PRODUCTIVE LANDSCAPES (PROLAND)

SUSTAINABLE LANDSCAPES (SL) OPPORTUNITIES ANALYSIS FOR WEST AFRICA: BIOPHYSICAL POTENTIAL

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JANUARY 2020

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ACRONYMS

CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
ECOWAS	Economic Community of West African States
FAA	Foreign Assistance Act
FAO	Food and Agriculture Organization
FMNR	Farmer-Managed Natural Regeneration
GHG	Greenhouse Gas
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
Mt	Million Tons (metric)
$MtCO_2e$	Million Tons (metric) of Carbon Dioxide Equivalent
NDC	Nationally Determined Contributions
ProLand	Productive Landscapes Project
SL	Sustainable Landscapes
tC/ha	Tons (metric) of Carbon per Hectare
tCO_2e	Tons (metric) of Carbon Dioxide Equivalent
USAID	United States Agency for International Development

1.0 PURPOSE OF DOCUMENT AND APPROACH

The goal of the sustainable landscapes (SL) opportunities analysis for West Africa is to provide decision support for prioritizing SL investments in West Africa. It focuses on 15 countries: the 14 continental members of the Economic Community of West African States (ECOWAS) plus Cameroon. This document focuses on the regional biophysical potential of 20 identified pathways for land-based greenhouse gas (GHG) mitigation as well as on the sub-regional geographical prioritization of the highest potential pathways.

1.1 SOURCES USED TO IDENTIFY THE SUITE OF OPTIONS

To provide an overview of SL mitigation options and the scale of their potential at the country level, this report relies heavily on the *Natural Climate Solutions* analysis (Griscom et al., 2017) and its recent update (Griscom et al., 2020). We believe these to be the best-available global sources for assessing land-based GHG mitigation potential both in terms of comprehensiveness of the pathways covered and the degree of sub-national disaggregation. Those 20 pathways are described in Table A1 (Appendix).

In addition to the Griscom et al. studies, we referred to three other types of primary sources to identify additional potential options for land-based GHG mitigation:

1. The IPCC Special Report on Climate Change and Land (2019),
2. Nationally Determined Contributions (NDC) and Intended Nationally Determined Contributions (INDC) document, and[1]
3. National Tropical Forest and Biodiversity Assessments carried out in response to Foreign Assistance Act (FAA) 118/119.

We found that while these additional documents provide useful context, none significantly added to the utility of the Griscom material for this biophysical potential analysis. Specifically, in the case of (1), the response options identified (Figure A3) were for the most part either equivalent to Griscom pathways or addressed a similar issue but in a more generalized or indirect way. Those options that differed (e.g., integrating water management and reducing landslides) were primarily introduced as adaptation strategies and their mitigation potential was not discussed in detail in the main body of the report. The national INDC/NDC documents (2) are useful for identifying national intentions and priorities for mitigation programs; as such, they are summarized in Table A2. However, when taken collectively, they do not provide a particularly broad overview of potential options, and they generally provide poor quantification of the costs or potential of different options. Lastly, the 118/119 analyses (3) tend to focus climate mitigation potential in general terms, and to the extent that they do assess carbon density of ecosystems, tend to rely on global data sources that we have already included in this analysis.

1.2 STRUCTURE OF THIS DOCUMENT

The majority of the material in this document is presented in figures, tables, maps, and their explanatory text. We begin by providing a quantitative overview—based directly on the two Griscom et al. studies (2017; 2020)—of the mitigation potential of 14 of the 20 pathways (Table 1 and Figures 1 and 2). We also present information on the other six pathways for which it was not possible to present national-level estimates of potential. Next, we present spatial data highlighting the geographic potential of the three pathways with the largest overall potential in West Africa: avoided forest conversion, forest

[1] As of January 2020, 14 of the countries covered by this study had NDCs; however, Senegal has only an INDC.

restoration, and trees in agriculture. Those three pathways represent 73% of the potential of those 14 pathways for which national data is available. Lastly, for each of those three pathways, it identifies sub-national administrative areas with particularly high potential for SL investment.

This document does not address issues of social or institutional feasibility. Those considerations of feasibility will be essential to a question of prioritizing investments. This document provides an overview of biophysical potential as a starting point.

2.0 MITIGATION POTENTIAL BY PATHWAY

Griscom et al. (2017) calculated the global potential for 20 natural climate solutions (i.e., land-based GHG mitigation strategies) while safeguarding biodiversity and the production of food and fiber. The same study also made national-scale estimates for 10 of those 20 pathways for all countries worldwide, while the updated analysis (Griscom et al., 2020) extended that national-scale analysis to 14 out of 20 pathways for 79 tropical countries. The estimates from the two Griscom et al. studies for the 15 focal countries in West Africa are shown in Table 1. Countries are sorted from having the most total land-based mitigation potential (top to bottom) while mitigation pathways are sorted left to right from largest total potential (avoided forest conversion) to smallest. Totals by country (and percentages of the region) for these 14 pathways are shown in the right-most two columns of Table 1, while totals by pathway (and percentages of region) are shown in the bottom two rows. Individual cells are also shaded in blue with darker shades indicating larger potential.

The 14 pathways presented below in Table 1 combine data from the two Griscom studies with the more recent study taken as more definitive if the data differed. The remaining six pathways that do not have national-scale estimates of potential are summarized in Table 2 and are as follows:

- Biochar,
- Improved feed for livestock,
- Improved plantations,
- Conservation agriculture,
- Improved livestock management, and
- Avoided grassland conversion.

Those six pathways are estimated to represent 12.4% of the global total potential (Griscom et al., 2017), meaning that more than 85% of global potential is captured by the pathways in Table 1. However, we cannot say exactly what that percentage is for the West African study countries specifically.

Figure 1, following Table 1, presents the same data visually. In Figure 1, the country with the highest total potential (Nigeria) is on the left, with countries declining in total potential from left to right. The mitigation pathways with the highest potential (avoided forest conversion) are at the bottom and potential for each pathway declines moving upward.

Table 1: Cost-effective potential–with safeguards–of 14 land-based mitigation pathways (millions of tons CO_2e per year) for 15 continental ECOWAS members plus Cameroon.* Further explanation of data on the following page.

Country	Avoided Forest Conv-ersion	Trees in Agricul-tural Lands	Refor-estation	Improved Natural Forest Manage-ment	Reduced Wood Fuel Harvest	Imp-roved Rice Cult-ivation	Optimal Grazing Intensity	Avoided Man-grove Loss	Grazing Legumes	Peat Rest-oration	Avoided Peat Impacts	Improved Fire Manage-ment Savannas	Man-grove Rest-oration	Nutrient Manage-ment	Total national potential NCS (Mt CO_2e)	National NCS potential as % of region
Nigeria	7.78	20.06	20.76	16.45	3.02	2.34	0.78	0.87	n.d.	0.42	0.64	0.83	0.08	0	**74.03**	**20.4%**
Côte d'Ivoire	34.92	0.75	16.72	8.68	0.89	0.48	0.16	0.04	n.d.	0.42	0.42	0	0	0	**63.48**	**17.5%**
Cameroon	16.69	7.73	12.29	12.77	0.72	0.06	0.08	0.25	n.d.	0.14	0.05	n.d.	0.02	0	**50.80**	**14.0%**
Niger	0	37.84	0.03	1.99	0.29	0.06	0.4	0	1.62	0.01	0.06	0	0	0	**42.30**	**11.6%**
Ghana	13.12	2.69	8.24	11.34	1.25	0.12	0.16	0.1	n.d.	0.03	0.01	n.d.	0.02	0	**37.08**	**10.2%**
Guinea	5.89	0.4	10.76	2.55	0.68	0.78	0.44	0.23	0	0.7	0.26	0.33	0.03	0	**23.05**	**6.3%**
Liberia	16.4	0	1.29	1.96	0.33	0.06	0.04	0.03	n.d.	0.06	0.07	0	0	0	**20.24**	**5.6%**
Sierra Leone	6.97	0	3.29	0.57	0.27	0.48	0.2	0.07	0	0.06	0.07	0.14	0.01	0	**12.13**	**3.3%**
Burkina Faso	0	7.06	0.36	3.32	0.61	0.12	0.2	0	n.d.	0.07	0.03	n.d.	0	0	**11.77**	**3.2%**
Mali	0.04	3.76	0.79	2.32	0.26	0.66	0.54	0	0.66	0.07	0.03	0.1	0	0	**9.23**	**2.5%**
Benin	0.57	0.62	2.65	1.2	0.3	0	0.03	0	n.d.	0.07	0.03	n.d.	0	0	**5.47**	**1.5%**
Senegal	0.03	0	0.74	3.19	0.42	0.06	0.08	0.5	n.d.	0.01	0.02	n.d.	0.06	0.02	**5.13**	**1.4%**
Togo	0.5	0.44	2.04	0.33	0.31	0.06	0.03	0	n.d.	0.03	0.06	n.d.	0	0	**3.80**	**1.0%**
Guinea-Bissau	1.09	0	1.02	0.52	0.13	0.18	0.07	0.26	n.d.	0.01	0	0.1	0.03	0	**3.41**	**0.9%**
Gambia, The	0.01	0	0.09	0.89	0.05	n.d.	0.01	0.1	n.d.	0.03	0.01	n.d.	0.01	0	**1.20**	**0.3%**
Total potential by mitigation pathway	**104.01**	**81.35**	**81.07**	**68.08**	**9.53**	**5.46**	**3.22**	**2.45**	**2.28**	**2.13**	**1.76**	**1.50**	**0.26**	**0.02**	**363.12**	
Mitigation pathway as % of regional total	**28.6%**	**22.4%**	**22.3%**	**18.7%**	**2.6%**	**1.5%**	**0.9%**	**0.7%**	**0.6%**	**0.6%**	**0.5%**	**0.4%**	**0.1%**	**0.0%**		**100.0%**

*Cells that indicate a zero should be taken to mean that potential has been assessed, but that it rounds to zero (i.e., it is less than 0.005 million tons or 50,000 tons). n.d. indicates no data.

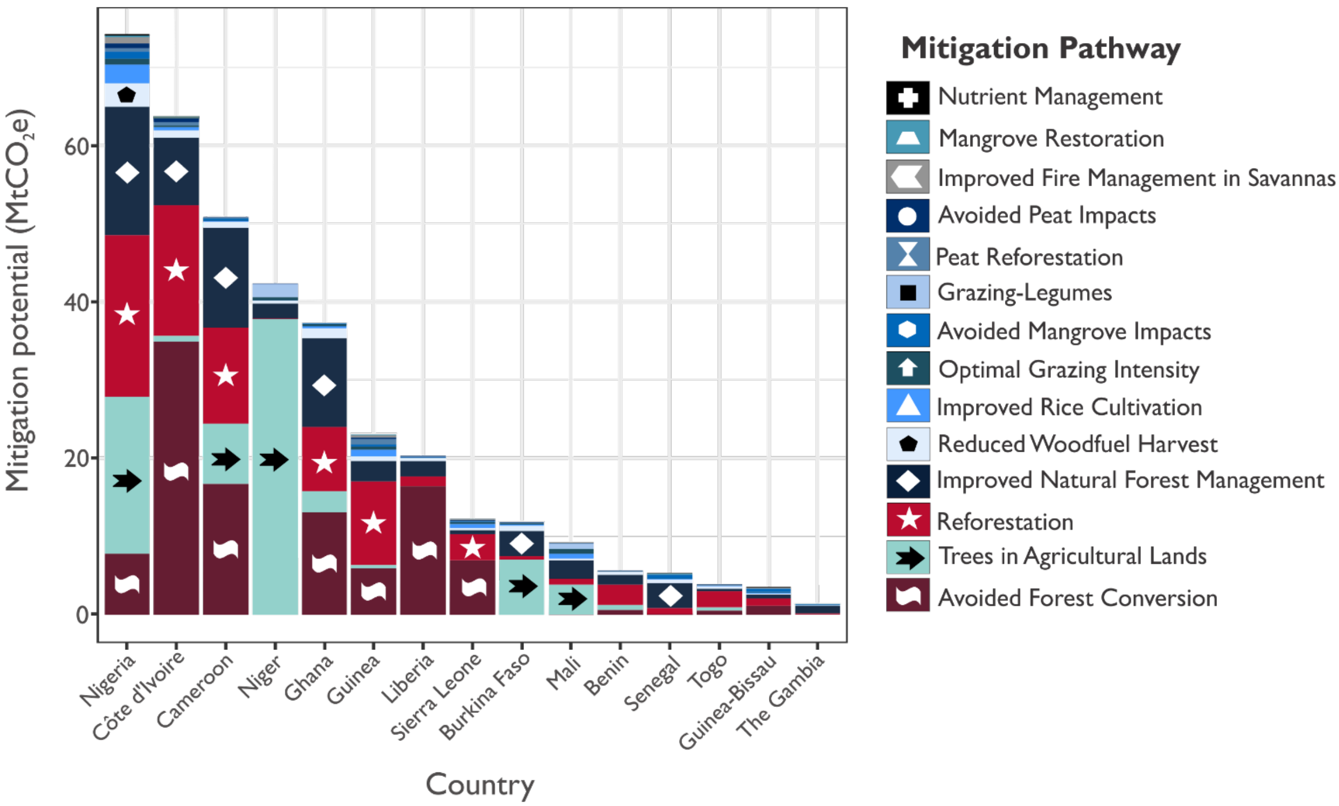

Figure 1: Total potential—with safeguards for human food and fiber production and for biodiversity—for 14 major pathways (for which national-scale data is available) of land-based climate mitigation in 15 countries of Western Africa (14 continental ECOWAS members plus Cameroon). Same data as presented in Table 1; further explanation of data provided in the description to Table 1. Pathways that are not included here because of data limitations are included in Table 2.

Looking at the mitigation potential scaled by country area changes the pattern somewhat (Figure 2). Scaling potential by area may be a useful metric, in that achieving emissions reductions in a smaller area is presumably more cost-efficient than achieving those same reductions across a larger geographic area. Nigeria, for example, while having the highest total potential in large part because of its size, has a per-area potential that is less than half that of Côte d'Ivoire or Cameroon. The countries with the highest potential per unit area are consistently those countries where avoided forest conversion plays a large role: Liberia, Cameroon, Sierra Leone, and Ghana. Generally, avoided forest conversion has a much higher impact per unit area than do the other large pathways. Avoided conversion can mitigate emissions of more than 500 tons CO_2 per hectare in carbon-dense forests (Tyukavina et al., 2015). With farmer-managed natural regeneration (FMNR)—the primary component of the trees in agriculture pathway in West Africa—estimates are that land can sequester 1.47 tons CO_2 per hectare per year (Leudeling & Neufeldt, 2012). In the case of reforestation, a meta-analysis of estimates from across tropics (Bonner, Schmidt & Shoo, 2013) indicate that naturally regenerating and plantation forests sequester an average per hectare of 4.8 tons of carbon per year and 6.2 tons of carbon per year, which represents 17.6 and 22.8 tons of CO_2e per year.

Table 2: Six pathways for land-based climate mitigation that were identified by Griscom et al. (2017) but for which neither of the two Griscom et al. (2017; 2020) studies estimated national-scale potential. Some information indicating the rough scale of potential in the West Africa region is included.

Pathway	Description and activities included	Available information for estimating regional or national potential in West Africa	Maximum potential globally (million tons CO2e / year)	Potential as % of total global NCS potential
Biochar	Carbon sequestration by amending agricultural soils with biochar derived from crop residue	Estimate is 0.66 tons CO2e sequestered long term for every dry ton of available crop residue feedstock (Griscom et al., 2017). National or regional estimates for West Africa would require assumptions about available feedstock that are not readily available in the literature. The Griscom global maximum estimate assumes half of global feedstock that is not fed to livestock is used for biochar. It should be noted that biochar has not been well demonstrated outside of research settings, and as such, there is more uncertainty regarding its widespread potential than is the case with most other mitigation pathways (Griscom et al., 2017). In particular, the long-term residence time of biochar carbon in the soil is poorly understood (Gurwick, Moore, Kelly & Elias, 2013).	1,102	4.63%
Grazing - Improved Feed	Avoided methane emissions due to reduced enteric fermentation from the use of more energy-dense feed and the associated reduction in total animal numbers needed to supply the same level of meat and milk demand	Cattle production in sub-Saharan Africa has very high emissions intensity per unit of production—more than 60 kg CO2e per kg animal weight—which is over four times higher than the most efficient systems globally (Gerber et al., 2013). According to Food and Agriculture Organization (FAO) data, there are just above 80 million head of cattle in the 15 study countries, with more than half of those found in Nigeria (25.9%), Niger (16.9%), and Mali (14.3%).	680	2.86%
Improved Plantations	Additional carbon sequestration achieved by extending harvest rotations to biologically optimal rotation lengths	Griscom et al. (2017) estimate an additional 0.47 tons carbon (=1.72 CO_2e) sequestered per year per hectare by extending rotation lengths. The Global Forest Resources Assessment 2015 (FAO, 2016) estimates 12.8M hectares of planted forests in Africa as a whole, suggesting this intervention has a continent-wide potential of 22 million tons CO_2e per year.	443	1.86%

Pathway	Description and activities included	Available information for estimating regional or national potential in West Africa	Maximum potential globally (million tons CO2e / year)	Potential as % of total global NCS potential
Conservation Agriculture	Additional soil carbon sequestration by planting cover crops during the part of the year when the main crop is not growing, where appropriate given climate factors and cropping systems	1.36 tons CO_2e/hectare/year estimated by Eagle et al. (2012). No data is available at national scale for potential area. Note that the quantity estimated here for conservation agriculture is limited to what is generally referred to as "cover cropping." This is only one component of conservation agriculture as the term is more generally used. Conservation agriculture also generally includes practices such as reducing tillage and rotating crops. As such, the estimate provided here by Griscom et al. (2017) should be considered conservative.	413	1.74%
Grazing - Animal Management	Avoided methane emissions resulting from reduced enteric fermentation due to improving livestock breeds and management techniques; improvements in reproductive performance, animal health, and weight gain lead to a reduction in total number of animals needed to supply the same amount of milk and meat	See information above under "Grazing - improved feed."	200	0.84%
Avoided Grassland Conversion	Avoided soil carbon emissions by avoiding the conversion of grasslands (including savannas and shrublands) to cropland	Estimated average loss of 68.4 tons CO_2e per hectare (Jobbagy & Jackson, 2000); however, there are no available estimates for the rate of conversion at regional or national scales.	116	0.49%
Total			**2,954**	**12.41%**

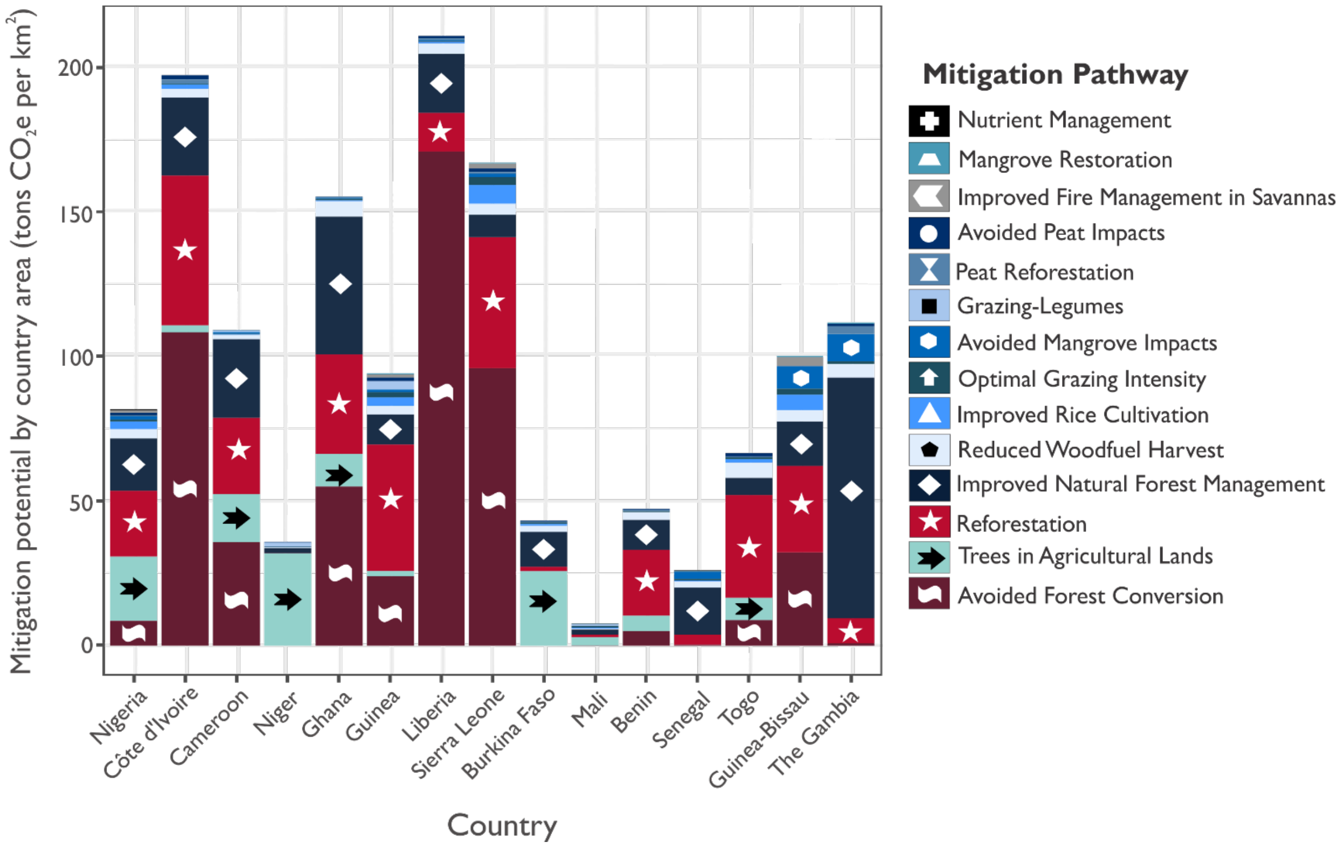

Figure 2: Cost-effective potential by mitigation pathway, scaled by country area.

3.0 AVOIDED DEFORESTATION

Avoiding forest conversion has a larger potential for mitigation in West Africa than does any other pathway—its cost-effective potential represents 28.6% of the potential of the 14 pathways with country-specific estimates. It is also the largest potential pathway in six of the 15 study countries: Côte d'Ivoire, Liberia, Cameroon, Ghana, Sierra Leone, and Guinea-Bissau.

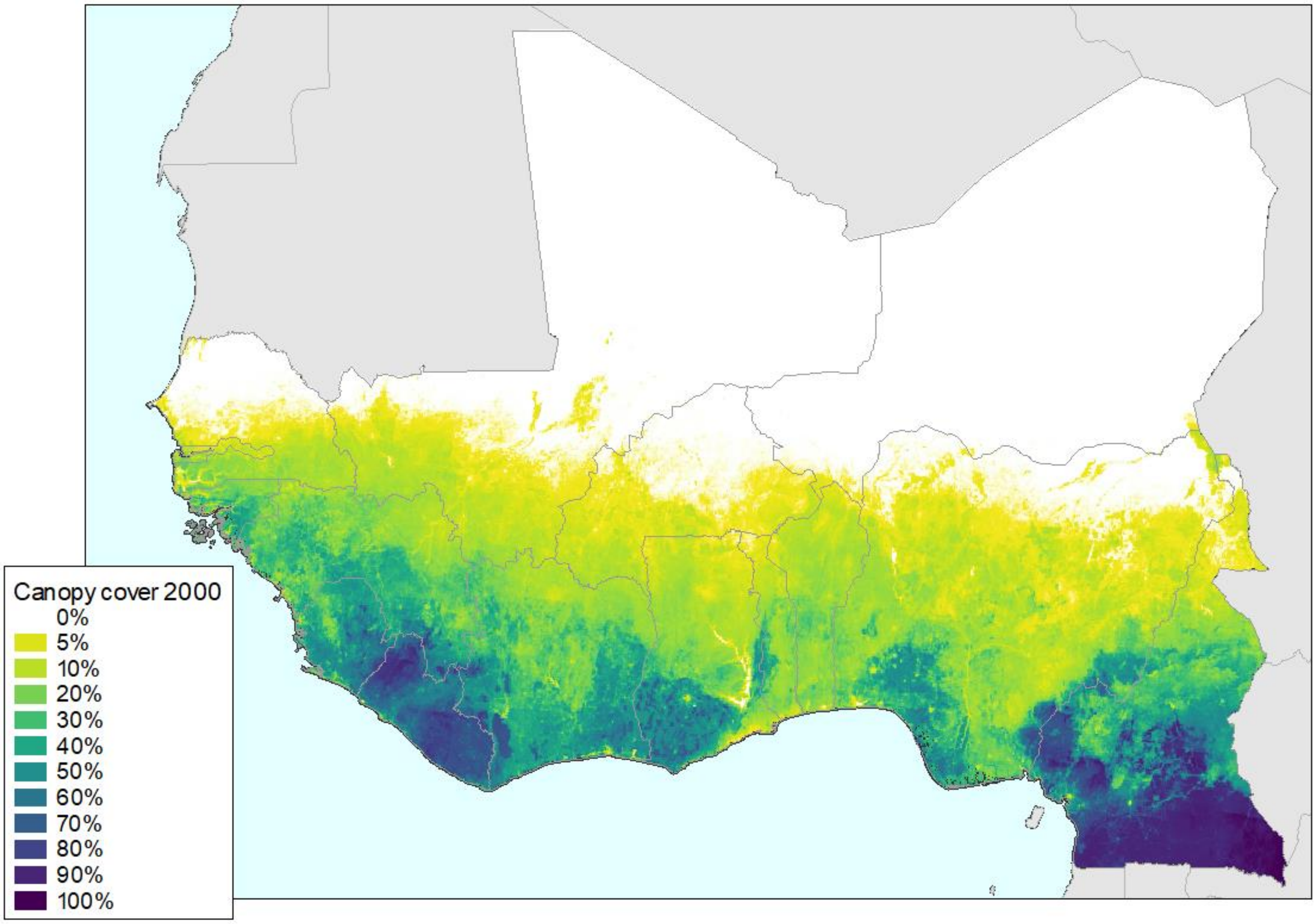

Figure 3: Forest cover in West Africa. Data from Hansen et al. (2013; version 1.6, 2019).

Forest cover in West Africa varies greatly from south to north with the most carbon-dense forests in Cameroon, Sierra Leone, and Liberia (Tyukavina et al., 2015). The most carbon-dense forests in the region store more than 170 tons of carbon per hectare (equivalent to 622 tons of CO_2 if converted completely); however, as shown in Figure 3, density drops steeply with the woodlands shown in shades of green and yellow, generally having 10-50 tons of carbon per hectare (Tyukavina et al., 2015). The areas of greatest forest *carbon* loss in the region are in Côte d'Ivoire and Liberia (Tyukavina et al., 2015). This differs slightly from the patterns of forest *area* loss shown in Table 3, because of differences in carbon density: Guinea had a higher rate of loss of forest area than did Liberia over a similar time period. However, lower-density forests in Guinea meant that this loss in area did not constitute emissions as large as those from Liberia. Côte d'Ivoire is the most significant area for forest loss in West Africa, whether one measures in terms of carbon or in terms of forest area. Figure 4 shows the patterning of the loss of forest area in West Africa from 2001 to 2018.

Table 3: Forest cover (2000) and forest cover loss (2001-2018) by country in West Africa. Based on Hansen et al. (2013; updated 2019) data.

Country	Tree cover in 2000 (km2)	Tree cover in 2000 (% of total area)	Forest loss 2001-2018 (km2)	Forest loss 2001-2018 (% of initial forest area)
Côte d'Ivoire	104,340	32.4%	37,495	35.9%
Nigeria	110,485	12.2%	24,321	22.0%
Guinea	65,748	26.9%	20,074	30.5%
Liberia	66,885	69.7%	15,371	23.0%
Ghana	57,642	24.2%	14,617	25.4%
Sierra Leone	33,203	45.7%	14,154	42.6%
Cameroon	250,354	53.7%	13,251	5.3%
Benin	15,235	13.2%	5,590	36.7%
Mali	15,299	1.2%	3,058	20.0%
Burkina Faso	7,715	2.8%	2,292	29.7%
Guinea-Bissau	8,521	25.1%	2,266	26.6%
Togo	9,102	16.0%	1,466	16.1%
Senegal	8,650	4.4%	1,256	14.5%
Gambia	906	8.5%	168	18.6%
Niger	207	0.0%	5	2.3%

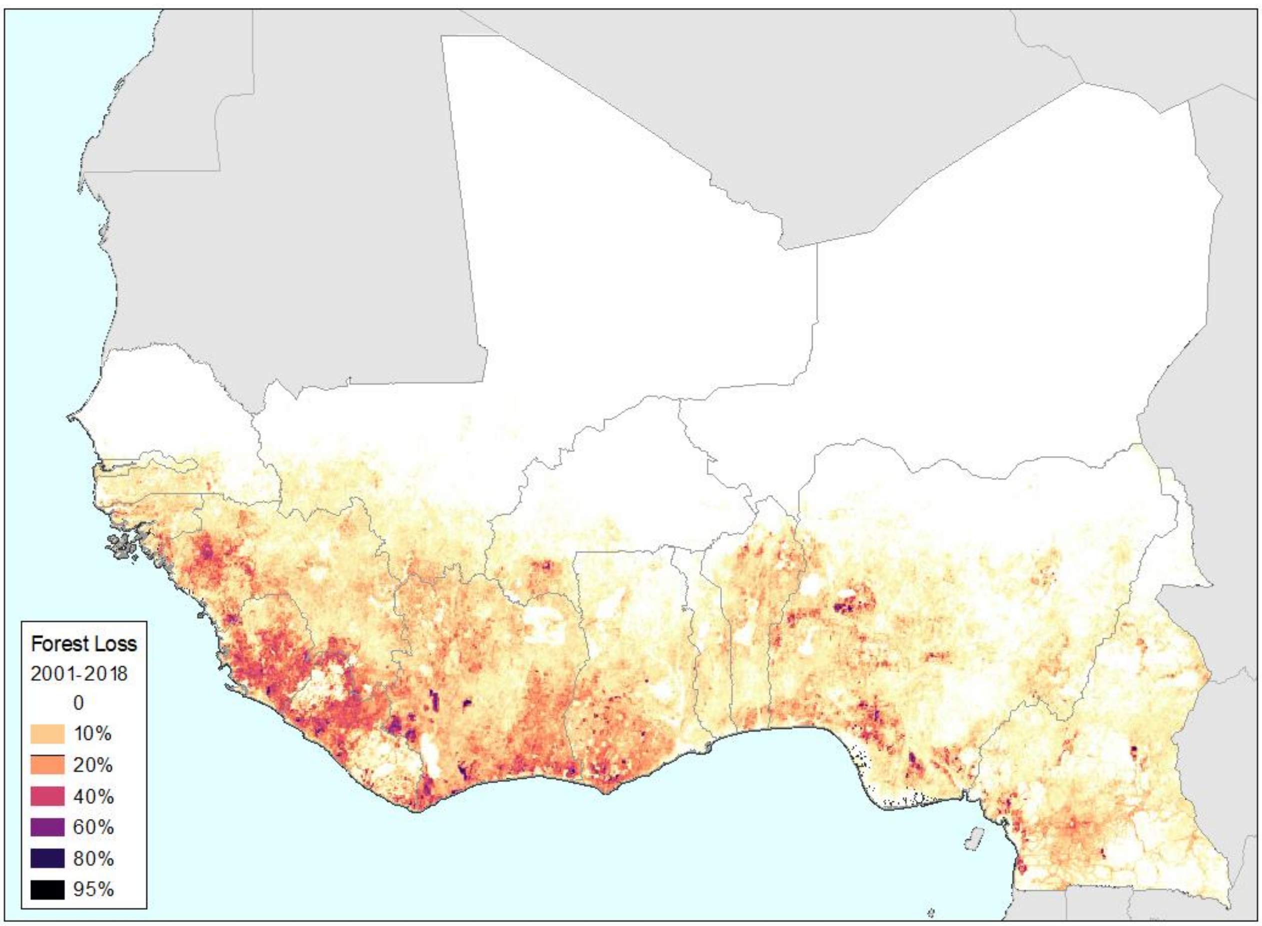

Figure 4: Deforestation in West Africa from 2001-2018. Based on Hansen et al. (2013; updated 2019) data at 30m x 30m resolution and aggregated upward to pixels of 4800m x 4800m.

The great majority of change in forest area in West Africa takes place in inland forests rather than mangroves. Mangroves are found in 10 countries in West Africa as well as in Cameroon (CILSS, 2016; Cameroon is not included in that analysis hence the discussion of mangroves in only 10 countries in West Africa). Among the ECOWAS countries, Nigeria lost the largest area of mangroves between 1975 and 2013 with 432 km^2 over those 38 years (11.4 km^2/year) (CILSS, 2016). Senegal and Guinea-Bissau followed with 288 km^2 and 220 km^2 of loss, respectively. These numbers are orders of magnitude lower than losses of inland forests; Côte d'Ivoire lost more than 2,000 km^2 per year between 2001 and 2018 while Nigeria lost slightly more than 1,350 km^2 (CILSS, 2016).

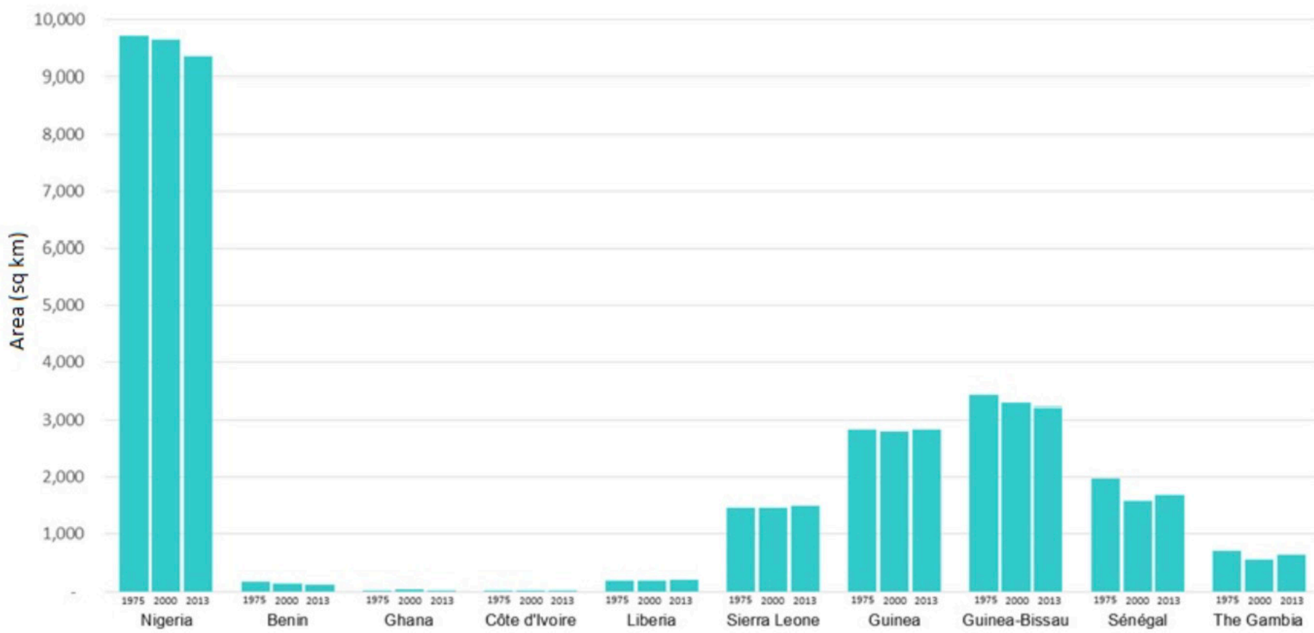

Figure 5: Mangrove area in 10 countries of West Africa in 1975, 2000, and 2013 (Figure from CILSS, 2016).

Despite their small area relative to upland forests, mangroves can be very carbon dense. Griscom et al. (2017) combined seven studies and used an estimated mangrove carbon density of 194 tons of carbon per hectare (equivalent to 712 tons of CO_2). Emissions from mangroves happen slowly as carbon in sediments is released; it is estimated that 54% is released within 20 years. This is equivalent to 384 tons over 20 years—a value comparable to above-ground emissions from high-density upland forests. The maximum estimated loss in above-ground carbon resulting from deforestation in Africa is 143 tons of carbon per hectare—equivalent to 525 tons CO_2e. The great majority of deforestation or forest degradation results in lower emissions (Tyukavina et al., 2015).

Figure 6 shows first-level administrative divisions in West Africa and the relative amount of forest area loss in each administrative area, expressed as a percentage of total administrative area. Table 4 presents the same data for the top 10 administrative divisions, both in terms of the total area of forest loss, as well as in terms of the percentage of forest cover (in 2000) that was lost.

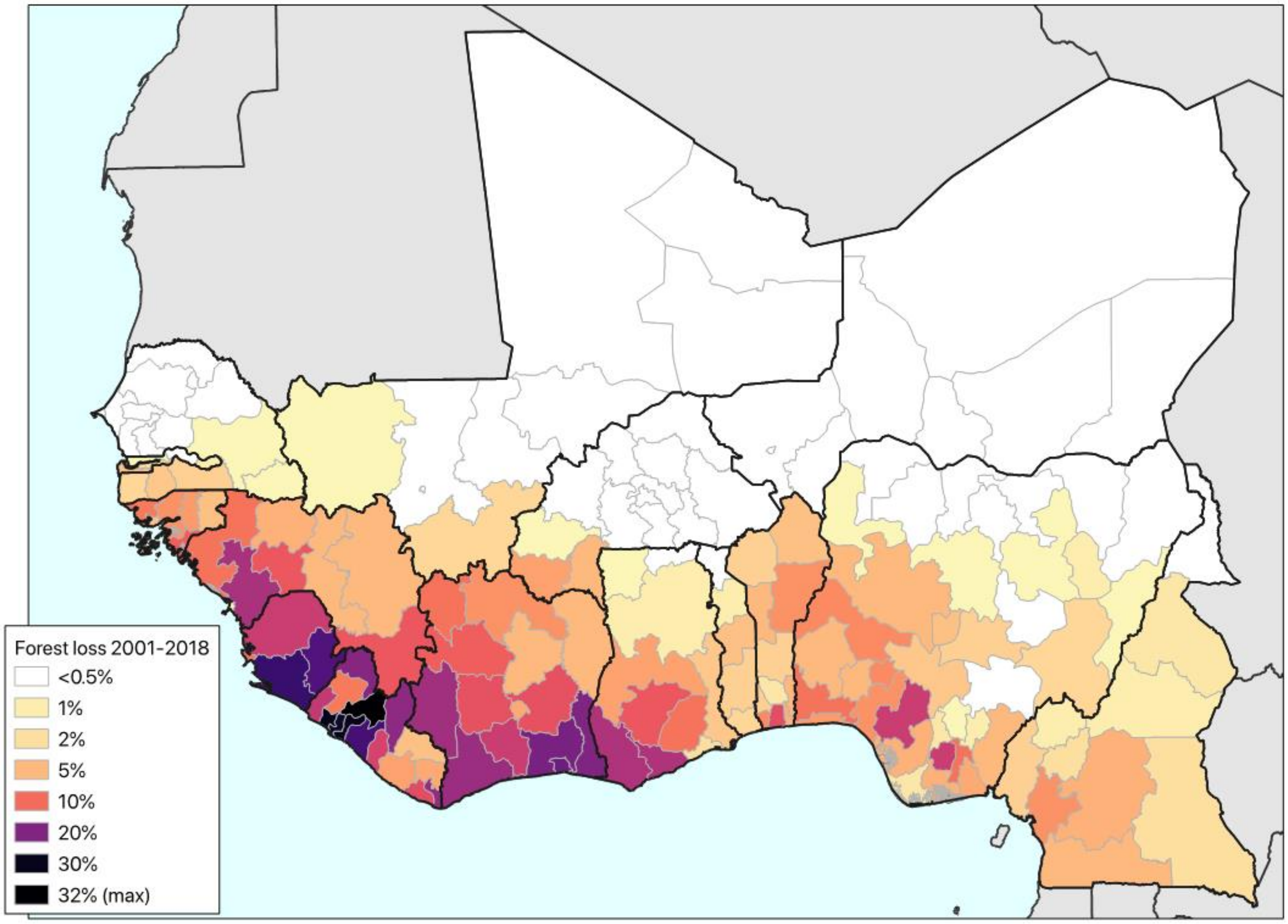

Figure 6: Deforestation rates by first-level administrative divisions (Hansen et al., 2013, updated 2019). Scaled by total area of administrative area.

Table 4: Deforestation rates by first-level administrative divisions for area that are in the top ten either by total area of forest loss or by forest loss as a percentage of 2000 forest cover (Hansen et al., 2013, updated 2019).

Country	First-level administrative division	Tree cover in 2000 (km2)	Tree cover in 2000 (% of total area)	Forest loss 2001-2018 (km2)	Forest loss 2001-2018 (% of initial forest area)	Rank (out of 174) in total area of forest loss	Rank (/174) in forest loss as % of initial forest area
Côte d'Ivoire	Montagnes	16,024	53%	5,339	33%	1	41
Sierra Leone	Northern	14,153	39%	5,179	37%	2	36
Sierra Leone	Southern	9,599	48%	5,170	54%	3	10
Côte d'Ivoire	Bas-Sassandra	13,418	48%	4,960	37%	4	32
Guinea	Kindia	7,503	29%	4,392	59%	5	6
Guinea	Nzérékoré	15,174	42%	4,084	27%	6	55
Côte d'Ivoire	Lagunes	9,849	49%	4,050	41%	7	23
Ghana	Western	13,650	56%	4,029	30%	8	48
Sierra Leone	Eastern	9,178	58%	3,738	41%	9	25
Cameroon	Centre	44,724	65%	3,669	8%	10	124
Burkina Faso	Cascades	1,893	10%	1,132	60%	44	4

Country	First-level administrative division	Tree cover in 2000 (km2)	Tree cover in 2000 (% of total area)	Forest loss 2001-2018 (km2)	Forest loss 2001-2018 (% of initial forest area)	Rank (out of 174) in total area of forest loss	Rank (/174) in forest loss as % of initial forest area
Liberia	Margibi	1,541	55%	843	55%	54	8
Burkina Faso	Sud-Ouest	1,390	9%	808	58%	57	7
Nigeria	Imo	1,288	24%	754	59%	59	5
Liberia	Montserrado	961	53%	526	55%	68	9
Côte d'Ivoire	Abidjan	758	36%	457	60%	75	3
Benin	Atlantique	532	17%	376	71%	86	1
Guinea-Bissau	Bissau	9	11%	7	70%	141	2

4.0 REFORESTATION

The Atlas of Forest Landscape Restoration Opportunities (Laestadius et al., 2011; WRI, 2014) identifies land area that could support forest or woodlands but that at present is not under tree cover. It further classifies those areas of land into categories with respect to the land's potential for forest restoration, reforestation, or afforestation. In West Africa, the categories used are as follows:

- Potential for widespread restoration: areas where human habitation is low (<10 persons per km^2) and where closed canopy forests could potentially be established;
- Potential for mosaic restoration: areas where human habitation is moderate (10-100 persons per km^2) and where restoration to a mix of trees and croplands, or to mosaic forest patches, would be possible; and
- Limited potential for restoration: areas presently under intensive agricultural use or that have high population density.

Figure 7 maps these categories in the 15 study countries. Table 5 shows the total areas estimated to have potential for forest restoration in the 15 countries, ranked from the country with the largest total area of restoration potential (Nigeria) to the smallest area of potential. Figure 8 adds the potential for forest restoration—combining potentials for widespread and mosaic restoration—and aggregates it for first-level administrative divisions relative to the total area of the administrative division. Table 6 shows that same data—restoration potential for first-level administrative divisions—for those administrative divisions that are either in the top 10 for total area of restoration potential or for percentage of area that has potential for restoration.

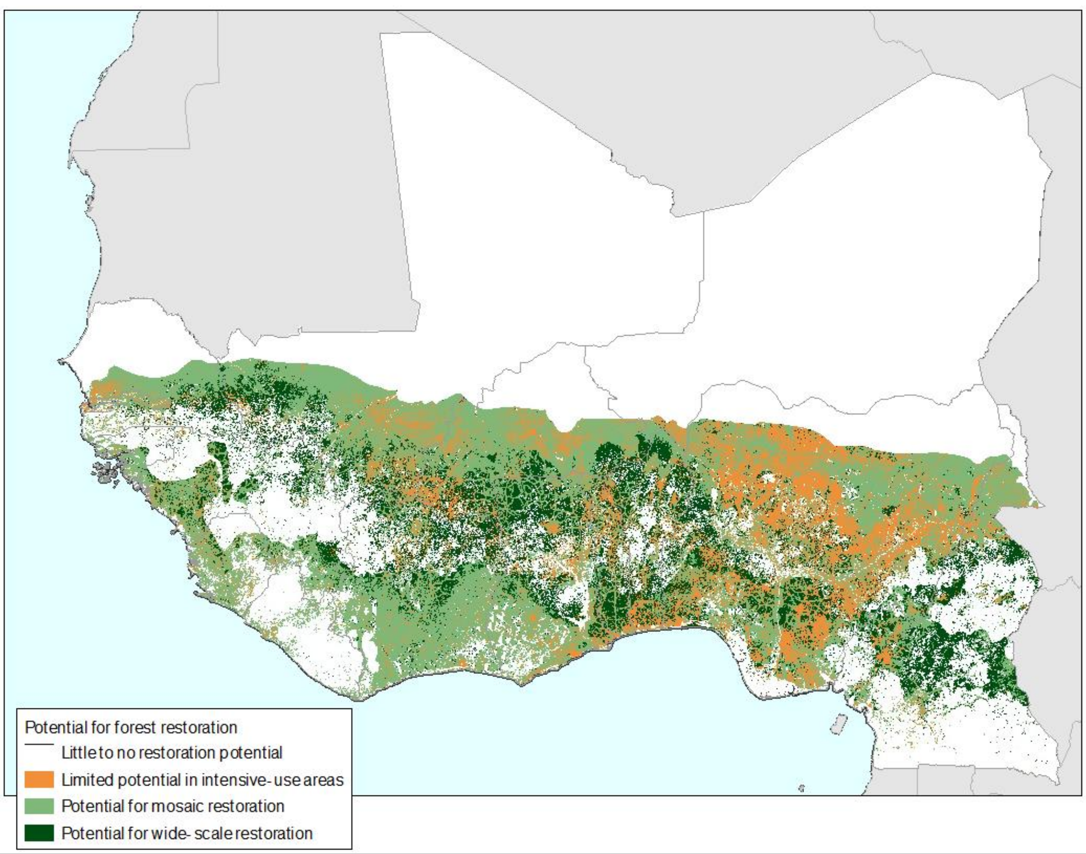

Figure 7: Potential for reforestation by category. Based on Laestadius et al., 2011.

Table 5: Forest restoration potential by country divided into the two categories with higher potential: mosaic and widespread forest restoration.

Country	Mosaic and widespread restoration potential		Mosaic restoration potential		Widespread restoration potential	
	Area (km2)	Percent of area (%)	Area (km2)	Percent of area (%)	Area (km2)	Percent of area (%)
Nigeria	366,062	40%	263,927	29%	102,136	11%
Côte d'Ivoire	206,840	64%	147,067	46%	59,773	19%
Mali	167,726	13%	122,595	10%	45,131	4%
Cameroon	155,006	33%	71,811	15%	83,195	18%
Ghana	145,089	61%	85,384	36%	59,705	25%
Burkina Faso	143,972	53%	109,027	40%	34,945	13%
Guinea	96,799	40%	59,800	24%	36,999	15%
Benin	66,029	57%	22,825	20%	43,204	37%
Senegal	54,945	28%	41,087	21%	13,858	7%
Togo	35,156	62%	14,295	25%	20,861	37%
Sierra Leone	33,175	46%	30,518	42%	2,657	4%
Liberia	12,607	13%	12,391	13%	217	0%
Guinea-Bissau	11,720	35%	10,118	30%	1,602	5%
Gambia	5,546	52%	5,415	51%	131	1%
Niger	5,006	0%	4,601	0%	405	0%

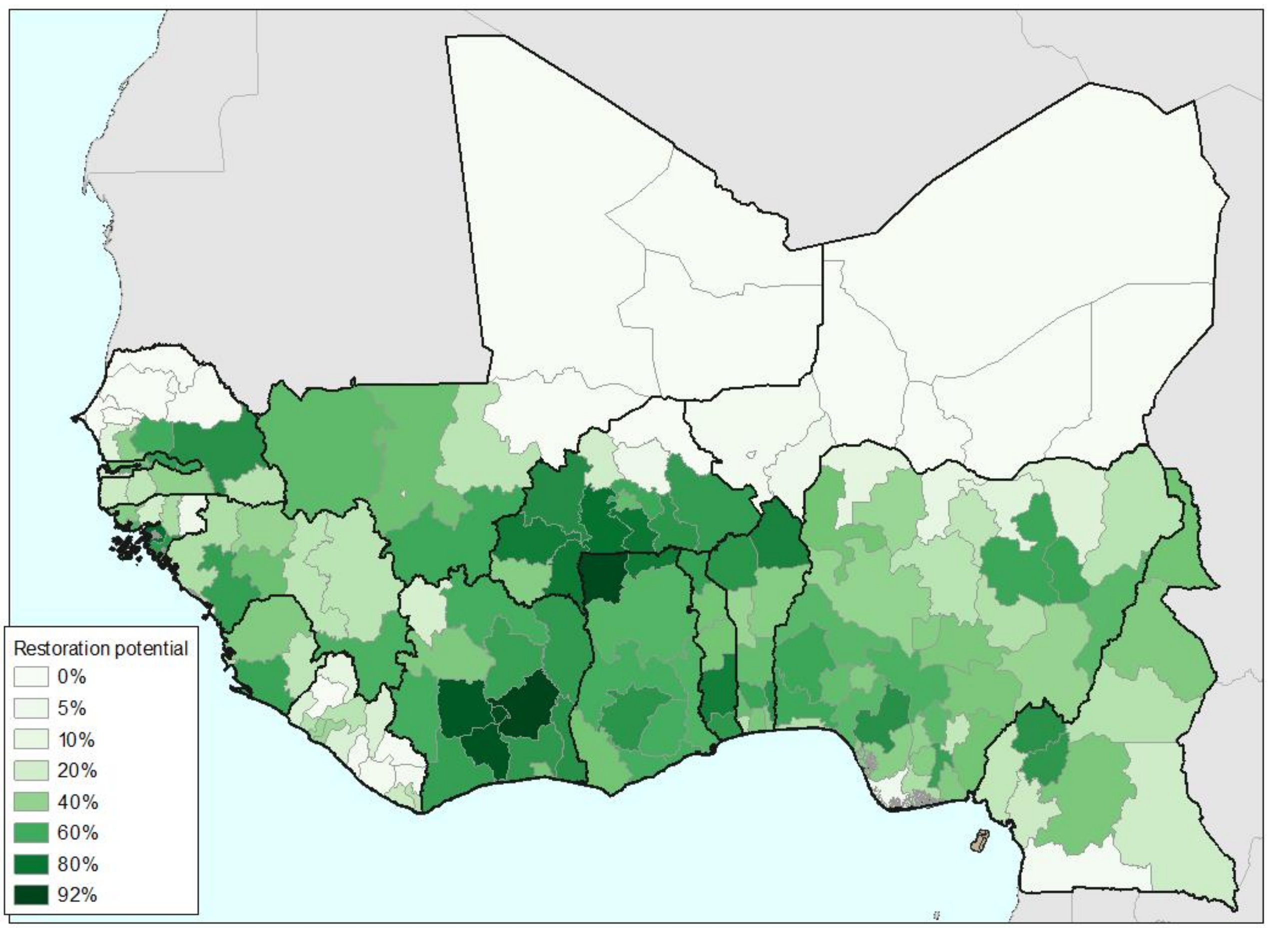

Figure 8: Potential for widespread or mosaic forest restoration (combined) by first administrative division. Data based on Laestadius et al., 2011.

Table 6: Potential for widespread or mosaic forest restoration (combined) by first administrative division. Data based on Laestadius et al., 2011. Top 10 countries administrative areas in each category are included.

Country	First-level administrative division	Total restoration potential (widespread and mosaic)		Mosaic restoration potential		Widespread restoration potential		Total restoration potential: rank by total area	Total restoration potential: rank by percentage of area
		Total area (km2)	Perc. of area (%)	Total area (km2)	Perc. of area (%)	Total area (km2)	Perc. of area (%)		
Mali	Kayes	64,713	53%	38,014	31%	26,699	22%	1	62
Mali	Koulikoro	45,638	50%	41,271	45%	4,367	5%	2	67
Mali	Sikasso	43,389	61%	28,436	40%	14,953	21%	3	42
Ghana	Northern	38,354	55%	12,720	18%	25,634	37%	4	56
Cameroon	Centre	32,128	47%	7,883	11%	24,245	35%	5	78
Nigeria	Bauchi	30,434	62%	28,203	57%	2,231	5%	6	41
Burkina Faso	Est	30,381	65%	21,329	46%	9,052	19%	7	29
Senegal	Tambacounda	30,077	70%	23,130	54%	6,947	16%	8	17
Cameroon	Nord	29,447	44%	13,520	20%	15,927	24%	9	84
Nigeria	Niger	28,608	40%	17,950	25%	10,659	15%	10	96
Côte d'Ivoire	Lacs	24,263	93%	20,317	78%	3,946	15%	13	1
Côte d'Ivoire	Sassandra-Marahoué	21,246	87%	18,618	77%	2,628	11%	18	5
Burkina Faso	Centre-Ouest	17,737	81%	14,641	67%	3,095	14%	29	7
Ghana	Upper West	17,221	91%	7,698	41%	9,523	50%	32	2
Côte d'Ivoire	Gôh-Djiboua	13,923	89%	13,102	83%	822	5%	43	4
Burkina Faso	Sud-Ouest	12,815	78%	5,560	34%	7,255	44%	48	10
Burkina Faso	Centre-Sud	9,152	79%	6,380	55%	2,771	24%	65	8
Ghana	Upper East	6,767	79%	4,359	51%	2,408	28%	75	9
Guinea-Bissau	Quinara	2,427	82%	2,247	76%	180	6%	103	6
Côte d'Ivoire	Yamoussoukro	1,860	91%	1,541	75%	319	16%	116	3

5.0 TREES IN AGRICULTURE

Griscom et al. (2017) defined the area of land that had potential for the trees in agriculture pathway as any land that was (a) covered by crops, and (b) had less than 10% forest cover. The map below combines forest cover (Hansen et al., 2013; updated 2019) for 2000 with crop coverage (Pittman, Hansen, ecker-Reshef, Potapov & Justice, 2010) to indicate where those two conditions overlap. This mapping is consistent with the Griscom et al. (2017; 2020) conclusions that the largest potential for trees in agriculture is in Niger and Nigeria by a wide margin, with Burkina Faso, Mali, and Cameroon following.

Potential for trees in agriculture pathway mapped at 1km resolution. Defined as areas that are primarily covered by cropland and that have tree cover less than 10%.

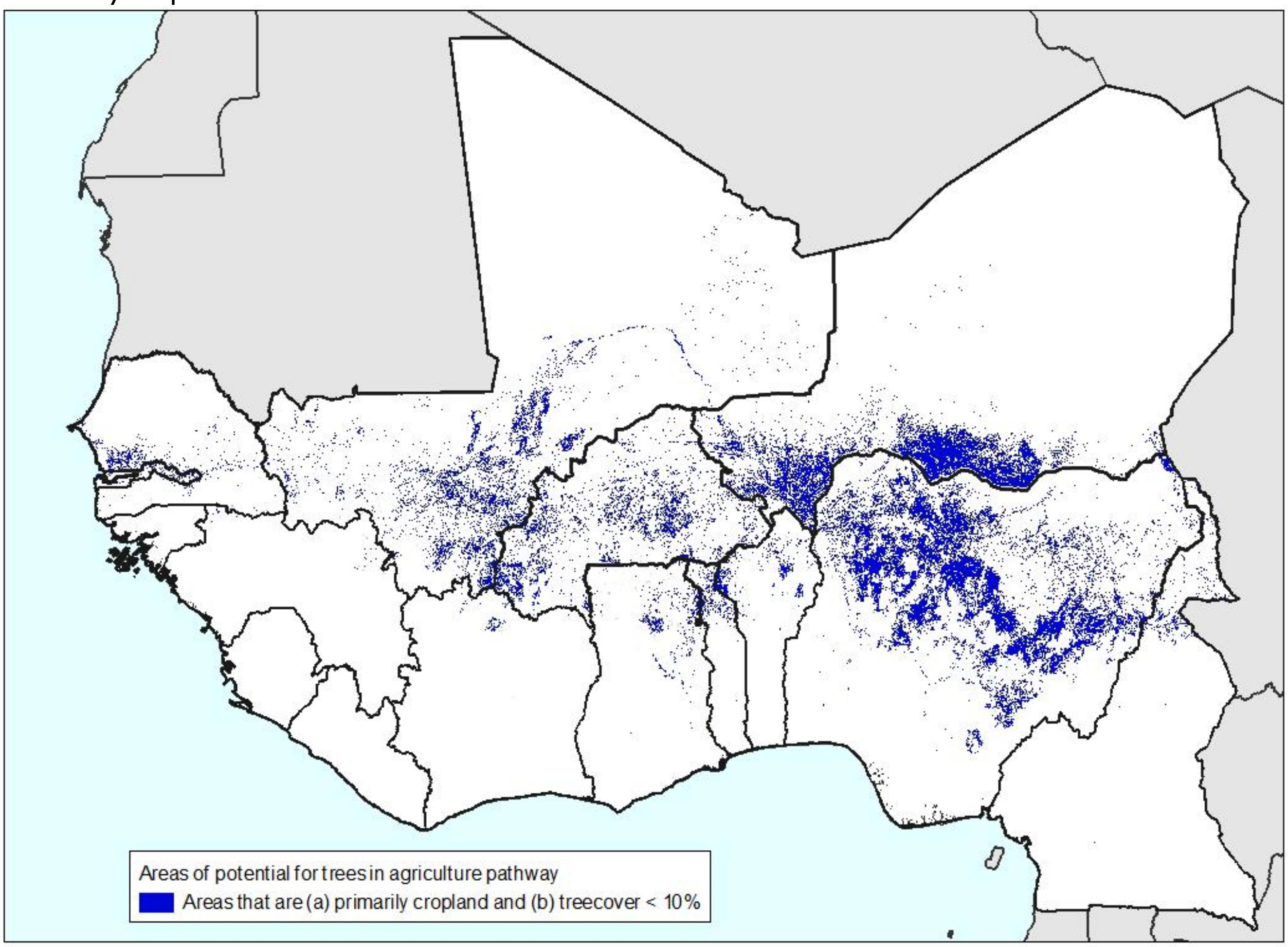

Figure 9: Potential for trees in agriculture pathway mapped at 1km resolution. Defined as areas that are primarily covered by cropland and that have tree cover less than 10%.

6.0 IMPROVED FOREST MANAGEMENT

Spatial data on forestry operations in West Africa is limited; we did not find any data that covered all the countries included in this study. However, Karsenty (2016) compiled data on four of the study countries —Cameroon, Liberia, Ghana, and Côte d'Ivoire—and we present those data below in Table 7. Global Forest Watch also mapped images of concessions, available for online visualization for those same four countries.[2]

Table 7: Forest concessions in four countries in West Africa with percentage of certification indicated where data available. Table from Karsenty (2016).

Country	Concessions		Concessions with a management plan		Certified concessions (FSC or legal timber)		FSC certified	FSC certified as % of all concessions
	Total area (ha)	Avg. area (ha)	Total area (ha)	%	Total area (ha)	%	Area (ha)	%
Cameroon	7,058,958	63,594	5,071,000	72%	3,409,593	48	940,945	13%
Liberia	772,740	77,000	265,000	34%	n.d.	n.d.	0	0
Ghana	3,096,320	50,029	767,000	26%	n.d.	n.d.	0	0
Côte d'Ivoire	700,000	1,840	436,000	62%	n.d.	n.d.	0	0

2 www.globalforestwatch.org

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ANNEX A

Table A1: Description of all 20 mitigation pathways described in Griscom et al. (2017). For pathways where country-level data is not available (Table 1; Figure 1), a description is provided here of available data. Pathways are ranked from largest to smallest in their total estimated potential globally. Green rows represent forest-sector pathways, yellow are agriculture sector, and blue are wetlands and coastal. The right-most column is an indicator of uncertainty in the estimation of each potential – it presents the ratio between the upper and lower bounds of the 95% confidence interval in the estimate.

Pathway	Description and activities included	Country-level estimates available?	Available information for estimating regional or national potential in West Africa	Maximum potential globally (million tons CO_2e/ year)	Uncertainty in global estimate (ratio of upper:lower bounds)
Reforestation	Conversion of land from non-forest (< 25% tree cover) to forest (> 25% tree cover) in areas ecologically appropriate and desirable for forests.	Yes	See Table 1	10,124	6.6
Avoided Forest Conversion	Emissions of CO_2 avoided by avoiding forest conversion. Baseline emissions derived from Tyukavina et al. (2015), which defined "forest" as >25% tree cover.	Yes	See Table 1	3,603	1.4
Natural Forest Management	Additional carbon sequestration (above- and below-ground) in native forests managed non-intensively for wood production. Maximum scenario is defined as the deferral of all harvests for 50 years (meets safeguard by assuming that plantations can cover fiber needs).	Yes	See Table 1	1,470	8.9
Biochar	Carbon sequestration by amending agricultural soils with biochar derived from crop residue.	No	Estimate is 0.66 tons CO_2e sequestered long-term for every dry ton of available crop residue feedstock (Griscom et al., 2017). National or regional estimates for West Africa would require assumptions about available feedstock that are not readily available in the literature. The Griscom global maximum estimate assumes half of global feedstock that is not fed to livestock is used for biochar.	1,102	2.3

Pathway	Description and activities included	Country-level estimates available?	Available information for estimating regional or national potential in West Africa	Maximum potential globally (million tons CO_2e/ year)	Uncertainty in global estimate (ratio of upper:lower bounds)
Trees in Croplands	Carbon sequestration in both above- and below-ground tree biomass and soil carbon, that results from the integration of trees into croplands at levels that do not reduce crop yields. In West Africa, particularly in the Sahel, this pathway will consist largely of farmer-managed natural regeneration (FMNR).	Yes	Africa as a whole is estimated to have 450 million hectares suitable for FMNR (WRI, 2013) with a potential of 1.47 tons CO_2e /ha*year in biomass and soils on those lands (Leudeling & Neufeldt, 2012).	1,040	4.0
Coastal Wetland Restoration	Rewetting of coastal wetlands (mangroves, salt marshes, seagrass beds) to avoid oxidation of soil carbon and to enhance soil carbon sink.	Yes	Carbon burial rates in these ecosystems is very high, but there is limited information on areal extent by country, which makes estimating national potential difficult. Burial rates, in tons CO_2e per hectare per year, are estimated to be 8.0, 8.3, and 5.1 for salt marshes, mangroves, and seagrasses, respectively (McLeod et al. 2011).	841	1.7
Peatland Restoration	Re-wetting of freshwater wetlands (tropical, temperate, and boreal peatlands) to avoid oxidation of soil carbon and to enhance soil carbon sink.	Yes	See Table 1	815	3.5
Avoided Peatland Impacts	Avoided emissions from loss of above- and below-ground biomass as well as from loss of soil carbon that would result from degradation or loss of freshwater wetlands (tropical, temperate, and boreal peatlands).	Yes	See Table 1	754	5.1

Pathway	Description and activities included	Country-level estimates available?	Available information for estimating regional or national potential in West Africa	Maximum potential globally (million tons CO_2e/ year)	Uncertainty in global estimate (ratio of upper:lower bounds)
Cropland Nutrient Management	Avoided N_2O emissions due to reduced fertilizer use and improved application methods.	Yes	At present, average efficiency globally of N-uptake resulting from fertilizer application is about 53%, with that number likely lower in developing countries (Bodirsky et al., 2014). Assumptions are that this efficiency can be increased to 75%, effectively halving N_2O emissions (25% vs. 47%). However, data on fertilizer use at national scales is lacking, making it difficult to estimate the scale of this potential at national scales.	706	2.4
Grazing - Improved Feed	Avoided methane emissions due to reduced enteric fermentation from the use of more energy-dense feed and the associated reduction in total animal numbers needed to supply the same level of meat and milk demand.	No	Cattle production in sub-Saharan Africa has high emissions intensity per unit of production—more than 60 kg CO_2e per kg animal weight—which is more than four times higher than the most efficient systems globally (Gerber et al., 2013). The technical potential for mitigation per unit animal is thus quite high. FAO has national-scale data on livestock production that can be used to estimate potential by country.	680	29.0
Improved Plantations	Additional carbon sequestration achieved by extending harvest rotations to biologically optimal rotation lengths.	No	Griscom et al. (2017) estimate additional 0.47 tons carbon (= 1.72 CO_2e) sequestered per year per hectare by extending rotation lengths. GFRA (2015) estimates 12.8 million ha of planted forests in Africa as a whole, suggesting this intervention has a continent-wide potential of 22 million tons CO_2e per year	443	6.0

Pathway	Description and activities included	Country-level estimates available?	Available information for estimating regional or national potential in West Africa	Maximum potential globally (million tons CO_2e/ year)	Uncertainty in global estimate (ratio of upper:lower bounds)
Conservation Agriculture	Additional soil carbon sequestration by planting cover crops during the part of the year when the main crop is not growing, where appropriate given climate factors and cropping systems.	No	1.36 tons CO_2e/ha*yr estimated by Eagle et al. (2012). No data available at national scale for potential area.	413	1.7
Avoided Woodfuel Harvest	Avoided emissions, all gases, due to reduced harvest of woodfuel used for cooking and heating, without reducing heating or cooking utility.	Yes	See Table 1	367	1.2
Avoided Coastal Wetland Impacts	Avoided emissions from loss of above- and below-ground biomass as well as from loss of soil carbon that would result from degradation or loss of coastal wetlands (mangroves, salt marshes, and seagrass beds).	Yes	Information on mangroves is provided in Table 1. National-scale or regional data is not available on emissions from conversion of salt marshes or seagrass beds. However, conservative global estimates are that 917 and 512 tons of CO_2e per hectare for salt marshes and seagrass beds, respectively, are vulnerable to being emitted on conversion of the land cover (Pendleton et al., 2012).	304	3.3
Improved Rice Cultivation	Avoided CH_4 and N_2O emissions from rice cultivation resulting from periodic draining of rice paddies and from the removal of crop residues from flooded and upland rice production lands.	Yes	See Table 1	265	1.4
Fire Management	Additional sequestration and avoided emissions in above- and below- ground tree biomass due to three forms of additional fire management: (i) prescribed fires, (ii) fire control practices (e.g., fire breaks) applied to edges of forests, and (iii) use of early season fires in savanna ecosystems to avoid higher emissions from late season fires.	Yes	Item (iii) (early-season savanna fires used to avoid larger fires later) is the most relevant for West Africa; however, no regional estimates for the total potential intervention has been found.	212	2.5

Pathway	Description and activities included	Country-level estimates available?	Available information for estimating regional or national potential in West Africa	Maximum potential globally (million tons CO_2e/ year)	Uncertainty in global estimate (ratio of upper:lower bounds)
Grazing - Animal Management	Avoided methane emissions resulting from reduced enteric fermentation as a result of improving livestock breeds and management techniques. Improvements in reproductive performance, animal health, and weight gain lead to a reduction in total number of animals needed to supply the same amount of milk and meat.	No	Cattle production in sub-Saharan Africa has very high emissions intensity per unit of production—more than 60kg CO2e per kg animal weight—which is more than four times higher than the most efficient systems globally (Gerber et al., 2013). The technical potential for mitigation per unit animal is thus quite high. FAO has national-scale data on livestock production that can be used to estimate potential by country.	200	2.9
Grazing - Optimal Intensity	Additional soil carbon sequestration due to grazing optimization on rangeland and planted pasture. Prescribes a decrease in stocking rates in areas that are overgrazed and an increase in stocking rates in areas that are undergrazed.	Yes	See Table 1	148	4.7
Grazing - Legumes in Pastures	Additional soil carbon sequestration due to sowing legumes in planted pastures.	Yes	See Table 1	147	107.1
Avoided Grassland Conversion	Avoided soil carbon emissions by avoiding the conversion of grasslands (including savannas and shrublands) to cropland.	No	Estimated average loss of 68.4 tons CO_2e per hectare (Jobbagy & Jackson, 2000); however, there are no available estimates for the rate of conversion at regional or national scales.	116	5.0

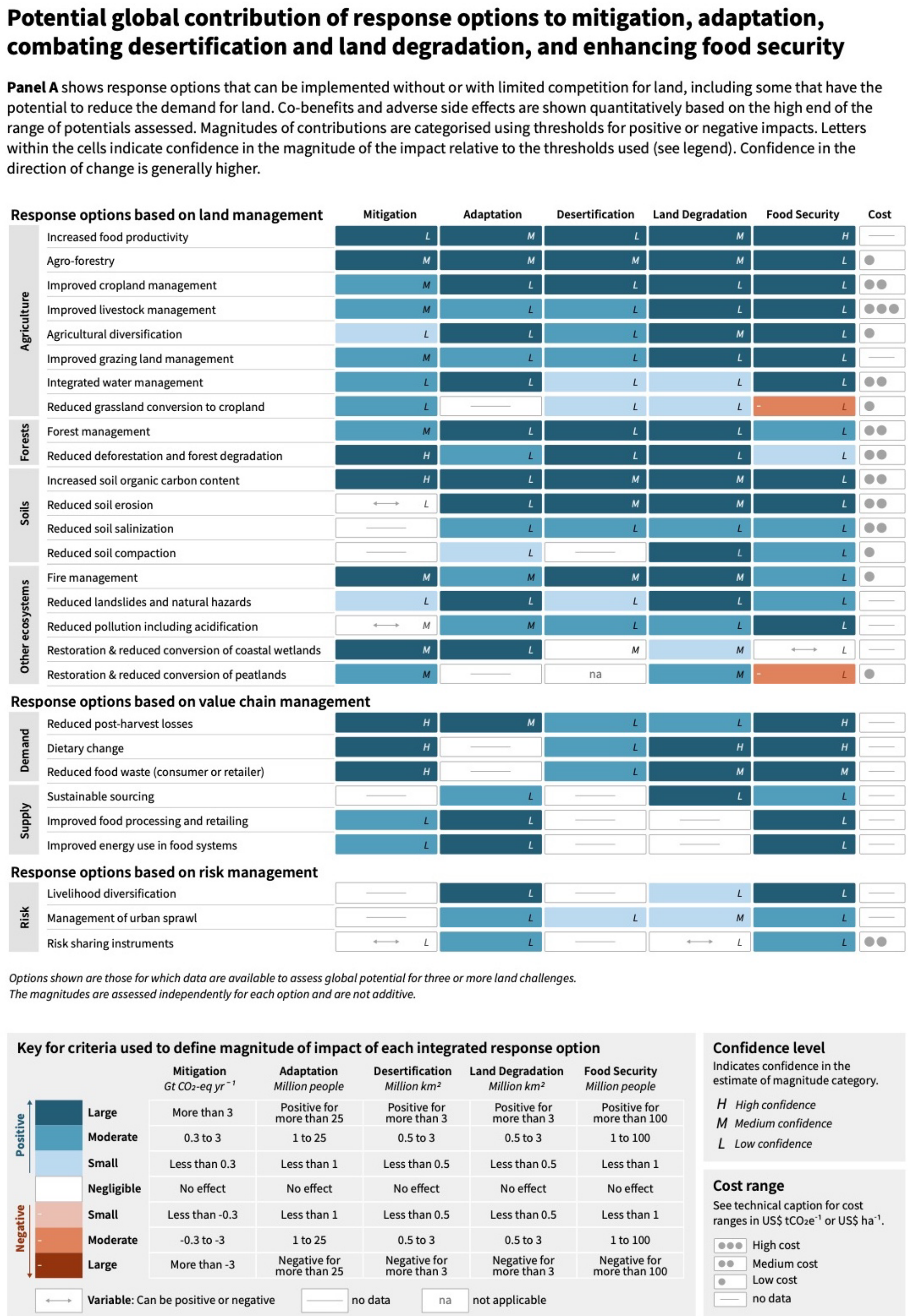
Table A2: Mitigation strategies proposed in Nationally Determined Contributions (NDC) documents (or the INDC in the case of Senegal) for the 15 countries included in the study. Strategies are generally focused on the sectors with the largest potential regionally; i.e., reforestation activities across many countries, and avoided forest conversion and trees in croplands interventions in the countries where those interventions are most important. Activities in the livestock sector are generally underrepresented among these NDC interventions.

Sector	Mitigation pathway	NDC Strategy	INDC
Agriculture and Grasslands	Cropland nutrient management	Organic fertilisation of crop land	Burkina Faso INDC
Agriculture and Grasslands	Trees in croplands	Stone barriers + zai + assisted natural regeneration	Burkina Faso INDC
Agriculture and Grasslands	Trees in croplands	Hedge-rows; access protection; assisted natural regeneration	Burkina Faso INDC
Agriculture and Grasslands	Improved rice cultivation	Promotion of efficiency in rice production, estimated emission reductions are 437.8 GgCO2e in 2020, 707.0 GgCO2e in 2025 and 2030.	Gambia INCD
Agriculture and Grasslands	Improved rice cultivation	Production of NERICA upland production in place of Swamp Rice, estimated emission reductions are 124.1 GgCO2e in 2020, 397.7 GgCO2e in 2025 and 2030.	Gambia INDC
Agriculture and Grasslands	Grazing - animal management	Improved livestock practices (limited details provided)	Niger NDC
Agriculture and Grasslands	Trees in croplands	Planting hedgerows: 145,000 km; planting of multi-use species: 750,000 ha; planting of Moringa oleifera: 125,000 ha; seeding of roadways: 304,500 ha.	Niger NDC
Agriculture and Grasslands	Trees in croplands	Restoration of agricultural, forest and grazing land: 1,030,000 ha;	Niger NDC
Agriculture and Grasslands	Trees in croplands	Agroforestry promotion	Nigeria INDC
Agriculture and Grasslands		Climate-smart agriculture (no specifics)	Nigeria INDC
Agriculture and Grasslands	Improved rice cultivation	Reducing water used in rice irrigation	Senegal INDC
Agriculture and Grasslands	Trees in croplands	Agroforestry promotion	Senegal INDC
Agriculture and Grasslands	Trees in croplands	Climate-smart ag including assistend natural regeneration, agroforestry, and use of organic fertilizers	Senegal INDC
Agriculture and Grasslands	Conservation agriculture	Conditional: Adoption and application of climate-smart and conservation agriculture through best agricultural practices that enhance soil fertility and improve crop yield	Sierra Leone INDC
Agriculture and Grasslands	Grazing - improved feed	Introduction of fodder to improve animal digestion, support in the promotion of local breeds, and extensive livestock farming	Togo INDC
Agriculture and Grasslands	Improved rice cultivation	Identification and promotion of varieties of rain-fed rice, and support and guidance in the better use of organic matter (for faster decomposition) in the paddy fields	Togo INDC
Forests	Avoided woodfuel harvest	Improved household cook stoves	Burkina Faso INDC

Sector	Mitigation pathway	NDC Strategy	INDC
Forests	Reforestation	Reforestation	Burkina Faso INDC
Forests	Avoided Forest Conversion	Forest conservation;	Burkina Faso INDC
Forests	Natural forest management	Development / management of local forests	Burkina Faso INDC
Forests	Avoided Forest Conversion	Land use planning to allow agricultural development while limiting deforestation and degradation	Cameroon INDC
Forests	Avoided Forest Conversion	Agricultural intensification to enable the limitation of deforestation and degradation	Cameroon INDC
Forests	Avoided woodfuel harvest	Bioenergy in rural areas, including reducing unsustainable woodfuel use and use of agricultural wastes	Cameroon INDC
Forests	Reforestation	Continue 10,000ha annual reforestation/afforestation of degraded lands	Ghana INDC
Forests	Reforestation	Double 10,000ha annual reforestation/afforestation of degraded lands translating to 20,000ha on annual basis.	Ghana INDC
Forests	Avoided Forest Conversion	Forest conservation;	Guinea Bissau INDC
Forests	Reforestation	Reforestation	Guinea Bissau INDC
Forests	Avoided woodfuel harvest	Support the dissemination of technologies and practices that are energy- efficient or use alternatives to wood and charcoal. Consequently, Guinea aims between now and 2030 to reduce final demand for firewood and charcoal by 50% per capita (in urban and rural areas) as compared to 2011, particularly through: • organization of local industrial supply chains to enable the introduction of at least 1 million improved stoves; • establishment of 5000 wood carbonization units giving a better charcoal yield; • replacement with butane (40k toe); • extension of pilot initiatives to disseminate improved smokehouses and stabilized earth blocks.	Guinea INDC
Forests	Avoided woodfuel harvest	Replacing cooking stoves with low thermal efficiency (5-10%) with the higher- efficiency (40%) stoves	Liberia
Forests	Avoided Forest Conversion	Management of classified forests and of protected areas	Mali INDC
Forests	Avoided Forest Conversion	Existing projects (national and international; p17 of INDC) targeting land use planning and PA management	Mali INDC
Forests	Avoided woodfuel harvest	Existing projects promoting improved cook stoves	Mali INDC

Sector	Mitigation pathway	NDC Strategy	INDC
Forests	Improved plantations	Improving plantation management	Mali INDC
Forests	Reforestation	Assisted natural regeneration	Mali INDC
Forests	Avoided Forest Conversion	Climate-smart ag to reduce deforestation	Niger NDC
Forests	Avoided woodfuel harvest	Reducing woodfuels to reduce deforestation	Niger NDC
Forests	Improved plantations	Private forestry: 75,000 ha.	Niger NDC
Forests	Natural forest management	Sustainable management of forests in order to reduce GHG emissions due to deforestation.	Niger NDC
Forests	Natural forest management	Management of natural forests: 2,220,000 ha;	Niger NDC
Forests	Reforestation	Assisted natural regeneration: 1,100,000 ha;	Niger NDC
Forests	Reforestation	Dune fixation: 550,000 ha;	Niger NDC
Forests	Avoided woodfuel harvest	Reducing use of wood fuel	Nigeria INDC
Forests	Avoided woodfuel harvest	Unconditional: Development of alternative energy sources such as bio-fuels from sugarcane, corn, rice husk, etc.; Developing agricultural and urban waste incineration programmes for energy production	Sierra Leone INDC
Forests	Avoided Forest Conversion	sustainable forest planning and protection (by managing brush fires, regenerating degraded sites, and demarcating and developing protected areas and tourist sites)	Togo INDC
Forests	Fire management	In respect of the burning of the savannahs, the planned actions target a participatory fight against bush fires	Togo INDC
Forests	Improved plantations	promotion of private, community and State reforestation through the creation of plantations and the promotion of agroforestry on cultivated land	Togo INDC

Figure A1: IPCC SRCCL land management response options (IPCC, 2019).



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