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CAMEROON MANGROVE ECOSYSTEM RESTORATION AND RESILIENCE (CAMERR)

SEA LEVEL RISE ASSESSMENT

MARCH 2025

PLANETE URGENCE
Groupe SOS

silvestrum
CLIMATE ASSOCIATES

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1. Overview

The Cameroon Mangrove Ecosystem Restoration & Resilience (CAMERR) is a mangrove restoration grouped project, of which the first project instance aims to restore 1,055 ha of mangroves in the Douala-Edea municipality in Cameroon's Wouri estuary (Figure 1) under the Verified Carbon Standard (VCS) VM0033 Methodology. This report outlines the procedures followed to assess the impact of sea level rise (SLR) on the CAMERR first project instance, which is split into two strata (Stratum 1: intact mangroves; Stratum 2: degraded mangroves) and three restoration zones: Dibombari, Manoka and Mouanko (Figure 1).

Per Section 5.2.3 of the VM0033 Methodology for Tidal Wetland and Seagrass Restoration v2.1, restoration projects are required to assess the impacts of expected relative SLR on the project area. This includes considering the potential for landward expansion of the project area to account for wetland migration, inundation, and erosion. Projected wetland boundaries must be delineated on maps from the project start date until the end of the project crediting period, at intervals appropriate to the rate of change due to sea level rise, and at a 100-year timeframe. In v2.0, this task was part of accounting for the effects of sea level rise which required the quantification of carbon loss in both the baseline and project scenarios using the previous version of the non-permanence risk tool (NPRT), i.e. without SLR as a risk factor. With the current version of the NPRT (v4.2), this detailed presentation of project boundaries at relatively small intervals is not needed because the risk of reversal due to SLR in the time window relevant for the assessment, i.e., 100 years, is now dealt with in the NPRT. Hence, the methodology application to the project does deviate from the procedures set out in VM0033 v2.1 due to the inconsistency between the procedures in v2.1 and v4.2 of the NPRT. This report describes:

I. The selection of an appropriate elevation range within which mangroves exist in the CAMERR first project instance.
II. The sea level rise assessment, based on the topography of the project area and the local sea level rise scenario, which estimates
    a. The percentage (%) of planted areas that will likely become too deep for mangrove survival due to SLR and hence are submerged/eroded and lost, i.e., the "% Coastal flooding". This percentage is then used in the SLR risk section to assign a score to "Coastal flooding" of the NPRT.
    b. The new inland areas which will likely become intertidal due to SLR, potentially giving rise to gradual colonization by mangroves. This is then used in the ecosystem-based adaptation (EbA) strategy in the NPRT.
    c. The extent of coastal erosion in the project area over a 100 years, if any. This value will then be used in the SLR risk section of the NPRT to assign a score to 'Coastal erosion'.

In addition to the mangrove elevation range, which is a critical factor in understanding the vulnerability of mangroves to flooding caused by SLR, other factors such as the tidal range, coastal erosion and sediment accretion below mangroves are also crucial to assess the full impact of SLR on the project area[1,2]. The balance between SLR and sediment accretion is the controlling factor in determining a mangrove ecosystem's vulnerability under SLR[3]. These parameters were factored into the sea level rise assessment of the CAMERR project.

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[1] Ellison, J. C. (2021). Factors influencing mangrove ecosystems. *Mangroves: Ecology, Biodiversity and Management*, 97-115.

[2] Xie, D., Schwarz, C., Kleinhans, M. G., Zhou, Z., & van Maanen, B. (2022). Implications of coastal conditions and sea-level rise on mangrove vulnerability: a bio-morphodynamic modeling study. *Journal of Geophysical Research: Earth Surface*, *127*(3), e2021JF006301.

[3] Lovelock, C. E., Cahoon, D. R., Friess, D. A., Guntenspergen, G. R., Krauss, K. W., Reef, R., ... & Triet, T. (2015). The vulnerability of Indo-Pacific mangrove forests to sea-level rise. *Nature*, *526*(7574), 559-563.

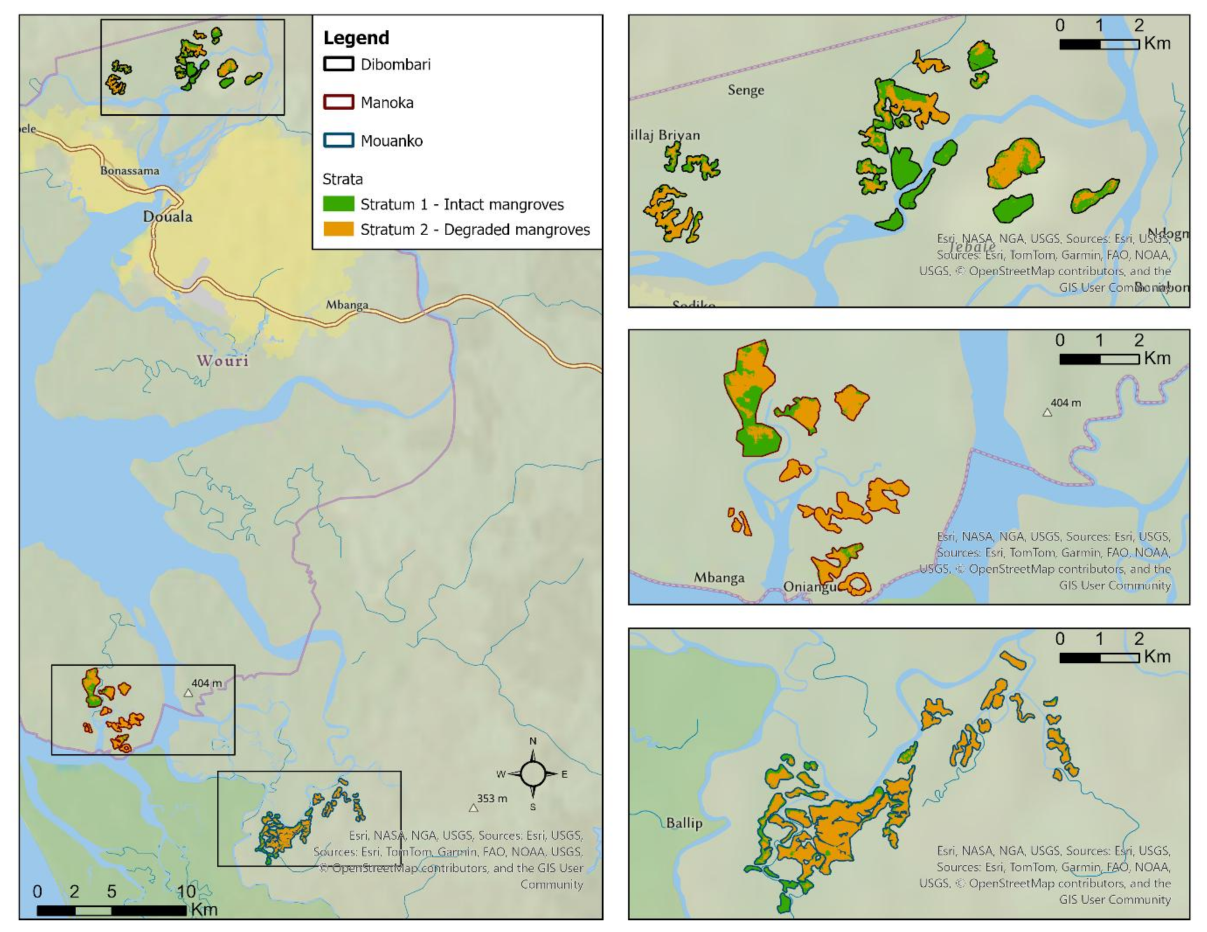

Figure 1. CAMERR First Project Instance. The three project zones were stratified into two strata namely intact and degraded mangroves. The digital version of this map should be consulted for more details.

2. Methods

2.1 Dataset used

2.1.1 DeltaDTM terrain model

To project the extent of coastal flooding due to SLR, a free and publicly available digital terrain model (DTM) called the DeltaDTM[4] was used, with a ground spatial resolution of 30 m and a vertical resolution of 0.00001 m. Although other free DTMs such as the Ensemble DTM (EDTM)[5] and Forests and Buildings Removed Digital Elevation Model (FABDEM)[6] are also available, the DeltaDTM is the first global DTM focusing on the Low Elevation Coastal Zone (LECZ) below 10 m+mean sea level (10m+MSL)[7], which is the area most affected by

[4] Pronk, M., Hooijer, A., Eilander, D., Haag, A., de Jong, T., Vousdoukas, M., M., Vernimmen, R., Ledoux, H., and Eleveld, M. (2024). DeltaDTM: A global coastal digital terrain model. *Scientific Data*, *11*(1), 273.
[5] Ho, Y.-F., Hengl, T., Parente, L., (2023). Ensemble Digital Terrain Model (EDTM) of the world (Version 1.1) [Data set]. Zendo. https://doi.org/10.5281/zenodo.7634679
[6] Hawker, L., Uhe, P., Paulo, L., Sosa, J., Savage, J., Sampson, C., & Neal, J. (2022). A 30 m global map of elevation with forests and buildings removed. *Environmental Research Letters*, *17*(2), 024016.
[7] McGranahan, G., Balk, D., & Anderson, B. (2007). The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and urbanization*, *19*(1), 17-37. https://doi.org/10.1177/0956247807076960.

extreme water levels[8] and storm surges[9]. The DeltaDTM was generated based on a fusion of CopernicusDEM with spaceborne lidar ICESat-2, and Global Ecosystem Dynamics Investigation (GEDI) elevation data. The vertical biases of surface data (e.g., canopy, buildings) present in CopernicusDEM were removed by using ICESat-2 and GEDI terrain elevation measurements. The European Space Agency (ESA) land cover data was also used in their classification algorithm. By using a classification approach here, a vertical mean absolute error (MAE) of 0.45 m was achieved, with more accurate results than regression methods recently used by others to correct DEMs, such as FABDEM that achieved an overall MAE of 0.72 m.

Like any global product, DeltaDTM is not perfect despite its high accuracy compared to other models and may contain errors or unusual data points ("outliers") and unintended features ("artifacts"). For example, the developers of the model acknowledge that because of the high accuracy of DeltaDTM, errors in resolving smaller features stand out for the first time. This means that this high level of precision can detect and represent very small features in the terrain but this also means that any errors in representing these small features become more noticeable. In particular, smaller features like embankments along major highways (which are actual elevated landforms next to highways) that were previously overlooked are now noticeable and mistakenly removed. Whereas previous corrected-DEM tend to overestimate the elevation due to the presence of forests and urban areas (errors of omission), DeltaDTM tends to underestimate the elevation because it mistakenly removes real terrain features such as embankments (errors of commission). Additionally, while better than other DEMs in correcting the bias due to vegetation, the largest errors observed were still in the "Tree Cover" land cover class, which the authors intend to improve in next versions. Despite these discrepancies, the DeltaDTM is the most appropriate and freely available dataset to model flooding due to SLR at this time due to its low error compared to other freely-available DTMs and the fact that it is the only freely-available DTM that has been peer reviewed and published.

2.2 Determination of mangrove elevation capital

Mangrove elevation range, also known as the elevation capital, is a critical factor in assessing the impacts of SLR on mangrove ecosystems. Mangroves typically grow within a specific elevation range relative to mean sea level, which allows them to thrive in intertidal zones where they are exposed to tidal flooding and sediment deposition. This elevation capital may vary by species, sediment supply and tidal range. The elevation capital must be determined in order to utilize the DTM to project how that range will shift with SLR, i.e., which areas will be flooded, and which areas have the potential to become intertidal for future mangrove colonization. That range must be specific to the location and region surrounding the project area.

The analysis to determine the mangrove elevation capital was two-fold:

- Elevations from the DTM were extracted at the GPS point locations where the baseline biomass assessment was carried out.
- A thorough literature review of studies collecting mangrove elevation data in the Wouri estuary.

The mangrove elevation capital was then plotted on a hypsometric curve[10] of the terrain elevations within an analytical domain that constitutes CAMERR's first project instance, and a 500 m buffer zone around the first project instance. This buffer was drawn around the project area to account for upland areas that may become tidal with sea level rise. Briefly, a hypsometric curve shows the proportion of area covered at various elevations for a specified terrain. It is plotted on a graph on which the x-axis represents the surface area

[8] Hooijer, A., & Vernimmen, R. (2021). Global LiDAR land elevation data reveal greatest sea-level rise vulnerability in the tropics. *Nature communications*, *12*(1), 3592.
[9] Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding-a global assessment. *PloS one*, *10*(3), e0118571.
[10] Strahler, A. N. (1952). Hypsometric (area-altitude) analysis of erosional topography. *Geological society of America bulletin*, *63*(11), 1117-1142.

covered and the y-axis represents elevation above sea level. This curve indicates the current elevation capital for mangroves and how that may change with SLR. It was generated for elevations ranging between 0 and 4 m, where elevations above 4 m were deemed too high for mangrove colonization.

2.3 Sea-level rise assessment

2.3.1 Sea level rise scenario

According to VM0033 v2.1, the projection of SLR within the project area can be based on IPCC regional forecasts or peer-reviewed literature applicable to the region. Here, the NASA sea level projection tool[11] is used, which depicts the median projections of global and regional sea level rise, relative to a 1995-2014 baseline as per the IPCC 6th Assessment Report. The sea level rise scenario used for the analysis is the IPCC's SSP5-8.5, which assumes a rise of 1.46 m by 2150 along the coast surrounding the Wouri estuary (Table 1). This scenario represents a worst-case GHG emissions scenario with no additional climate policy. This scenario was chosen for consistency with the scenario used to characterize future climate impacts within the NPRT. The values between each 10-year interval were interpolated to estimate SLR between the project start date in 2022 and 2122. Coastal flooding was assessed at t=40 years (year 2062) and t=100 years (year 2122) for each stratum to determine the extent of flooding within each. However, for the purpose of the NPRT, the total area lost to flooding across both strata at t=100 years were combined to determine the percentage of coastal flooding to be used in the SLR Risk section.

[11] NASA. (2023). Sea Level Projection Tool. Retrieved from https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool.

Table 1. Cumulative decadal sea level rise (SLR) for the Wouri estuary according to IPCC SSP5-8.5 SLR projections. This projection was scaled to calculate the SLR for the year 2122 for the first instance of the CAMERR project.

Year	cumulative SLR (m)	Date range	Average annual rate (m/yr)	Year	SLR (m per 10 years)
2020	0.062			2022	
2030	0.112	2021-2030	0.0054	2032	0.0658
2040	0.168	2031-2040	0.0050	2042	0.08
2050	0.238	2041-2050	0.0060	2052	0.0846
2060	0.302	2051-2060	0.0060	2062	0.1002
2070	0.378	2061-2070	0.0080	2072	0.1104
2080	0.454	2071-2080	0.0080	2082	0.128
2090	0.53	2081-2090	0.0080	2092	0.1432
2100	0.61	2091-2100	0.0090	2102	0.114
2110	0.692	2101-2110	0.0080	2112	0.1284
2120	0.774	2111-2120	0.0080	2122	0.13
2130	0.854	2121-2130	0.0080		
2140	0.933	2131-2140	0.0080		
2150	1.01	2141-2150	0.0080		
				Total	1.08 m

2.3.2 Sediment accretion rate

When submerged by tides, mangrove trees dissipate wave energy and reduce tidal currents[12]. This results in reduced hydrodynamic forces within the forest which facilitates the settling of suspended sediments. The complex root structures of mangroves trap those sediments, thereby increasing the sediment bed elevation in a process called sediment accretion. Sediment accretion plays a vital role in the stability and resilience of mangrove ecosystems with rising sea levels, often counterbalancing it[13].

The potential for tidal wetlands like mangroves to rise vertically is sensitive to sediment loads in the system. According to Section 5.2.3 in VM0033 v2.1, a sediment load of >300 mg/l has been found to balance high end IPCC scenarios for sea level rise[14]. Therefore, for marshes with a tidal range greater than 1 m, the project proponent may use >300 mg/l as a sediment load threshold above which wetlands are predicted to not be submerged.

To determine the sediment accretion rate and the sediment load in the project area, a literature review was conducted (see Section 3.2). Determining both the rate of sediment accretion and the sediment load in the

[12] Temmerman, S., Meire, P., Bouma, T. J., Herman, P. M., Ysebaert, T., & De Vriend, H. J. (2013). Ecosystem-based coastal defense in the face of global change. *Nature*, *504*(7478), 79-83.
[13] Krauss, K. W., McKee, K. L., Lovelock, C. E., Cahoon, D. R., Saintilan, N., Reef, R., & Chen, L. (2014). How mangrove forests adjust to rising sea level. *New phytologist*, *202*(1), 19-34.
[14] Orr, M., Crooks, S., & Williams, P. B. (2003). Will restored tidal marshes be sustainable?. *San Francisco Estuary and Watershed Science*, *1*(1).

CAMERR project area is important to determine how well the project area will adapt to sea level rise, which is part of the non-permanence risk assessment for carbon projects registered under the VCS.

2.3.3 Coastal erosion

Several studies carried out in the Wouri estuary have shown that the rate of coastal erosion varies across the estuary, highlighting the complex interplay of factors affecting coastal dynamics in the region. The downstream section of the estuary appears more prone to erosion with rates up to -5.8 m yr^{-1} of lateral retreat, while the upstream section of the estuary, where Dibombari is located, has been shown to experience lateral accretion between the year 1996 and 2012[15]. Around Manoka Island, where part of the project area is located, a coastal erosion rate of -2 m yr^{-1} was reported between 1996 and 2012, while a rate of -1.74 m yr^{-1} was reported between 2000 and 2016. A more recent study by Fongnzossie et al.[16] found that during the period of 2000–2017, the southern part of Manoka Island was being eroded while the northern part was subject to horizontal accretion. The locality of Mbenadikoumé, where the project planting polygons are located for Manoka, shows a retreat of about -5.1 m yr^{-1}, while other surrounding localities such as Youmé 1 and Epaka 1 showed erosion rates of-4.2 m yr^{-1} and -2.3 m yr^{-1} respectively. An analysis of coastal erosion across six different zones in the Wouri estuary showed a coastal erosion rate of-2.63 m on Manoka Island[17], located in Zone 5, between 2016 and 2024 (Figure 2).

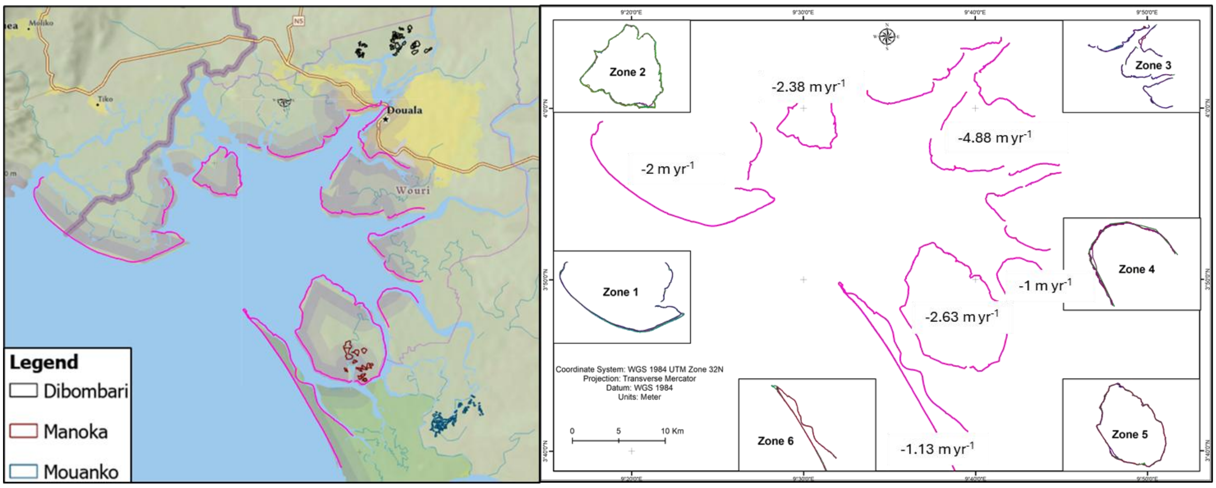

Figure 2. Coastal erosion rates for the period spanning 2016-2024 in six different zones in the Wouri estuary reproduced from Fendoung and Hubbert-Ferrari (2024).

To be conservative, the highest coastal erosion rate of approximately 5 m yr^{-1} reported in the project area, totaling a 500 m erosion of the coast by t=100 years, was used to evaluate the impact of coastal erosion on the project area. The position of the coastline surrounding the Wouri estuary in 2022[18] was used as the starting boundary to assess erosion on the project area by the year 2122, 100 years from the project start date. Given that the project area within Manoka and Mouanko is located at approximately 6 km from the

[15] Fossi Fotsi, Y., Pouvreau, N., Brenon, I., Onguene, R., & Etame, J. (2019). Temporal (1948–2012) and dynamic evolution of the Wouri estuary coastline within the Gulf of Guinea. *Journal of Marine Science and Engineering*, *7*(10), 343.

[16] Fongnzossie, E., Sonwa, D. J., Mbevo, P., Kentatchime, F., Mokam, A., Tatuebu Tagne, C., & Rim, L. F. E. A. (2022). Climate Change Vulnerability Assessment in Mangrove-Dependent Communities of Manoka Island, Littoral Region of Cameroon. *The Scientific World Journal*, *2022*(1), 7546519.

[17] Fendoung, M., & Hubert-Ferrari, A. (2024). Hydrogeomorphological dynamics and erosion of the soft coasts in tropical Africa, the case study of the Wouri estuary, Cameroon.

[18] Digital Earth Africa, (2025). Coastlines annual shoreline dataset. Accessed on 14 February 2025. Processed using ArcGIS Pro v3.2.4. Retrieved from: https://docs.digitalearthafrica.org/en/latest/data_specs/Coastlines_specs.html.

coastline position in 2022, a coastal erosion of 500 m by 2122 is not projected to impact the project area. However, a sensitivity analysis using buffer distances of 500, 1,000 and 1,500 m from the coastline position was performed in ArcGIS Pro v3.4.2[19] to determine how much erosion it would take for the project area to be impacted.

3. Results

3.1 Mangrove elevation capital

Table 2. Minimum and maximum terrain elevation extracted from the DeltaDTM in the CAMERR project area.

	Stratum 1		**Stratum 2**	
	Min (m)	Max (m)	Min (m)	Max (m)
Field GPS data points in the CAMERR project area	0.381	2.559	-0.219	1.572
Median values across the stratum polygons of the CAMERR project area	-0.205	5.819	-0.272	3.536

The values extracted from the GPS point locations showed that elevation ranged between 0.381 and 2.559 in stratum 1 and between-0.219 and 1.572 m in stratum 2 (Table 2). Across the strata polygon, median elevation ranged between -0.205 and 5.819 m in stratum 1 and between -0.272 and 3.536 m in stratum 2. A study carried out by Ellison and Zouh (2012) in the Wouri estuary measured the elevation range for several mangrove species present in the Douala-Edea mangrove ecosystem. Mangroves were found to occur at elevations ranging between 0.068 m and 0.752 m (Figure 3). The reason for the disparity that exists between the elevation values extracted from the DeltaDTM at given GPS locations and the elevation range measured on the ground by Ellison and Zouh (2012) is not clear. It is possible that the mangrove elevation capital is greater than reported by Ellison and Zouh (2012). However, given that the elevation values measured by Ellison and Zouh (2012) were peer reviewed and published in the project area, these two elevation values were used as the mangrove lower and upper limit for the purpose of the sea level rise assessment.

To understand whether the elevation capital has a meaning, it is also important to understand what the tidal range is within the project area. Ellison and Zouh (2012)[20] reported that the tidal range within the Wouri estuary is approximately 1.2 m. A more recent study by Tchindjang et al. (2025)[21] reported a mean tidal range of 1-2 m in the Douala region. Astronomical tidal range in the Wouri estuary was reported to range between 1.6 and 2 m[22]. According to these datasets, the average tidal range in the Wouri estuary appears to be 1.56 m. Given that mangroves are usually found in the upper half of the tidal range[23], the mangrove elevation range of approximately 0.69 cm reported by Ellison and Zouh (2012) matches with the average tidal range reported in the area (half of the average tidal range of 1.56 m = 0.78 cm). The average tidal range reported

[19] ESRI (2025). ArcGIS Pro: Release 3.4.2. Redlands, CA: Environmental Systems Research Institute.
[20] Ellison, J. C., & Zouh, I. (2012). Vulnerability to climate change of mangroves: assessment from Cameroon, Central Africa. *Biology*, *1*(3), 617-638.
[21] Tchindjang, M., Fendoung, P. M., & Kamgho, C. (2025). Coastal Hazard and Vulnerability Assessment in Cameroon. *Journal of Marine Science and Engineering*, *13*(1), 65.
[22] Fotsi, Y. F., Brenon, I., Pouvreau, N., Ferret, Y., Latapy, A., Onguene, R., ... & Etame, J. (2023). Exploring tidal dynamics in the Wouri estuary, Cameroon. *Continental Shelf Research*, *259*, 104982.
[23] Lewis, R. R., & Brown, B. (2014). Ecological mangrove rehabilitation–a field manual for practitioners. *Mangrove Action Project, Canadian International Development Agency, and OXFAM.*

in the Wouri estuary is categorized as microtidal and it has been suggested that SLR is predicted to cause a greater relocation of intertidal habitats in microtidal areas relative to macrotidal areas due to their vulnerability[24].

The elevation range extracted was then plotted on a hypsometric curve of the terrain elevations within the project area (Figure 4). This curve indicates the current elevation capital for mangroves and how that may change with SLR. The highest percentage of area covered by the CAMERR project area at each terrain elevation range (every 10 cm) was found to be between 1.4 and 1.5 m. From the hypsometric curve, it is possible that the upper mangrove limit may be higher than the elevation of 0.752 m reported in the literature. However, the value reported in the literature was measured on the ground and can be justified, which is the reason we chose 0.752 as the higher end of the elevation capital. Unless there are significant infrastructural barriers at the back end of the current tidal zone, the hypsometric curve shows that sufficient space appears to be available at higher elevations that could become available for mangroves to migrate landward.

Table 5. Relative elevation of mangrove substrate surface of the Doula-Edea mangrove area.

Station	Location	GPS Position	Mangrove zone	Elevation (cm)
0	Reference station Jonathan Creek	03° 48' 01.9" N 09° 34' 04.4" E	Seaward of mangroves	0
1	Kwelekwele Island	03° 48' 17.6" N 09° 35' 24.0" E	*Rhizophora racemosa*	6.8
2	Moukouke Island core site	03° 45' 54.9" N 09° 35' 40.4" E	*Rhizophora*	47.0
3	Seaward edge	03° 45' 27.5" N 09° 35' 37.6" E	*Rhizophora* and *Avicennia*	44.4
4	Seaward edge	03° 45' 35.1" N 09° 37' 09.0" E	*Avicennia*	21.3
5	Mid swamp	03° 44' 31.9" N 09° 37' 52.6" E	*R. mangle*	75.4
6	Mid swamp-Nkamba	03° 44' 46.7" N 09° 40' 41.42" E	*R. racemosa*	54.1
7	Landward edge	03° 43' 58.6" N 09° 44' 02.2" E	*Laguncularia* with some *Raphia* palms	73.1
8	Landward edge	03° 43' 05.6" N 09° 45' 09.0" E	Freshwater swamp	75.2

Figure 3. Elevation range for mangrove species present in the Douala-Edea mangrove ecosystem as measured by Ellison and Zouh (2012). A seaward mangrove limit of 0.068 m and landward mangrove limit of 0.752 m were used for the sea-level rise assessment.

[24] Ellison, J. C. (2015). Vulnerability assessment of mangroves to climate change and sea-level rise impacts. *Wetlands Ecology and Management*, *23*, 115-137.

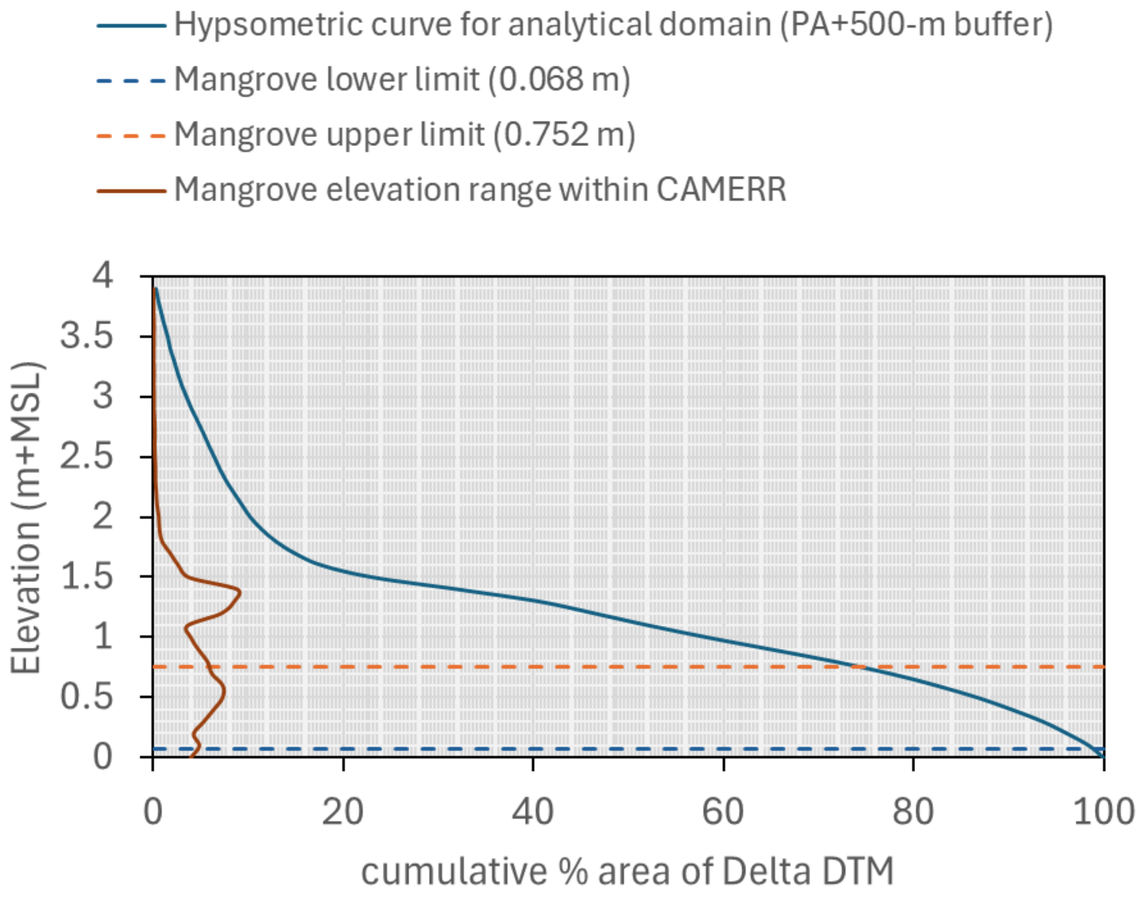

Figure 4. The mangrove elevation capital for the mangroves in the CAMERR project area plotted on a hypsometric curve of the project area.

3.2 Coastal flooding due to sea-level rise

In the Wouri estuary, Ellison and Zouh (2012) have reported an average long-term sediment accretion rate of 2.5 mm year^{-1} around Manoka Island, which is within the project area. This net sediment accretion rate was based on radiocarbon dating of cores which represent the average over a 520-year record and does not include variation within different time periods. Such an approach using radiocarbon dating of cores may underestimate the ability of a mangrove system to build vertically, but provide a conservative estimate compared to modern measurements of surface elevation change using surface elevation tables which may overestimate sediment accretion rates due to the short-term record[25]. Fotsi et al. (2022)[26] have indicated that sediment loads in the central part of the Wouri estuary can reach an average of 800 mg/L. However, their study did not include data specific to the project area. While it is plausible that other regions surrounding the central Wouri estuary might also exhibit high sediment loads, this data is currently unavailable. Consequently, we could not apply the >300 mg/L sediment load to support the assertion that the mangrove areas in the project region would be able to keep pace with sea level rise (SLR). Therefore, we utilized a conservative sediment accretion rate of 2.5 mm/year. This accretion rate was incorporated into the SLR assessment (resulting in a vertical accretion of 25 cm over 100 years considered against an SLR of 1.08 m at t=100, i.e., 1.08-0.25 = 0.83 m) to evaluate the extent of coastal flooding in each stratum. To determine flooding in the

[25] McKee, K. L., Cahoon, D. R., & Feller, I. C. (2007). Caribbean mangroves adjust to rising sea level through biotic controls on change in soil elevation. *Global Ecology and Biogeography*, *16*(5), 545-556.
[26] FOTSI, Y. F., BRENON, I., ONGUENE, R., POUVREAU, N., & ETAME, J. (2022). Contribution de la modélisation numérique à l'étude de la dynamique hydro-sédimentaire dans l'estuaire du Wouri.

project area, we examined all pixels of the project area that would be submerged by 2122, specifically all elevation pixels below the mangrove lower limit at t=100 years.

3.2.1 Stratum 1

The assessment of the areas lost due to flooding from SLR in Stratum 1 is presented in Table 3. The current DeltaDTM remained static and applying the SLR scenario for t=40 years shows an area loss of 9 ha at the end between t=0 and t=40 (between a minimum elevation of 0.068 m at t=0 and 0.299 at t=40). Between t=40 and t=100 years, 110 ha are predicted to be lost due to flooding from SLR. Thus, a total of 119 ha is predicted to be lost by the year 2122 in Stratum 1. Manoka is projected to experience most of the area lost in stratum 1 due to SLR by 2122 (Figure 5).

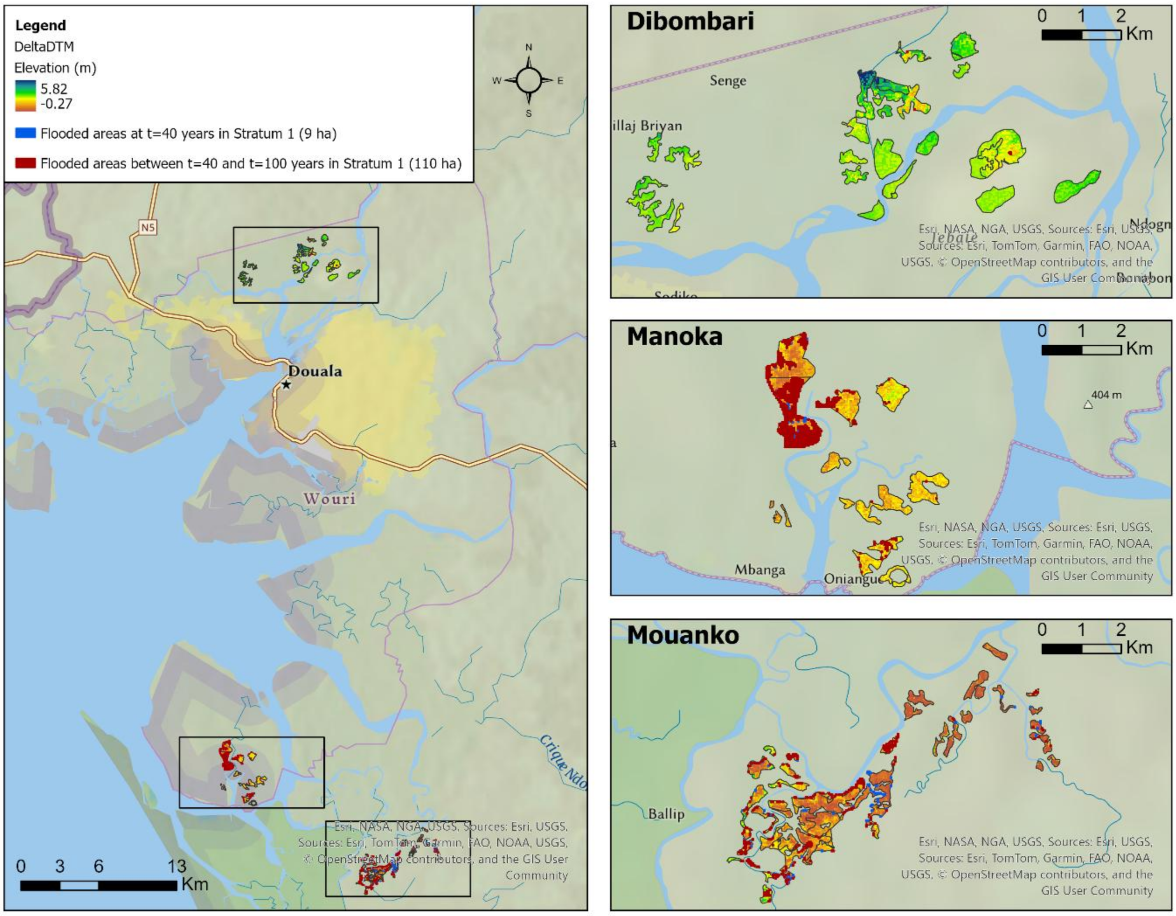

Figure 5. Predicted submerged areas in Stratum 1 of the CAMERR project due to projected sea-level rise at the end of the crediting period of 40 years and in a 100 years. The digital version of this map should be consulted for more details.

Table 3. Coastal flooding due to SLR for t=40 years and t=100 years in Stratum 1.

Year	Year t	cumulative SLR SSP5-8.5 (m)	Lower end for mangrove growth (m)	Area loss in stratum 1 (ha)	ARR area (ha)	% flooding
2022	0		0.068			
2062	40	0.23	0.299	9	372	2%
2122	100	0.83	0.903	110		30%
				Total % flooding for stratum 1		**32%**

3.2.2 Stratum 2

The assessment of the areas lost due to flooding from SLR in Stratum 2 is presented in Table 4. The current DeltaDTM remained static and applying the SLR scenario for t=40 shows an area loss of 95 ha between t=0 and t=40 (between a minimum elevation of 0.068 m at t=0 and 0.299 at t=40). Between t=40 and t=100 years, 269 ha are predicted to be lost due to flooding from SLR. Thus, a total of 364 ha is predicted to be lost by the year 2122 in Stratum 2. Manoka and Mounako are projected to experience the majority of area lost in stratum 2 due to SLR by 2122 (Figure 6).

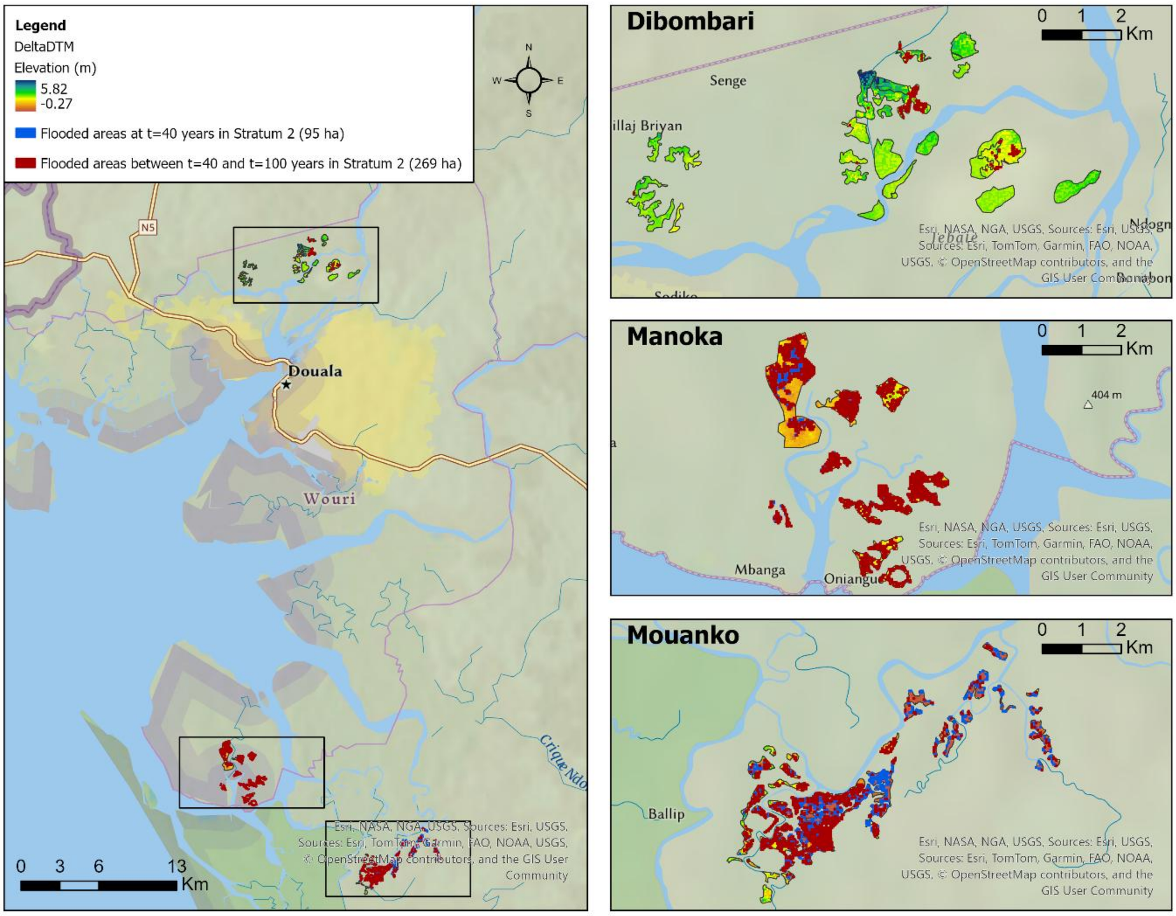

Figure 6. Predicted submerged areas in Stratum 2 of the CAMERR project due to projected sea-level rise at the end of the crediting period of 40 years and in a 100 years. The digital version of this map should be consulted for more details.

Table 4. Coastal flooding assessment due to SLR for t=40 years and t=100 years in Stratum 2.

Year	Year t	cumulative SLR SSP5-8.5 (m)	Lower end for mangrove growth (m)	Area loss (ha)	ARR area (ha)	% flooding
2022	0		0.068		683	
2062	40	0.23	0.299	95		14%
2122	100	0.83	0.903	269		39%
				Total % flooding for stratum 2		**53%**

3.2.3 Across the CAMERR project area

The assessment of coastal flooding due to SLR within both strata in the CAMERR project area showed that with a vertical accretion of 25 cm over 100 years factored into a SLR of 1.08 m at t=100, i.e., 1.08-0.25 = 0.83 m, a total of 483 ha would be lost by the year 2122, 100 years from the project start date (Table 5). This equates to a coastal flooding extent of 46%. Within the NPRT, this percentage of coastal flooding falls within the category of 'Medium flooding' where a value of 2 is used to calculate the SLR risk (Table 6).

Table 5. Coastal flooding assessment within strata 1 and 2 of the CAMERR project area.

Stratum	Area loss (ha)	ARR area (ha)	% flooding	NPRT Coastal Flooding score
1	119	372	46%	2
2	364	683		
Total	**483**	**1055**		

Table 6. Category of coastal flooding as assessed in the sea-level rise risk portion of the AFOLU non-permanence risk assessment tool.

Category level	Description	Value
Without flooding	Flooding is not present due to the geomorphological features or other characteristics that prevent it; therefore, it does not affect the capture, storage, and conservation of carbon in the area	0
Low flooding	Floods due to SLR in less than 10% of the area, with low impact on the capture, storage, and conservation of carbon	1
Medium flooding	Floods in between 10% and 50% of the area affect the capture, storage, and conservation of carbon	2
High flooding	More than 50% of the area presents flooding due to increased water levels, causing serious inconvenience in the storage, capture, and conservation of carbon contents	3

3.2.4 Potential areas available for landward migration of mangroves

As mentioned in Section 2.2, a 500 m buffer zone was drawn around CAMERR's first project instance to account for upland areas that may become intertidal with sea level rise. With a mangrove upper limit of 0.752 m in 2022, an increase in SLR by 0.23 m by 2062 (t=40 years) would result in 732 ha of new mangrove areas in the 500-m buffer zone surrounding the project area. Between the years 2062 and 2122, a total of 2,000 ha of elevation pixels in the 500-m buffer zone is projected to become intertidal. Overall, approximately 2,732 ha of upland areas have the potential to become intertidal with SLR, making them suitable for mangrove colonization (Figure 7). These areas can be used as an ecosystem-based adaptation strategy in the NPRT to mitigate the risk of SLR on the project area.

Table 7. Areas that may become intertidal with sea level rise at t=40 years and t=100 years.

Year	Year t	cumulative SLR SSP5-8.5 (m)	Upper end for mangrove growth (m)	Area gained (ha)
2022	0		0.752	

2062	40	0.23	0.983	732
2122	100	0.83	1.587	2,000
			Total area gained (ha)	**2,732**

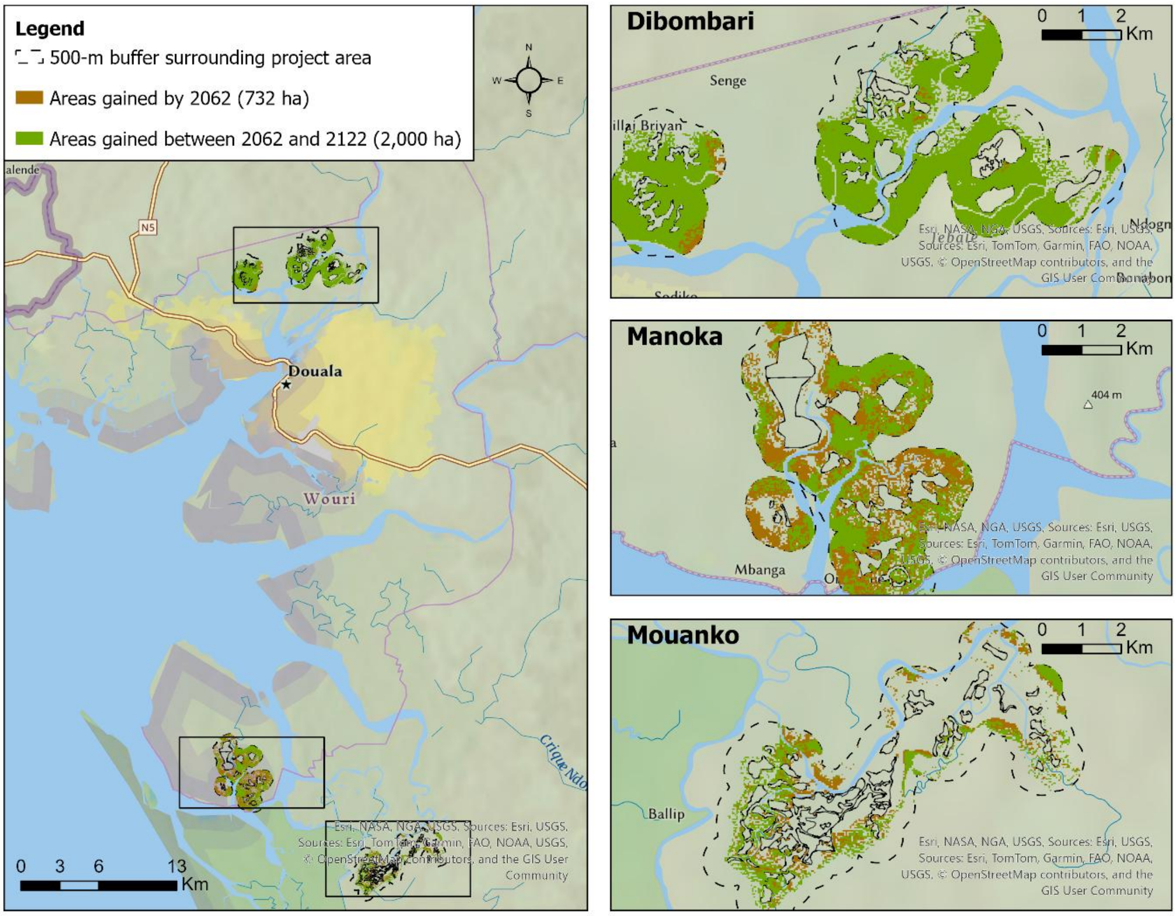

Figure 7. Maps of areas predicted to become intertidal and suitable for mangrove colonization by 2062 (t=40 years) and 2122 (t=100 years) with sea-level rise within a 500-m analytical buffer surrounding the project area.

3.3 Coastal erosion

An average coastal erosion rate of 5 m yr^{-1} was found to occur in the project area in previous studies. A sensitivity analysis to test how the project area will be impacted by coastal erosion showed that a 500 m erosion by t=100 years would not affect the project area. A 1,000 m coastal erosion by t=100 years would also not impact the project area. A 1500 m erosion by t=100 years is projected to result in the loss of only 4 ha of the project area located on Manoka Island (Figure 8). Overall, this sensitivity analysis suggests that coastal erosion would not have an impact on the project area during the 100-year permanence period. According to the guidance on SLR risk assessment in the NPRT[27], if a project area is far enough from the coastline and channel edges that erosion is not anticipated to reach it during the 100-year permanence period, the coastal erosion value should be set to equal 0. Therefore, although the average coastal erosion rate of 5 m yr^{-1} would be considered 'High erosion' under the current NPRT criteria for coastal erosion (Table

[27] This guidance was drafted by Silvestrum Climate Associates and has been reviewed by Verra. It is currently in the approval process and has not been published by Verra yet. However, a copy of the guidance is provided to Planete Urgence for reference purposes.

7), the project area is located far enough from the coastline that it would not be affected by erosion. Hence, a value of 0 was used in the NPRT for coastal erosion.

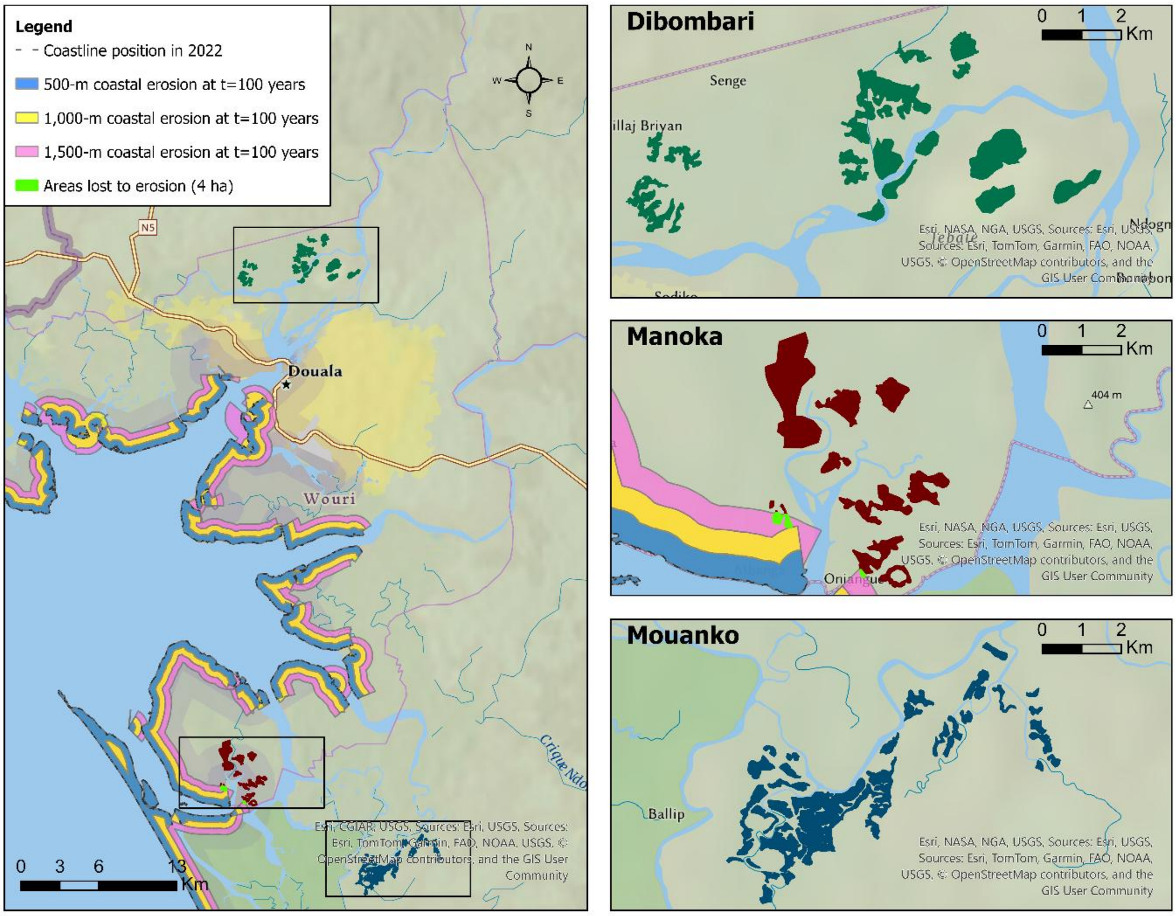

Figure 8. Sensitivity analysis of coastal erosion in the CAMERR project area using 500, 1,000 and 1,500-m buffers. The analysis showed that only a coastal erosion of 1,500 m is projected to affect the project area and result in 4 ha of mangrove loss on Manoka Island. The project area located in Dibombari and Mouanko would not be impacted by coastal erosion. The digital version of this map should be consulted for more details.

Table 8. Category of coastal erosion as assessed in the sea-level rise risk portion of the AFOLU non-permanence risk assessment tool.

Category level	Description	Value
No erosion	No coastal erosion, no loss of coastal ecosystems and/or elements of interest for AFOLU activities, and no impact on the capture, storage, and conservation of CO_2	0
Low erosion	The retreat of the coastline of less than 1 m yr^{-1} with little or no impact on AFOLU activities and/or ecosystems present in the area	1
Medium erosion	The retreat of the coastline of between 1 m to 3 m yr^{-1} with an impact on AFOLU activities and/or ecosystems present in the area	2
High erosion	Retreat of the coastline of over 3 m yr^{-1} affecting important AFOLU activities and/or ecosystems present in the area, and impacting the capture, storage, and conservation of CO_2	3

3.4 Total risk associated with SLR in the NPRT

The SLR assessment conducted for the CAMERR project area revealed a score of 2 associated with coastal flooding while a coastal erosion of 0 was assigned to the project due to no impact from erosion. According to the guidance on SLR risk assessment in the NPRT[28], the Ecosystem Degradation category evaluates how the level of degradation of the tidal wetland ecosystem will affect its resilience to SLR. For a value to be assigned for this criterion, coastal flooding and erosion need to be assessed first, both of which contribute to the degradation of an ecosystem. Hence, the level of degradation to be chosen, as defined in the NPRT, is dependent on the value assessed for coastal flooding and erosion. For tidal wetland projects such as the CAMERR project, the value chosen for ecosystem degradation should be equal to the higher value of either coastal flooding or coastal erosion. In this case, given a value of 2 was determined for coastal flooding, and a value of 0 was determined for coastal erosion, then the value for ecosystem degradation must be set to equal 2 (Table 9).

Regarding the Degree of Salinization, by definition, tidal wetland ecosystems are regularly inundated and exposed to high-salinity ocean tides, leading to salinization. Tidal wetland ecosystems experience varying levels of salinity, based on their proximity to the ocean, freshwater inflows, tidal patterns, and climate conditions. As such, salinization happens naturally in tidal wetland ecosystems due to constant flooding from tides, which means that rising sea levels would not lessen salinity levels in the project scenario. This factor is not well thought through in the NPRT and lacks clarity because the rating of 0-3 is not sensible. To adequately account for salinization in the NPRT, as per the guidance document, the value for this criterion must be set to equal 3 for projects taking place in tidal wetlands like the CAMERR project (Table 9). The value of 3 does not relate to the impact of SLR-induced salinization on tidal wetlands, but instead appropriately adjusts the risk score in the tool for projects with high rates of coastal flooding and/or erosion.

Table 9. Total risk associated with sea level rise in the AFOLU non-permanence risk assessment tool.

Overall SLR Impact level	Significance				SLR Risk	Adaptation Score	Sub-total Risk
	Category	Score		Level			
4.50	Ecosystem degradation	2	**Medium degradation**	**Major**	20	0.25	**5**
	Coastal flooding	2	**Medium flooding**				
	Coastal erosion	0	**No erosion**				
	Degree of salinization	3	**High saline intrusion**				
	Total	**7**					

The assessment of all four categories results in a total score of 7, which is equivalent to a Significance level of 'Major'. This Significance level is automatically populated in a matrix analyzing Significance in tandem with

[28] This guidance was drafted by Silvestrum Climate Associates and has been reviewed by Verra. It is currently in the approval process and has not been published by Verra yet. However, a copy of the guidance is provided to Planete Urgence for reference purposes.

the SLR impact level. Based on this matrix, a SLR risk score of 20 (Table 9) was determined based on a SLR impact level of 5 (4.5 rounded to 5) and a Significance of Major. If the project is able to identify two or more mitigation measures to determine their SLR Adaptation Score, for e.g the areas gained in the 500-m buffer zones could be justified as potential future areas of mangroves due to landward migration from SLR and the active involvement and participation of the local communities as local stakeholders, this would make the project eligible for a SLR Adaptation Score of 0.25. Based on the data available at this time and the assessment done according to this data, the overall risk of non-permanence from SLR for the CAMERR project area is projected to be 5% (Table 9).

4. Key findings and conclusion

The key findings of the sea level rise and coastal erosion assessment for the CAMERR project area are as follows:

1. Mangrove Elevation Capital: The elevation range within which mangroves can thrive is critical for their survival in the face of sea-level rise. The current elevation capital of mangroves was found to range between 0.068 m and 0.752 m according to a study carried out in the Wouri estuary. While this elevation capital may not be sufficient to accommodate the projected sea level rise based on the coastal flooding assessment, it is a conservative estimate, based on the data available now.
2. Coastal Flooding: Under the worst-case IPCC SSP5-8.5 SLR scenario of a 1.08 m rise by 2122, combined with a conservative sediment accretion rate of 2.5 mm year^{-1}, it is estimated that 46% of the CAMERR project area will be lost to coastal flooding. While this places the project in the 'Medium Flooding' category within the NPRT, this is a conservative estimate.
3. Coastal Erosion: An average coastal erosion rate of 5 m year^{-1} was reported in the project area. While this places the project in a 'High erosion' category, the project area is located far enough from the coastline to avoid immediate impact from coastal erosion. A sensitivity analysis demonstrated that erosion of 500 m and 1,000 m by t=100 years would not impact the project area, but a 1,500 m erosion of the coastline by 2122 would result in the loss of 4 hectares of the project area on Manoka Island.
4. **Non-permanence risk assessment:** The overall risk of non-permanence from SLR for the CAMERR project area is projected to be 5%, based on the SLR and coastal erosion assessment. However, an analysis of areas that could become intertidal by t=100 years showed that 2,732 ha of upland areas have the potential to become suitable for mangrove colonization by 2122, demonstrating the potential for landward migration of mangroves to keep up with SLR as an adaptative measure.

Although the results of the SLR assessment suggest moderate flooding due to SLR, they represent conservative projections. Evidence presented in Fossi et al. (2022)[29] suggests that sediment loads in the central part of the Wouri estuary can reach an average of 800 mg/L. While it is possible that the surrounding areas, including the project area, would have a high sediment load, the paper does not present such values for specific sites within the estuary, particularly close to the project area. The recommendation here, given the requirement from VM0033 regarding sediment loads, is for the project to collect measurements of suspended sediment to build an annualized dataset by the next verification which would help verify the sediment load in the project area. Justification of a high sediment load would give a score of zero to coastal flooding due to SLR in the NPRT, showing high confidence in the mangroves' ability to accrete vertically in the project area based on the sediment supply. With coastal flooding and coastal erosion both assigned a score

[29] FOTSI, Y. F., BRENON, I., ONGUENE, R., POUVREAU, N., & ETAME, J. (2022). Contribution de la modélisation numérique à l'étude de la dynamique hydro-sédimentaire dans l'estuaire du Wouri.

of zero, ecosystem degradation would also be zero, which would bring the Significance level to 'Insignificant' and only a 1% risk due to SLR.

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