutchison et al. 2014; Jardine and Siikamäki 2014).

Results and discussion

Size and distribution of West Africa's BC stocks

According to the datasets analyzed, BC coverage in the region is dominated by seagrasses (Fig. 3, Table 2). Specifically, Guinea and Guinea-Bissau contain 60% of the 4.83 million ha of seagrass in the region. Mangrove coverage is more distributed among the countries but the top two mangrove countries, Nigeria and Guinea-Bissau, contain 58% of the region's 1.97 million ha of mangroves. The 1.17 million ha of salt marshes are even more distributed among countries than mangroves. A breakdown of coverage shows that the 7.98 million ha of BC are distributed as 61% seagrasses, 25% mangroves, and 15% salt marshes.

In terms of C storage, the region contains 1830 Tg of C in total, of which 854 Tg (47%) is found in mangroves in above- and below-ground biomass and the top meter of soil, 673 Tg (37%) in seagrasses, and 303 Tg (17%) in salt marshes.

A further breakdown of the data on mangrove C storage presented above provides more detail on storage of biomass C above and below ground, as well as soil C (Table 3). Specifically, the data shows that 75% of the total C stored is located in the top meter of soil, with the remaining C stored in above ground (19%) and below ground (6%) biomass.

Potential value of payments to maintain West Africa's BC stocks

Under the assumption of continuing mangrove loss in the region, equal to the average global loss rate, the discounted values of avoided C emissions range between \$0–342 million, depending on C price and discount rate used (Table 4). The few countries in the region with limited mangrove resources also have low BC economic values. Predominantly, however,

West African countries' BC values are quite large, even under the assumption of a flat C price trend, as compared to the prevailing level at the time of writing.

Building from the above values, a preliminary economic analysis of the net present value (NPV) of the C storage benefits from mangrove conservation in West Africa is provided below, considering the potential payments for BC, as well as the opportunity costs of conservation, i.e. the benefits of conversion to agriculture. The additional benefits that intact mangrove forests provide are not included due to lack of data, such as supporting the region's fisheries. Hence, this analysis should be considered conservative, and indicative. However, even without including values for the benefits of intact mangroves in addition to BC storage and sequestration, the analysis suggests that conservation of mangroves is economically viable when factoring in net benefits (returns from the alternative use of land in agriculture) as high as \$460 / ha, with an average of \$221 / ha. Therefore, just on the basis of the potential payments for BC, most countries in West Africa can achieve a net economic benefit from mangrove conservation. The top 8 mangrove countries by mangrove area, for instance, can realize net benefits of millions of USD even under our conservative assumptions of C prices (Table 5). Together with payments for other services provided, mangrove conservation from an economic perspective in West African nations can be financially viable.

Securing payments to maintain West Africa's BC stocks

Regional development policy context for mangrove use

Current regional economic growth policies were established in 2010 by the ECOWAS Commission,¹ which set a future economic trend for the region in its "Vision for 2020" paper (ECOWAS-CEDEAO 2010). Sustainable development and environmental preservation are two key pillars of the vision statement of ECOWAS, and form guiding principles for national policies related to the use of mangroves throughout the region. At the national level, development and economic growth policies for West African countries are described in Poverty Reduction Strategy Papers (PRSPs). Environmental policies within the PRSPs typically focus on 1) improved biodiversity, 2) ecological restoration of natural communities, and 3) development of protected areas and wetlands. Moreover, PRSPs in countries in West Africa refer to unsustainable natural resource management decisions as key reasons for environmental degradation and set goals to better align their environmental policies with sustainable management principles.

¹ Members not studied in this report include Cape Verde, Mali, and Niger

Regional policy framework for mangrove use

Similarly to regional development policies, national Ministries of the Environment in the region have defined their policy goal as "to ensure environmental protection and the conservation of natural resources for sustainable development" (Nigeria 1999). Using Nigeria—the largest mangrove country in the region—as an example, and crosschecking national policies of other countries in the region to see whether they match policies of Nigeria, key components in national environmental policies can be identified as:

- 1) Environmental quality must not compromise good health and well being
- 2) Sustainable resource use
- 3) Restoration and maintenance of biodiversity
- 4) Linking of environmental, social, and economic development goals
- 5) Encouraging individual and community participation in environmental improvement initiatives
- 6) Raising public awareness and engendering a national culture of environmental preservation
- 7) Building partnership among relevant stakeholders including government at all levels, international institutions and governments, non-governmental agencies and communities

These components of environmental policy are fairly consistent among countries in West Africa, and the regional need to better manage the use of mangrove forests stemming from this policy consistency has been indicated in international workshops (USAID et al. 2014) and reports (Ajonina et al. 2014) on BC as well as ongoing research in the region.

Opportunities, constraints, issues of uncertainty

Recent research has identified the opportunities, constraints, and issues of uncertainty associated with payments for maintaining BC stocks (Barnes 2014). Indeed, there are growing opportunities to receive payments for BC, mostly in mangroves, building off of improved measurement, reporting, and verification. The ability to effectively measure, report and verify reductions in emissions is a requirement for effective BC policies (Ullman et al. 2013). This may be straightforward for living tissue that can burn or quickly decompose, though quantitatively estimating CO₂ emissions from below-ground biomass and soil fractions is likely to be highly variable and still exists as a primary hurdle in blue carbon understanding.

Despite these hurdles, successful recent BC project demonstration sites, such as Mikoko Pamoja in Kenya, are paving the path to more complete and geographically widespread adoption of payments for conservation. However, for every

Table 2 West Africa's BC stocks: area of habitats and C stored

Country	Area (ha)				C stored (Tg)			
	Mangroves	Seagrasses	Salt marshes	Total	Mangroves	Seagrasses	Salt marshes	Total
Angola	15,400	60,050	190,900	266,350	7	8	49	64
Benin	1800	135,808	11,100	148,708	1	19	3	23
Cameroon	148,300	–	56,400	204,700	65	–	15	80
Congo	1500	–	15,500	17,000	1	–	4	5
Côte d'Ivoire	3200	–	50,100	53,300	1	–	13	14
D.R. Congo	18,300	–	5400	23,700	6	–	1	7
Eq. Guinea	18,100	–	43,400	61,500	8	–	11	19
Gabon	145,700	–	103,200	248,900	66	–	27	93
Gambia	51,911	–	8800	60,711	22	–	2	25
Ghana	7600	271,858	53,200	332,658	3	38	14	55
Guinea	188,900	1,301,092	68,700	1,558,692	82	181	18	281
Guinea-Bissau	280,600	1,560,911	152,700	1,994,211	116	217	40	373
Liberia	18,900	–	53,000	71,900	8	–	14	22
Mauritania	40	–	112,800	112,840	0	–	29	29
Nigeria	857,300	884,495	88,800	1830,595	377	123	23	523
São Tomé and Príncipe	ND	–	20,600	20,600	ND	–	5	5
Senegal	120,000	151,982	55,600	327,582	50	21	14	85
Sierra Leone	95,500	447,248	77,600	620,348	41	62	20	123
Togo	200	18,804	5200	24,204	0	3	1	4
West Africa Grand Total	1,973,251	4,832,247	1,173,000	7,978,498	854	673	303	1830

Carbon stored in mangroves includes above- and below-ground biomass and the top meter of soil

Sources: (Fatoyinbo and Simard 2013; Green and Short 2003; Halpern et al. 2008; Pendleton et al. 2014)

opportunity regarding payments for BC conservation, there are just as many constraints. With protected area establishment costs as high as over \$230 per hectare together with ambiguity around a clear path forward for the acceptance of BC into C offset markets, such payments often cannot be viewed as a stand-alone solution to finance mangrove conservation. Despite these constraints, payments for BC have been advancing in a number of developing countries.

An important issue to keep in mind when developing blue carbon projects is additionality. If a project is started before payments for the avoided carbon emissions are received through a carbon market transaction, for instance, the additionality criterion might be compromised. If a blue carbon market were to form, these would essentially become environmental market products that could help mangrove conservation project developers cover the cost of protected area establishment and management. These credits, then could be used as marketable “offsets” that buyers could use to help meet their regulatory or voluntary GHG goals.

If other ecosystem service payments, other than carbon, could be paid to mangrove conservation project developers the issue of credit stacking could arise. Stacking refers to receiving multiple environmental payments to finance the mangrove conservation project. Clearly, multiple payments

can increase revenues and thus increase the attractiveness of the conservation project. However, the use of stacked credits also introduces the possibility that some of the stacked credits might be “non-additional” in that they do not produce incremental pollution reductions and thus are suspect for use in offsetting the offset buyer's GHG pollution, in the case of carbon.

West African countries or communities interested in securing payments for BC now have access to multiple guidance documents from project planning and delivery to finance. Recent and detailed guidance exists for planning a BC project from concept development to regulatory compliance (UNEP_and_CIFOR 2014) as well as for fast-tracking national implementation of BC activities in developing countries.

Perhaps the most ambiguous yet crucial potential impediment to the success of a BC projects is land tenure. The overlapping of marine and terrestrial resources in BC itself creates tenure ambiguities making resource management and coastal decision making challenging. In addition, land tenure issues specific to REDD+ (i.e. forest tenure and C rights) as described in (Galik and Jagger 2015) pose a risk to BC project development and management. That is partly because of differences in formal or de facto and informal or de jure land tenure as these relate to the right of alienation of land with

Table 3 West African BC stocks in mangrove forests

Country name	Mangrove area (ha)	Mean C Storage (Mg/ha)				Total C Storage (Tg)			
		Top meter of soil	Above ground biomass	Below ground biomass	All stocks	Top meter of soil	Above ground biomass	Below ground biomass	All stocks
Angola	15,400	354.4	53.0	17.6	425.0	5.5	0.8	0.3	6.5
Benin	1800	317.1	72.3	23.1	412.5	0.6	0.1	0.0	0.7
Cameroon	148,300	324.2	86.9	29.5	440.5	48.1	12.9	4.4	65.3
Congo	1500	321.4	54.7	17.1	393.2	0.5	0.1	0.0	0.6
Côte d’Ivoire	3200	321.6	80.1	24.3	426.0	1.0	0.3	0.1	1.4
D.R. Congo	18,300	321.6	ND	ND	321.6	5.9	ND	ND	5.9
Eq. Guinea	18,100	340.8	75.2	24.4	440.4	6.2	1.4	0.4	8.0
Gabon	145,700	368.3	66.9	20.9	456.1	53.7	9.7	3.0	66.5
Gambia	51,911	343.4	65.2	20.2	428.8	17.8	3.4	1.0	22.3
Ghana	7600	320.2	75.1	22.3	417.6	2.4	0.6	0.2	3.2
Guinea	188,900	317.5	86.4	29.3	433.1	60.0	16.3	5.5	81.8
Guinea-Bissau	280,600	316.3	73.4	23.7	413.4	88.8	20.6	6.7	116.0
Liberia	18,900	322.2	95.5	28.6	446.4	6.1	1.8	0.5	8.4
Mauritania	40	333.5	ND	ND	333.5	0.0	ND	ND	0.0
Nigeria	857,300	322.0	87.8	29.9	439.7	276.0	75.3	25.6	376.9
São Tomé and Príncipe	ND	ND	ND	ND	ND	ND	ND	ND	ND
Senegal	120,000	328.2	64.0	22.0	414.2	39.4	7.7	2.6	49.7
Sierra Leone	95,500	320.0	81.1	26.9	428.1	30.6	7.7	2.6	40.9
Togo	200	314.4	ND	ND	314.4	0.1	ND	ND	0.1
West Africa Grand Total	1,973,251					642.4	158.6	53.1	854.1

Sources: (Fatoyinbo and Simard 2013; Jardine and Siikamäki 2014; Hutchison et al. 2014)

BC resource. But more than that, under REDD+ payments, changes in land tenure might result from the contractual agreement especially regarding C rights that are assigned at the development of the BC project, leading to the argument of land grabbing and the possibility of the exclusion of certain groups from accessing their traditional areas. These issues regarding land tenure must be appropriately resolved based on the latest scientific advances and recommendations including recommendations for and lessons learned from operationalizing REDD+ (Olander et al. 2012).

Along with the development of BC projects, national climate mitigation efforts might also consider incorporating BC activities into their programs by following the steps outlined by (Herr and Pidgeon 2015). The newly-released VCS methodology for BC restoration (VCS 2015) provide guidance as to the use of the methodology to secure payments for BC. To finance these activities and projects, multiple current BC-relevant financing options are described in the literature (Herr et al. 2015). Those interested might also look at the example and leadership of Guinea-Bissau in securing BC payments.

Other BC demonstration sites for conservation and restoration projects have begun to emerge around the globe,

demonstrating the use of a wide range of various financing mechanisms available to project developers, or countries with BC resources they set out to protect (Ministerio del Ambiente 2015; Herr et al. 2015). The use of C finance in all of its various forms to pay for maintenance of the BC stocks in mangroves is nascent, and the above sample of projects are all small steps compared to the scale at which mangrove conversion and sequestration capacity globally.

Potential viability of BC payments

Regardless the specific market, private C finance offers a potentially viable source of payments for BC. Economic analyses have estimated that large scale conservation of the BC stocks in mangroves is feasible, even at relatively low C prices such as \$10 per ton of C dioxide equivalent, while also considering opportunity costs (i.e. the revenue streams from economic activities on converted mangrove habitats) (Siikamäki et al. 2012; Murray et al. 2011). To put \$10 per ton into perspective, at the end of 2015 C was trading at \$12.70, \$8.45, and \$5.50 per metric ton on the California compliance C market, European Union Emissions Trading Scheme, and Regional Greenhouse Gas Initiative markets, respectively.

Table 4 BC financial value for West African countries

Country name	Mangrove area (ha)	Avoided C emissions (20 yr, Mg)	Discounted value of avoided C emissions (million USD)			
			5%		8%	
			\$3/tCO ₂ e	\$5/tCO ₂ e	\$3/tCO ₂ e	\$5/tCO ₂ e
Angola	15,400	526,814	\$ 3.2	\$ 5.4	\$ 2.4	\$ 4.0
Benin	1800	62,695	\$ 0.4	\$ 0.7	\$ 0.3	\$ 0.5
Cameroon	148,300	5,642,486	\$ 35.5	\$ 59.1	\$ 26.6	\$ 44.3
Congo	1500	48,088	\$ 0.3	\$ 0.5	\$ 0.2	\$ 0.4
Côte d'Ivoire	3200	116,214	\$ 0.7	\$ 1.2	\$ 0.5	\$ 0.9
Democratic Republic of the Congo	18,300	415,856	\$ 2.4	\$ 4.1	\$ 1.7	\$ 2.9
Equatorial Guinea	18,100	670,312	\$ 4.2	\$ 7.0	\$ 3.1	\$ 5.2
Gabon	145,700	5,452,036	\$ 33.7	\$ 56.2	\$ 25.0	\$ 41.6
Gambia	51,911	1,835,923	\$ 11.4	\$ 19.0	\$ 8.4	\$ 14.1
Ghana	7600	268,337	\$ 1.7	\$ 2.8	\$ 1.2	\$ 2.1
Guinea	188,900	7,084,009	\$ 44.6	\$ 74.3	\$ 33.4	\$ 55.6
Guinea-Bissau	280,600	9,819,840	\$ 61.3	\$ 102.2	\$ 45.7	\$ 76.2
Liberia	18,900	735,654	\$ 4.6	\$ 7.7	\$ 3.5	\$ 5.8
Mauritania	40	942	\$ 0.0	\$ 0.0	\$ 0.0	\$ 0.0
Nigeria	857,300	32,642,801	\$ 205.3	\$ 342.2	\$ 153.8	\$ 256.3
São Tomé and Príncipe	ND	N/A	N/A	N/A	N/A	N/A
Senegal	120,000	4,124,332	\$ 25.6	\$ 42.7	\$ 19.0	\$ 31.7
Sierra Leone	95,500	3,502,329	\$ 22.0	\$ 36.6	\$ 16.4	\$ 27.4
Togo	200	4444	\$ 0.0	\$ 0.0	\$ 0.0	\$ 0.0
West Africa Grand Total	1,973,251	72,953,113				

Avoided emissions were calculated under the assumption of 0.7% annual loss (Pendleton et al. 2012)

The voluntary markets have been trading C at a lower market-average price of \$4.90, with REDD+ credits applicable to BC averaging \$4.20 according to 2013 data from Forest Trends (Goldstein and Gonzalez 2014). So, while \$10 per tonne is achievable on the compliance market, the voluntary market, where BC credits could more likely be traded, will have to increase their prices considerably. This does not mean that the BC projects are not viable at the lower price range of C, but there must be other revenue streams associated with the project (e.g. tourist revenues) to cover some of the higher costs of the project, such as large-scale restoration activities.

In general, C market prices and trading volumes have fluctuated over the past few years. Experts, however, are optimistic about future C market developments both in terms of volume and prices (Goldstein and Gonzalez 2014). Regulated carbon markets are driven by an arbitrary cap on emissions and the marginal cost of carbon offset alternatives, for example, from the power sector.

The price of C may also be bolstered by recent global political events, such as the United Nations Conference on Climate Change (COP) 21 in Paris in December 2015. This COP meeting sent a strong signal to the global environmental community that C pollution is to be reduced such that the predicted global

average temperature increase remains “well below” 2 degrees Celsius above pre-industrial levels (United Nations 2015b). The extent to which BC will be able to play a role in achieving this target will depend on the development of market-specific methodologies to credibly measure, report, and verify (MRV) greenhouse gas emissions from BC ecosystems. Moving forward, the two biggest uncertainties for BC projects to access C markets at scale remain (1) the uncertainty of whether policies will be enacted to create C markets of global scale and breadth, (2) whether such markets will accept BC conservation or restoration as credible activities, and (3) whether the influx of a large quantity of new offsets will “flood” the market, increase supply way above demand, resulting in a large drop in market price.

With the finalization of the Verified C Standard (VCS) Tidal Wetland Restoration protocol (V-C-S 2015), the entry of payments for BC into voluntary C markets is a real possibility and a significant opportunity to scale up financing. While voluntary or compliance C markets are only one way to generate payments for BC projects and activities, they offer positive aspect for developing financing capacity if the disparate regional C markets, including the compliance-driven E.U. and South Korea Emissions Trading Schemes, the California-

Table 5 Net benefit of BC conservation in West Africa's mangroves under low and high conservation cost scenarios

Country name	Net financial benefit of mangrove conservation (million USD)			
	\$3/tCO ₂ e		\$5/tCO ₂ e	
	5%	8%	5%	8%
Angola	\$ 2.8	\$ 2.0	\$ 4.9	\$ 3.6
	\$ 2.4	\$ 1.8	\$ 4.6	\$ 3.4
Benin	\$(0.2)	\$(0.1)	\$ 0.0	\$ 0.0
	\$(0.3)	\$(0.2)	\$(0.0)	\$ 0.0
Cameroon	\$(12.6)	\$(7.7)	\$ 11.1	\$ 10.0
	\$(15.7)	\$(10.2)	\$ 7.9	\$ 7.5
Congo	\$ 0.3	\$ 0.2	\$ 0.4	\$ 0.3
	\$ 0.2	\$ 0.2	\$ 0.4	\$ 0.3
Côte d'Ivoire	\$ 0.0	\$ 0.1	\$ 0.5	\$ 0.4
	\$(0.0)	\$ 0.0	\$ 0.5	\$ 0.4
Democratic Republic of the Congo	\$ 1.9	\$ 1.3	\$ 3.5	\$ 2.5
	\$ 1.5	\$ 1.0	\$ 3.1	\$ 2.2
Equatorial Guinea	\$ 1.0	\$ 0.8	\$ 3.8	\$ 2.9
	\$ 0.6	\$ 0.5	\$ 3.4	\$ 2.6
Gabon	\$ 29.2	\$ 21.7	\$ 51.7	\$ 38.4
	\$ 26.1	\$ 19.3	\$ 48.6	\$ 36.0
Gambia	\$ 0.9	\$ 0.9	\$ 8.4	\$ 6.6
	\$(0.3)	\$ 0.1	\$ 7.3	\$ 5.7
Ghana	\$(0.1)	\$(0.0)	\$ 1.0	\$ 0.8
	\$(0.3)	\$(0.1)	\$ 0.9	\$ 0.7
Guinea	\$ 12.4	\$ 10.4	\$ 42.1	\$ 32.6
	\$ 8.3	\$ 7.2	\$ 38.0	\$ 29.5
Guinea-Bissau	\$ 13.5	\$ 11.6	\$ 54.4	\$ 42.1
	\$ 7.5	\$ 6.9	\$ 48.4	\$ 37.4
Liberia	\$ 1.4	\$ 1.2	\$ 4.5	\$ 3.5
	\$ 1.0	\$ 0.9	\$ 4.1	\$ 3.2
Mauritania	\$ 0.0	\$ 0.0	\$ 0.0	\$ 0.0
	\$(0.0)	\$(0.0)	\$ 0.0	\$ 0.0
Nigeria	\$ 72.6	\$ 59.0	\$ 209.5	\$ 161.5
	\$ 54.2	\$ 44.7	\$ 191.1	\$ 147.3
São Tomé and Príncipe	N/A	N/A	N/A	N/A
	N/A	N/A	N/A	N/A
Senegal	\$ 10.2	\$ 8.0	\$ 27.3	\$ 20.7
	\$ 7.7	\$ 6.0	\$ 24.7	\$ 18.7
Sierra Leone	\$ 5.7	\$ 4.8	\$ 20.3	\$ 15.7
	\$ 3.7	\$ 3.2	\$ 18.3	\$ 14.2
Togo	\$(0.0)	\$(0.0)	\$(0.0)	\$(0.0)
	\$(0.0)	\$(0.0)	\$(0.0)	\$(0.0)

For each country the top row represents results for a low conservation cost scenario, while the bottom row represents results for a high conservation cost scenario as described in the methodology above. Discount rates of 5 and 8%, and C prices of \$3 and 5 were used in the analysis to provide results under alternative scenarios

Quebec market, the Regional Greenhouse Gas Initiative; and the voluntary and Climate Action Reserve (CAR), VCS, and others, that are currently developing and operating independently, become linked or integrated in the future.

From the types of C markets, the voluntary markets would likely be more adaptable to the West Africa region, as opposed to a regulated market or compliance scheme requiring a national, regional or international cap on greenhouse gas emissions.

Voluntary markets can serve as a testing ground for new procedures, methodologies and technologies that may later be included in the introductory of a regulatory scheme, as projects can be implemented with fewer transaction costs than in the compliance markets. At the same time, voluntary markets would have lower C prices and trading volumes than regulated markets.

Additionally, ‘debt-for-nature’ swaps may be another mechanism to finance mangrove conservation, whereby a portion of a country’s foreign debt is forgiven in exchange for local investments in environmental conservation. For example, in the Seychelles, the country has completed a debt-swap to redirect a portion of their current debt payments from external creditors to fund marine conservation activities such as marine protected areas.

Summary and conclusions

West African communities and countries could capture global funding for mangrove conservation, in payment for the C sequestration function of these ecosystems. While mangroves provide many well-documented benefits for communities along West Africa’s coast, for example as protection from flooding and nursery areas for commercially important fish stocks, they also provide C storage for which the international community may be willing to pay. Hence if communities can capitalize the global benefits to fund the costs of local conservation and benefits, it may be an additional pathway to poverty reduction in some cases.

With the Paris COP in 2015, a number of opportunities have emerged or are continuing that may provide useful sources of capital to finance conservation of West African mangroves, including cap-and-trade under the UNFCCC, large non-UNFCCC dependent cap-and-trade schemes such as the European Union Emissions Trading System (ETS), large national schemes, sub-national schemes, or the voluntary C market.

Over 93% of West Africa’s estimated area of mangroves can be found in seven countries: Nigeria, Guinea-Bissau, Guinea, Cameroon, Gabon, Sierra Leone, and Senegal. These countries represent the top BC investment opportunities for West Africa. From these seven countries, initial opportunities might be identified based on consideration of political, governance, technical, social, or environmental risks. For these opportunities to materialize, important steps need to be taken regionally and nationally. At the regional level, a support program and information clearinghouse could be established to assist countries to undertake the work needed to capture this opportunity. This assistance could include socio-economic assessments and monitoring of mangrove condition, facilitation of enhanced regional cooperation, or the development of pathways for West African BC projects to access international finance.

At the national level, efforts to conserve mangroves are often fragmented. From a juridical-administrative point of

view, the mangrove forests are a composite and unstable area, difficult to define. Despite these difficulties, efforts should continue in building on national mapping activities to focus on identifying key areas that will be crucial for climate change mitigation and adaptation. These efforts could lead to maps that help prioritize areas that are most important for coastal protection, fisheries production, climate change mitigation and adaptation. Key additional aspects of mangrove conservation are sustainable management on the landscape scale, increased community awareness and benefit-sharing.

As individual BC projects are developed, it will be crucial to determine the motivating factor in order to establish the project expectations, whether it is to obtain sustainable financing, national report strategies or a tool to better inform and motivate mangrove conservation. It cannot be overstated, that it is far better to protect mangroves now than have to restore or rehabilitate later. In short, BC is possible and would be helpful within West Africa, both to continue to promote the conservation of mangroves, but also in helping to provide a source of innovative financing, while bringing to light the wealth contained within these coastal ecosystems and their values – economically, ecologically as well as culturally – at a community and regional level as well as at a global level.

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