# Annex 5 – Technical Annex: The West African Coastal Barrier System Coastal Erosion, Flooding, Climate Change Adaptation, and Resilience

## Professor Larissa A. Naylor

This Technical Annex provides additional detail to explain current and future risks and impacts of coastal erosion on coastal processes, coastal landforms, ecosystems, communities, and infrastructure in West Africa. Coastal erosion and flooding are consequences of the combined effects of global climate change pressures and regional-local human impacts such as development pressures that restrict sediment supply. Together these pressures influence coastal erosion rates and their geographical extent, long-term (decades to centuries) evolution of coastal landforms, and thus impacts on the resilience of people and assets occupying these landscapes.

This annex describes the physical geography of coastal barrier systems and key oceanographic, human, and climate change drivers shaping them, including longshore sediment – the transport system that supplies sand to barrier beach systems. It also considers potential cumulative impacts of human activities on the sediment supply and coastal erosion risks to people and assets. It then describes how barrier beach systems will likely adjust to coastal climate change impacts, illustrating the long-term (decades to centuries) adaptation limits and options using global data to highlight the risks. The vulnerabilities and risks outlined here are equally relevant for many low-lying, small, island states built on unconsolidated, sandy deposits, for landmasses where communities are built on or near low-lying beach and dune systems, and where people and assets occupy sedimentary deltas. All of these regions face future biophysical adaptation limits as climate change risks intensify.

The West African Coastal Barrier System illustrates the effects on sediment supply, coastal erosion, and barrier beach evolution of the interactions between various human- and climate-change factors. This annex is divided as follows:

- Section 1 provides global and local synopses of two key, coastal, climate change risks: sea level rise (SLR) and storminess, placing local risks for West Africa in the global context.
- Section 2 details the coastal processes and landform evolution of coastal barrier systems, outlining how natural coastal barrier systems respond to key human activities affecting sediment supply, using the West African Coastal Barrier system as a case study.
- Section 3 covers the climate change risks and known coastal barrier responses to SLR fluctuations to highlight the likely, longer-term impacts of climate change on coastal barrier systems.
- Section 4 outlines the longer-term physical adaptation limits and options for managing combined human impacts and climate change risks along coastal barriers.

## 1. Global and Local Climate Change Risks

"*It is unequivocal that human activities have heated our climate. Recent changes are rapid, intensifying, and unprecedented over centuries to thousands of years. With each additional increment of warming, these changes will become larger, resulting in long-lasting, irreversible implications, in particular for sea level rise*."[i]

### 1.1. Global Sea Level Rise

Global sea levels are higher today than in the past 3,000 years; the rate of SLR has accelerated over the past 100 years, with confidence increasing with each new Intergovernmental Panel on Climate Change (IPCC) Report. The 2007 IPCC stated, there is high confidence that the rate of sea level rise has increased between the mid-19th and the mid-20th centuries.[ii] The 20 cm global average SLR since 1900 is unprecedented over the long-term record (Figure A).[iii]

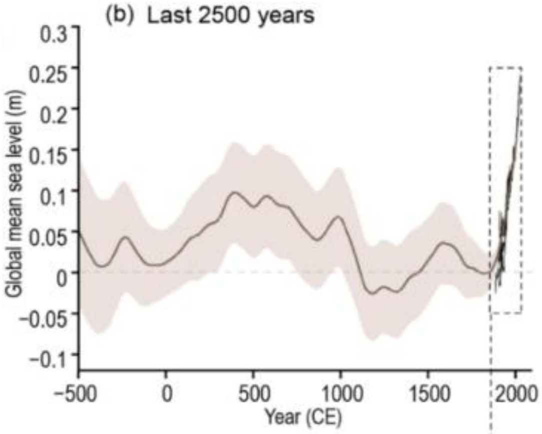


Figure A. Changes in Global Mean Sea Level: Reconstructions for the last 2,500 years based upon a range of proxy sources with direct instrumental records superposed since the late 19th century, showing the unprecedented rate of SLR in the past century compared to the long-term average.[iv]

---

[i] IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391, p. v.

[ii] Ibid., p. 5.

[iii] Ibid., p. 89.

[iv] IPCC, 2021. Figure 2.28 in IPCC, 2021: Chapter 2. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Gulev, S.K., P.W. Thorne, J. Ahn, F.J. Dentener, C.M. Domingues, S. Gerland, D. Gong, D.S. Kaufman, H.C. Nnamchi, J. Quaas, J.A. Rivera, S. Sathyendranath, S.L. Smith, B. Trewin, K. von Schuckmann, and R.S. Vose, 2021: Changing State of the Climate System. pp. 287–422, doi:10.1017/9781009157896.004.] In IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896, p. v.

The IPCC[v] has measured nearly a three-fold increase in the global rates of SLR observed over the period of 2006-2018, to 3.7 millimeters per year compared to the rate for 1901-1990 (1.35 millimeters per year). The IPCC[vi] calls this a "*robust acceleration (high confidence) of global mean sea level rise over the 20th century*." Importantly, this finding of recent, accelerated SLR is not new; it was reported in the IPCC's Fourth Assessment Report in 2007. What is new is the three-fold increase in the rate of change between then and now. The rate and extent of SLR are closely tied to global emissions; progress reducing the World's emissions is currently slow. As a result, current global SLR rates are at the high end of those predicted (Figure B-d, below). SLR projections for 2100 and 2300 show continued increases in future SLR.[vii]

There is also a lag between carbon dioxide and atmospheric warming, and their effect on sea level. This means that past emissions will continue to drive future SLR, even if net zero is achieved tomorrow.

---

[v] IPCC, 2021, Chapter 9: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896, p. 1,289.

[vi] IPCC, 2021. Figure SPM.8 in IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY,USA, pp. 3−32.

[vii] IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896., p. v.

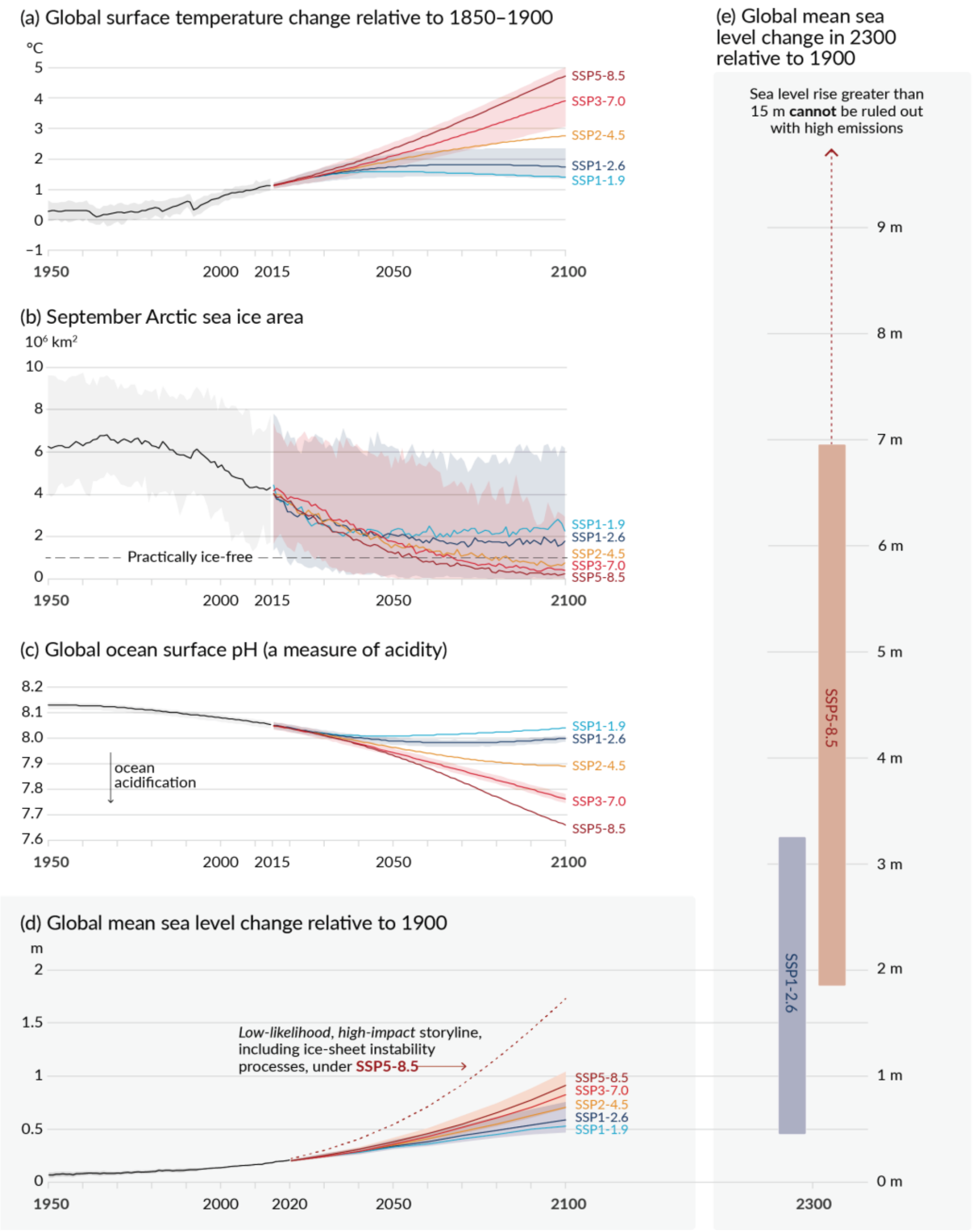


Figure B. Selected indicators of global climate change based on long-term averages for the Sixth IPCC Assessment Report (2021). Projections for the five scenarios are in color. Shades represent uncertainty ranges – more detail is provided below. The black curves represent the historical simulations (panels a, b, and c) or the observations (panel d). Historical values are included in all graphs to provide context for the projected future changes.

(a) Global surface temperature changes.
(b) September Arctic sea ice area.
(c) Global ocean surface acidity (pH).
(d) Global mean sea level change in meters, relative to 1900.
(e) Global mean sea level change in 2300 in meters, relative to 1900.[viii]

---

[viii] IPCC, 2021. Figure SPM.8 in IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY,USA, pp. 3−32.

## 1.2. Sea Level Rise in West Africa

Africa is a data scarce region, where research is underfunded and more limited local, instrumental (e.g., tide gauge) data and modelling are available for all risks and impacts.[ix] This is especially the case for key climate change risks: past, recent, and future SLR and storminess. The latest IPCC report shows medium-to-higher confidence of past SLR in West Africa, and high confidence of future increases in relative sea level.[x] Records of past (over 100 years to millennial) sea level changes for West Africa are scarce; the proxy data that does exist shows past sea level trends and, crucially, how the West Africa Coastal Barrier is a geologically young and ephemeral landform created in response to past fluctuations in sea level.[xi]

Locally, past (1979-2007) sea level change has been calculated using satellite data from the European Centre for Medium-Range Weather.[xii] Between 1993-2007, measured SLR rates were about 2.5 millimeter per year;[xiii] these rates are above the long-term global average reported by the IPCC for the 20th century.[xiv] Importantly, these data analyses stop in 2007 and the IPCC has measured an almost three-fold increase in the global rates of SLR in 2006-2018, to 3.7 millimeters per year.

Future SLR projections for West Africa are equally scarce,[xv] limited to a few, local, detailed modelling studies, or are extracted in reports from global studies which have poor spatial resolution. The local studies, such as Kebede et al. 2018, modelled SLR in West Africa and conclude that rates are expected to be up to 1.1 meter by 2100 under the high emissions scenario (based on the RCP8.5). These forecasts are similar to the IPCC's global predictions, which are likely underestimated as Africa has above average global SLR. With these underestimations, it is projected that in the 21st century this region will endure five times the SLR of the last century. Indeed, United Nations Under-Director-General Vera Songwe has said, "*Africa is enduring more than the average global sea level rise*."[xvi]

---

[ix] IPCC, 2021: Factsheet on Coastal Cities and Settlements, p. 1. In Climate Change 2021: The Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

[x] IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896., p. 122.

[xi] Amieux, P., Bernier, P, Dalongeville, R., Medwecki, V. Cathodoluminescence of Carbonate-cemented Holocene Beachrock from the Togo Coastline (West Africa) an Approach to Early Diagenesis, 1989. Sedimentary Geology, 65: 261-272, p. 262.

[xii] European Centre for Medium-Range Weather, ERA-interim grid point 5b (5.25 degrees North, 1.5 degrees East), via: https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim.

[xiii] World Bank. Effects of climate change on coastal erosion and flooding in Benin, Côte d'Ivoire, Mauritania, Senegal, and Togo-Technical Report,2020, p. 78.

[xiv] IPCC, 2019. Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, 2019: Ch. 4 Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge Univ. Press, Cambridge, UK and New York, NY, USA, pp. 321–445.

[xv] World Bank, 2020. Effects of climate change on coastal erosion and flooding in Benin, Côte d'Ivoire, Mauritania, Senegal, and Togo – Technical Report, p. 9.

[xvi] Mafaranga, H. Sea level rise may erode development in Africa, 2020. *Eos, 101*.

As SLR in Africa is accelerating faster than the global average, these climate change effects will be felt sooner.

## 1.3. Global Storminess, Flooding, and Coastal Erosion

Trends in global storminess have more modelling uncertainties than those for SLR, due to the complex interactions between the oceans and atmosphere, and regional variation. However, for the late 21st century there is medium confidence that the average intensity of precipitation associated with storms will increase, and a high proportion of tropical cyclones will be in the highest two intensity classes (Category 4 or 5).[xvii] Importantly, there is *very high confidence* that SLR will lead to higher storm surge levels for most storm events.[xviii] "*Historically rare extreme sea level events will occur annually by 2100, compounding these* [human, infrastructure, ecosystem] *risks (high confidence),*[xix] increasing the height of storm surges. Globally, there is high confidence of greater coastal flooding and erosion on all continents, and high confidence of coastal erosion along most sandy coasts.[xx]

## 1.4. Extreme Sea levels, Wave Climate, and Storminess in West Africa

Local instrumented wave data in the region is limited to Ghana in West Africa.[xxi] Satellite wave data have been used to generate trends in waves, showing a regional increase in wave heights in recent decades. While the wave heights in the Gulf of Guinea are not especially high (an average significant

---

[xvii] IPCC, 2019. Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, 2019: Ch. 4 Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge Univ. Press, Cambridge, UK and New York, NY, USA, p. 360.

[xviii] IPCC, 2019. Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, 2019: Ch. 4 Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge Univ. Press, Cambridge, UK and New York, NY, USA, p. 376.

[xix] IPCC.: *Climate Change 2022: Impacts, Adaptation, and Vulnerability*, 2022. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., TS.C.5 p. 62.

[xx] IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896., p. 120-126.

[xxi] IPCC, 2019. Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, 2019: Ch. 4 Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge Univ. Press, Cambridge, UK and New York, NY, USA, pp. 358-359.

wave height of 1.5 meters and annual significant wave heights of 2.5 meters[xxii]) the combination of long period waves, strong Guinea current, seasonal monsoonal winds, and the narrow continental shelf makes the waves and longshore sediment transport system especially strong. "*This narrow shelf and paucity of sheltering islands allow deep-water waves and surface ocean currents to approach unmodified close to the mainland shore where they are unusually influential in moving sediment*."[xxiii] This means that when waves hit shallow water near the coast in this region they break more abruptly, with more power to cause erosion and flooding. On average, there are at least 10 days per year when wave heights exceed two meters.[xxiv]

Simply put, this means the Gulf of Guinea coastal system has a naturally strong wave climate that is already experiencing more frequent, larger waves abruptly breaking nearshore and causing erosion and flooding. The interaction between the coast and these waves sets up eastward-flowing, longshore currents that are highly effective at transporting sediment, when available, in the dominant wave direction – from Cote d'Ivoire to Nigeria. During the stormy season especially, these waves accelerate sediment transport and cause erosion and flooding of the barrier beach system, adversely impacting the communities, assets, and infrastructure built on these naturally vulnerable barriers.

### 1.4.1. Climate Change Impacts on Erosion and Storminess in West Africa

The wave climate is already changing in this region, a trend discernable even though global data on extreme sea level events have a large and notable gap for West Africa,[xxv] and future predictions of changes in storminess and wave climate in this region are severely limited. Modelled data for 1979-2018 from the globally renowned European Centre for Medium-Range Weather (ERA-interim grid point 5b – 5.25°N, 1.5°E), shows the strength of waves increasing through time where the frequency of large waves (over 2.5 meters) has increased since 1996.[xxvi] This is in line with the IPCC's trends (see Section 1.3) and as SLR will increase wave heights further, risks of future flooding (also called marine submersion) and erosion from an increasingly strong wave climate are expected. However, local evidence exists from a variety of sources that storms already cause extensive coastal erosion and flooding, and shows that storms and storm surges in this region are not exceptional. Coastal flood frequency in West Africa has grown in the past 50 years and future increases are expected.[xxvii] Average erosion rates are 1.8 meters per year for this region, with some countries, such as Benin, having average erosion rates of four meters per year in the recent past (e.g., last two decades); local erosion rates can be as high as 15 meters per year.[xxviii]

---

[xxii] World Bank, 2020. Effects of climate change on coastal erosion and flooding in Benin, Côte d'Ivoire, Mauritania, Senegal, and Togo – Technical Report, p. 71.

[xxiii] Orme, A.R. Africa, Coastal Geomorphology, 2005. In: Schwartz, M.L. (eds) Encyclopedia of Coastal Science. Encyclopaedia of Earth Science Series. Springer, Dordrecht, p. 1.

[xxiv] Acciona, 2018. Development of a West Africa Coastal Areas Regional Proposal to the Green Climate Fund (GCF): Institutional and Policy Gap Analysis and Recommended Measures for Climate Resilient Coastal Zone Management in West Africa. Climate Change Assessment Report.

[xxv] IPCC, 2019. Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, 2019: Ch. 4 Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge Univ. Press, Cambridge, UK and New York, NY, USA, pp. 358-359.

[xxvi] World Bank, 2020. Effects of climate change on coastal erosion and flooding in Benin, Côte d'Ivoire, Mauritania, Senegal, and Togo – Technical Report, p. 71.

[xxvii] World Bank, 2020. Effects of climate change on coastal erosion and flooding in Benin, Côte d'Ivoire, Mauritania, Senegal, and Togo – Technical Report, p. 9.

[xxviii] Ibid.

### 1.5. Effects on Global Coastal Communities

Low-lying, coastal cities and settlements worldwide already experience the impacts of climate change hazards on land and livelihoods. The IPCC states that "*Under all climate and socioeconomic scenarios, low-lying cities and settlements (…) will face severe disruption by 2100, and as early as 2050 in many cases (very high confidence) {TS.C.5.3}*."[xxix] There is high confidence that approximately one billion people worldwide, including in small island states, will be at risk from coastal-specific climate hazards by mid-century, and that these risks will accelerate after 2050.[xxx] The IPCC adds that "*Cities and settlements by the sea are thus on the frontline of action to adapt to climate change, mitigate greenhouse gas emissions and chart climate resilient development pathways. {CCP2.1.1}*."[xxxi]

The acute urgency of this situation is reflected by the landmark decision at the Convention of the Parties[xxxii] annual meeting in 2022 (called "COP27") to establish a loss and damage fund to finance adaptation and resilience in lesser-developed countries, which would first prioritize low-lying, small island states, and by the establishment of the World Bank's blue economy fund to improve food security and manage flood and erosion risks.[xxxiii]

---

[xxix] IPCC, 2021: Factsheet on Coastal Cities and Settlements, p. 1. In Climate Change 2021: The Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

[xxx] IPCC, 2022: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844. TS.C.5 p. 62.

[xxxi] IPCC, 2021: Factsheet on Coastal Cities and Settlements, p. 1. In Climate Change 2021: The Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

[xxxii] Convention of the Parties (COP) COP is the name given to the United Nations Climate Change Conferences where all 197 member countries, or 'Parties', of the United Nations Framework Convention on Climate Change (UNFCCC) who meet annually to evaluate progress on existing and agree new targets to limit climate change (UK Met Office, 2022). See, Aaagard, T. et al. 2021. Holocene development and coastal dynamics at the Keta Sand Spit, Volta River delta, Ghana. Geomorphology, 387: 107766.

[xxxiii] World Bank. Blue Economy for Resilient Africa Program, 2022.

## 2. Coastal Processes and Coastal Barrier Landform Evolution

"*Hard and soft limits to adaptation have been reached in some ecosystems and regions. Maladaptation is happening in some sectors and regions*."[xxxiv]

Barrier beaches and barrier islands are common coastal landforms flanking many of the world's wave-dominated coasts, notably in western Africa, eastern America, New South Wales in Australia, and along the eastern coast of South America.[xxxv] These barriers are not static landmasses, nor are they long-term features in the geological record. Instead, they are geologically young and ephemeral, only appearing in the last approximately 5,000 years in most cases. They are dynamic, low-lying landforms built of unconsolidated sand (Figure C-I, below), which change shape and adjust their position relative to land as sea levels rise and fall (Figure C-II, below), as sediment supply changes (Figure C-III, below), and/or as natural geomorphic change occurs in response to interactions with currents, waves, sea level, and human activities through time.[xxxvi]

These shifting barrier beaches provide an important, natural coastal barrier between the open coast and the land behind them (Figure C-I, below). For example, barrier beaches protect the mainland by reducing some risks of natural flooding and erosion. They form where there is a strong, alongshore sediment transport system, such as is the case for the "West African Coastal Barrier" (hereafter, WACB). These geological conditions create minimal resistance to oceanographic stressors like strong currents, waves, storms, and SLR. This means that coastal barriers are typically geologically weak and highly vulnerable to erosion by waves.  Three key factors affect the resilience of coastal barriers in their current day locations: 1) absence of sand, 2) curtailing of longshore sediment transport, and 3) climate change impacts, notably SLR and storminess.

---

[xxxiv] IPCC AR6 Synthesis Report. Headline Statement A.3. Current Progress in Adaptation and Gaps and Challenges.

[xxxv] Davidson-Arnott, R. . Chapter 3.04 Wave-Dominated Coasts, 2011. In Treatise on Estuarine and Coastal Science, Elsevier. 73-116, p. 103.

[xxxvi] Davidson-Arnott, R. . Chapter 3.04 Wave-Dominated Coasts, 2011. In Treatise on Estuarine and Coastal Science, Elsevier. 73-116, p. 107.

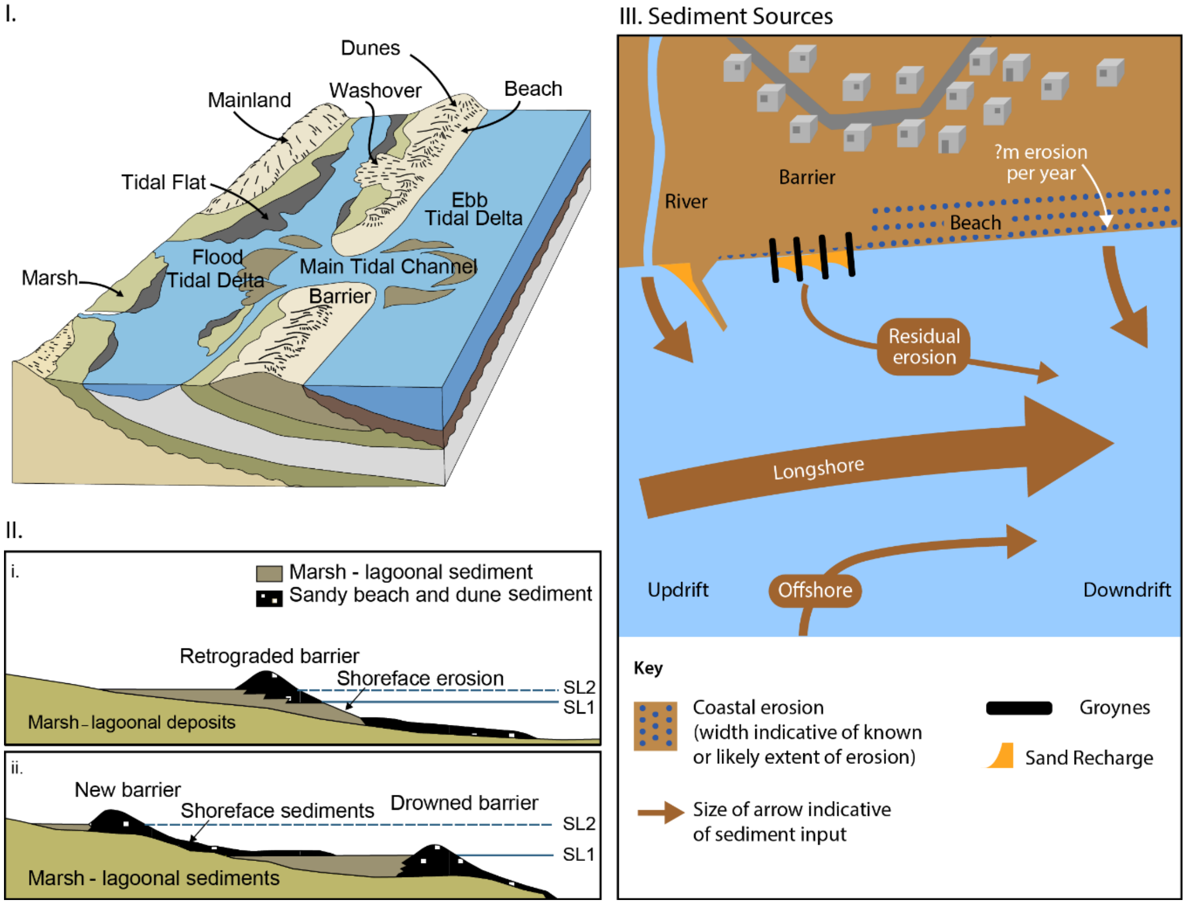


Figure C – I-III.: I) a characteristic, natural, beach-dune barrier beach system; II) barrier beach responses to SLR, illustrating the natural dynamics of barrier beach systems to SLR where II(i) shows landward migration of the barrier and II(ii) illustrates drowning of the old barrier and creation of a new one inland; III) illustrates the main sediment sources to barrier systems worldwide, where size of sediment inputs vary regionally. Illustrated here are the relative inputs from different sources to the WACB. Sources of I and II: permission from R. Davidson-Arnott; C Author.

These sediment-related pressures on barrier systems can, to some extent, be actively managed by replacing with new material the sand supply being trapped behind dams from the longshore sediment transport system by ports or groynes. This can be achieved using expensive soft, hard, or combined coastal protection works that require continued sand inputs to limit downdrift erosion. However, there are long-term, biophysical limits to this approach on developed, low-lying, barrier systems as climate change impacts accelerate and amplify in coming decades (see Section 3).

## 2.1. Sediment Supply to Coastal Barrier Systems

Coastal barriers are supplied with sand from three main sources: 1) offshore from the seabed where the nearshore shelf surface is primarily sand-to-muddy-sand, 2) fluvial sediments from rivers and lagoons, and 3) erosion of coastal landforms along the coast.[xxxvii]

---

[xxxvii] Anthony, E. et al. Response of the Bight of Benin (Gulf of Guinea, West Africa) Coastline to Anthropogenic and Natural Forcing, Part 2: Sources and patterns of sediment supply, sediment cells, and recent shoreline change, 2019. Continental Shelf Research, 173, p. 94.

Continued growth of sandy coastal barriers like the WACB relies on a sediment budget large enough to provide a net, positive input to the barrier beach (Figure D-left) that allows it to adjust to changes in oceanographic or climate change forces, such as SLR.[xxxviii] In the absence of a sustained sediment supply these systems will erode and narrow.

## 2.2. Human Impacts on Sand Supply to Barrier Systems

The sand supply to coastal barriers in developed regions of the world has been severely curtailed by human activities including sand extraction, damming of rivers – which reduces fluvial sediment inputs to the coast, and the building of ports and coastal protection measures like groynes – which block the longshore transport of sediment (Figure D-right). This reduced sediment supply further diminishes the resilience of coastal barriers to current and future coastal climate change pressures.

In many regions of the world, coastal barriers are already narrowing, being overwashed or breached due to reduced sediment supply and current climate change impacts (see Section 3) – even *before* feeling more rapid climate change impacts expected in the near future (i.e., the next few decades). Where multiple, local-regional scale projects are developed sequentially, cumulative loss of sediment supply, from damming and/or coastal protection infrastructure, can increase downdrift erosion.

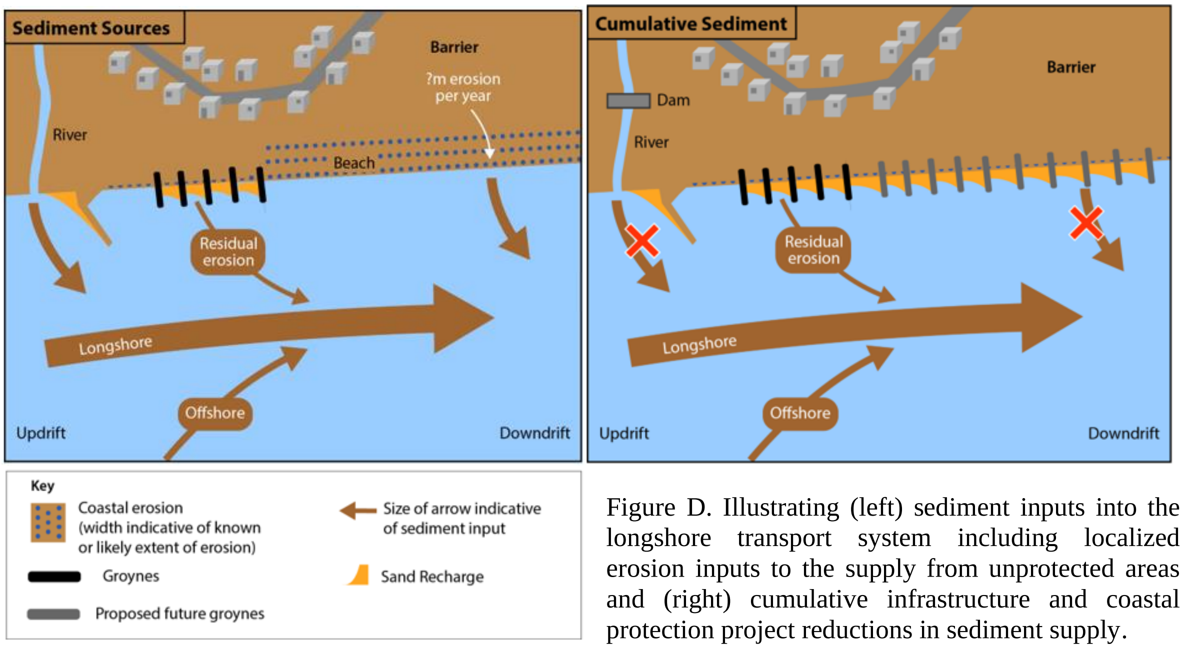


Figure D. Illustrating (left) sediment inputs into the longshore transport system including localized erosion inputs to the supply from unprotected areas and (right) cumulative infrastructure and coastal protection project reductions in sediment supply.

Cumulative impacts provide a good example of an adaptation gap. Protective hard pathways (Figure I-I below at the end of the document) will limit erosion locally, reducing risks of near-term social harm in these locations. However, in doing so, they will greatly reduce the beach and barrier erosion source of sediment for the overall regional sediment supply (Figure D, right). Localised erosion can still occur (and be amplified in areas which are unprotected) using soft, hard and/or combined protection pathways. Where coastal protecting, hard measures are used along the entire length of a developed coast, there will be increased need to replace the sediment supply lost when localized erosion inputs to the sediment supply are reduced to residual erosion inputs only (Figures H and I, below).

---

[xxxviii] Davidson-Arnott, R. 2011. Chapter 3.04 Wave-Dominated Coasts, p. 107. In Treatise on Estuarine and Coastal Science, Elsevier. 73-116.

## 2.3. West African Coastal Barrier

The Gulf of Benin coastal system is classified as a micro-tidal (less than two-meter tidal range), sedimentary, wave-dominated open coast, directly exposed to southerly swells generated on the far side of the Atlantic Ocean.[xxxix] The dominant, coastal landform upon which the Côte d'Ivoire, Ghana, Togo, and Benin coastal communities are built is called the WACB. The WACB is the only land between the Atlantic Ocean and inland coastal areas. The main economy and populations of these nations are built on coasts with a highly erodible, low-lying sand barrier. Coastal communities thus have minimal resilience and extremely high vulnerability to coastal erosion, flooding, and climate change pressures. This inherent low resilience and high vulnerability is already clearly evident from the high rates of erosion along the barrier (approximately 1.8-four meters per year on average) between the late 1960s and the present day. This is especially the case in areas downdrift of major infrastructure projects (e.g., dams and ports) and coastal protection measures associated with these (e.g., groynes), which results from both an exceptionally high reduction in sediment supply and curtailing of the sediment transport system due to human development activities, along with relatively modest SLR and wave climate changes when compared to the more rapid acceleration in rates of SLR predicted until 2300 (Figure B, above).

### 2.3.1. Sediment Supply to the West African Coastal Barrier

Key sources of sand from fluvial systems have been vastly reduced by damming the Volta River in 1964; sediment discharge before dam construction (approximately 153 million cubic meters per year, Ly 1980) has dropped more than 90 percent.[xl] This sediment is then transported by a strong longshore drift system, where human activities and infrastructure (such as marine-structures, ports or groynes) restrict this natural sediment transport system, increasing coastal erosion in a downdrift direction.[xli] This absence of sand due to human activity has led to a massive sediment deficit.[xlii]

### 2.3.2. Human Impacts on Sediment Transport Along the West African Coastal Barrier

Human activities, notably the building of ports and hard coastal protection such as groynes, have severely curtailed the natural, west-to-east sediment transport processes, leading to accelerated erosion downdrift of these features.[xliii] This infrastructure traps sand that would have helped the coastal barrier grow and adjust to climate change pressures. As a result, the West African sandy coastal barrier is eroding almost everywhere along its length[xliv] and narrowing in response to reduced sediment supply and modest, current day climate change impacts, causing nearly five percent of annual GDP losses in the region.[xlv]

---

[xxxix] Orme, A.R. Africa, Coastal Geomorphology, 2005. In: Schwartz, M.L. (eds) Encyclopedia of Coastal Science. Encyclopaedia of Earth Science Series. Springer, Dordrecht, , pp. 1-5.

[xl] Amenuvor, M, et al. 2020. Effects of Dam Regulation on the Hydrological Alteration and Morphological Evolution of the Volta River Delta. Water, 12(3), 646, p. 1.

[xli] Giardino, A. et al. A Quantitative Assessment of Human Interventions and Climate Change on the West African Sediment Budget, 2018. Ocean & Coastal Management, 156: 249-265, pp. 249-250.

[xlii] Anthony, E. et al. Response of the Bight of Benin (Gulf of Guinea, West Africa) Coastline to Anthropogenic and Natural Forcing, Part 2: Sources and patterns of sediment supply, sediment cells, and recent shoreline change, 2019. Continental Shelf Research, 173, p. 94.

[xliii] Ibid.

[xliv] Giardino, A. et al. 2018. A quantitative assessment of human interventions and climate change on the West African sediment budget, p. 249. In Ocean & Coastal Management, 156.

[xlv] Ibid.

## 2.4. Coastal Erosion and Flood Risk

Their naturally low-lying topography and unconsolidated sandy composition make barrier beach and barrier island systems highly prone to erosion and flooding. This is especially the case where human activities are already adversely impacting sediment supply and/or restricting how barrier systems can naturally respond to changes in key factors, such as sediment supply and oceanographic conditions (Figure E, below). Coastal erosion and flooding of barrier beach systems worldwide will be accelerated and amplified by continued human pressures as well as climate change impacts, including SLR and increased storminess.

## 2.5. Developed Coastal Barriers

The risks described immediately above are amplified for developed barrier systems. The problem for barrier systems with extensive human developments is that the natural response of the barrier beach system causes erosion and flooding of people and assets built on this highly unstable and vulnerable sandy land (Figure E, below). In these developed barrier systems, without relocation of people and assets to higher ground, capacity for natural, landward retreat of the barrier system (Figure F-II, below) is limited and the barrier landforms are more prone to becoming fully submerged[xlvi] or narrowing through erosion, as is currently the case in more than half of the WACB.[xlvii]

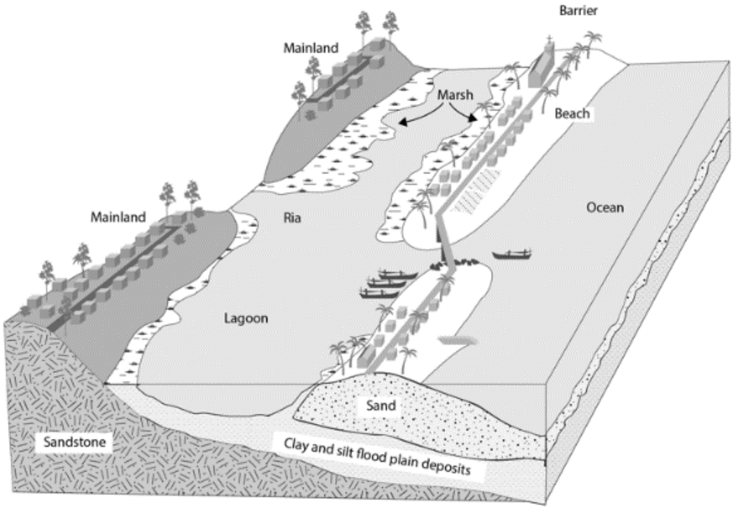


Figure E. Conceptual diagram of a developed barrier beach system illustrating the physical constraints this development has on natural barrier system response to changing sediment supply and/or sea level rise.

---

[xlvi] Lorenzo-Trueba, J, Ashton, AD. Rollover, Drowning, and Discontinuous Retreat: Distinct Modes of Barrier Response to Sea-level Rise Arising from a Simple Morphodynamic Model, 2014. JGR Earth Surface, p. 779.

[xlvii] World Bank. The Cost of Coastal Degradation in West Africa, 2019, p. x.

## 3. Barrier Systems and Longer-term Climate Change Risks

"*Due to unavoidable sea level rise (…), risks for coastal ecosystems, people and infrastructure will continue to increase beyond 2100 (high confidence)*."[xlviii]

Coastal barrier beaches are not static landforms; they are naturally dynamic and highly responsive to oceanographic conditions, such as the effects of storms and SLR. Barrier systems typically respond to changes in sea level, storminess, and sediment supply by adjusting their shape or position at the coast, such as by migrating landwards or drowning as sea levels rise.[xlix] Overwash deposits – beach sediments deposited on land from storms – are key means by which open coastal barriers cause naturally functioning coastal barriers to migrate landwards. Storms and flooding reposition sediments, leading to a landward retreat of barrier beaches (Figure F, II and III, below).[l] "*It is well known that barrier islands retreat as sea levels rise*."[li] As rates of SLR projected in IPCC 2007 to IPCC 2021 and other sources far exceed those of the past few millennia, increases in hazards and unprecedented changes are possible, "*including the possibility for a total loss of protective natural barriers*."[lii] Indeed, new modelling highlights this risk: it shows that barrier systems will have a 50 percent acceleration in the retreat rate worldwide within a century, without including increases in the present rate of SLR.[liii] Combined with expected SLR of one meter by 2100 and at least three meters by 2300 (relative to 1900), future retreat rates of coastal barriers due to SLR will be much higher than in the recent past. In short, many barriers worldwide, including the WACB system, will be fully eroded through narrowing, moving landward, or fully submerging as climate change impacts accelerate (Figure F, II-IV, below).

Combined with expected SLR of approximately one meter by 2100, future retreat rates of coastal barriers due to sea level rise will be much higher than in the recent past. This will accelerate the erosion and narrowing of barriers like the WACB, where sediment supply is insufficient to allow adjustment in the barrier's current-day location (Figure F-II, below). Such narrowing increases the risk of barriers adjusting to SLR in two ways. One, this activates increasing overwash during storms, initiating landward migration of the barrier beach[liv] (Figure F-II, below). Two, as narrowing continues, the barrier is at increasing risk of being breached and broken into smaller sections (Figure F-III, below), as was observed in an approximately 60-meter-wide coastal barrier in southern Nigeria after a storm in September 2018, which has permanently split one community in half.[lv] In short, many of these barriers worldwide will be fully eroded through narrowing, migrating landwards, and/or ultimately being submerged as climate change impacts accelerate (Figure F-IV, below).

---

[xlviii] IPCC AR6 Synthesis Report of the IPCC Sixth Assessment Report (AR6) Summary for Policymakers, p. 15, released March 20, 2023.

[xlix] Anthony, E. et al. Response of the Bight of Benin (Gulf of Guinea, West Africa) Coastline to Anthropogenic and Natural Forcing, Part 2: Sources and patterns of sediment supply, sediment cells, and recent shoreline change, 2019. Continental Shelf Research, 173, p. 94.

[l] Lorenzo-Trueba, J, Ashton, AD. Rollover, Drowning, and Discontinuous Retreat: Distinct Modes of Barrier Response to Sea-level Rise Arising from a Simple Morphodynamic Model, 2014. JGR Earth Surface, p. 779.

[li] Mariotti, G. 2022. Interview, July 2022.

[lii] Lorenzo-Trueba, J, Ashton, AD. Rollover, Drowning, and Discontinuous Retreat: Distinct Modes of Barrier Response to Sea-level Rise Arising from a Simple Morphodynamic Model, 2014. JGR Earth Surface, p. 779.

[liii] Mariotti, G. Hein, CJ. Lag in Response of Coastal Barrier-island Retreat to Sea Level Rise, 2022. Nature Geoscience 15, 633-638, p 633.

[liv] Lorenzo-Trueba, J, Ashton, AD. Rollover, Drowning, and Discontinuous Retreat: Distinct Modes of Barrier Response to Sea-level Rise Arising from a Simple Morphodynamic Model, 2014. JGR Earth Surface, p. 779.

[lv] Affiah, U. Vulnerability of the Nigerian coast and communities to climate change induced coastal erosion- Unpublished PhD Thesis, 2023. University of Glasgow.

### 3.1. Combined Human Sediment Supply and Climate Change Impacts on the Long-term (> Century Scale) Resilience of Coastal Communities

Taken together, these continued, combined human development and climate change impacts create a challenging future for coastal communities on barrier beach systems and other low-lying coastal areas worldwide where coastal population, assets, and economic productivity are literally built on sand. If SLR outpaces the supply of sediment and/or the barrier is unable to move inland, the barrier will likely become eroded, breached, submerged, and/or disappear (Figure F, below).

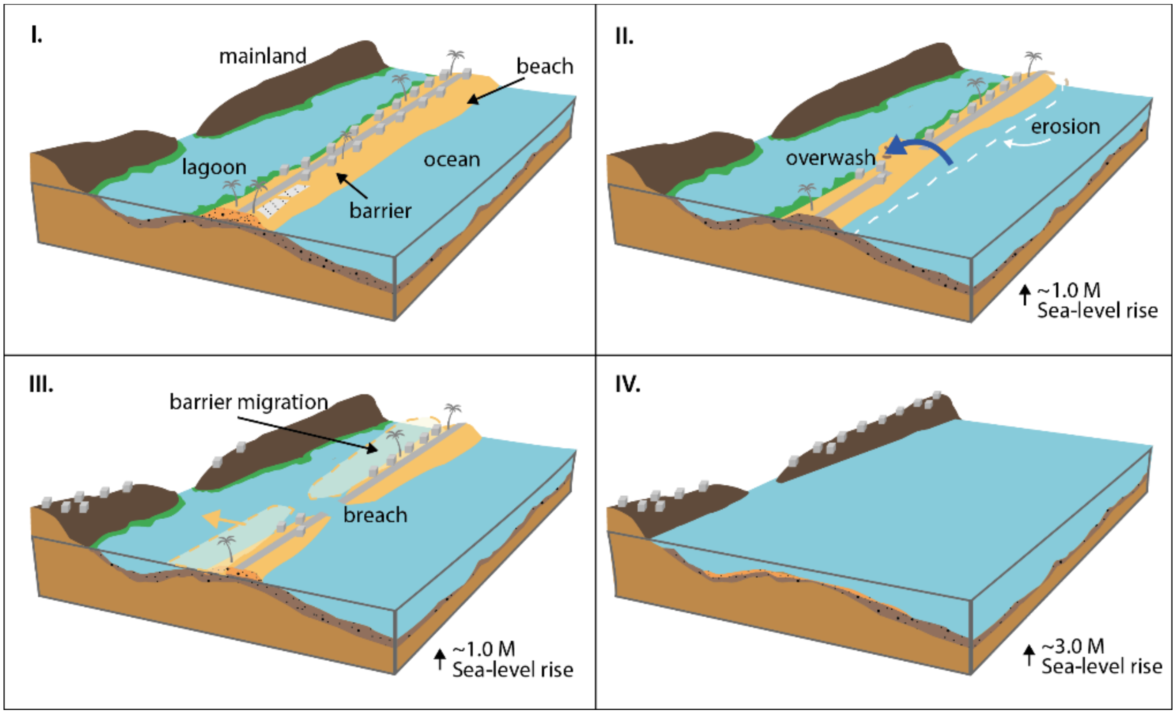


Figure F. Conceptual model of barrier retreat under rising sea levels, where (I) is a present-day barrier, (II) erosion and storm overwash occurs, (III) breaching and/or landward migration of the barrier occurs, and (IV) the barrier is fully eroded and/or submerged. Human disruption to sediment supply exacerbates these risks.

The coastal barriers in their current geographic positions and, crucially, the people and assets living upon them, are at long-term (over 100 years) risk of continued erosion, leading to their narrowing or, ultimately, submergence and disappearance (Figure F, above). This creates a physical adaptation limit to coastal protection measures to maintain community resilience (Figure G, below). In 2013, the IPCC stated that adaptation limits occur when "*adaptation efforts are unable to provide an acceptable level of security from risks to existing objectives and values and prevent the loss of key attributes, components, or services of an ecosystem*."[lvi]

---

[lvi] Wong, P.P., I.J. Losada, J.-P. Gattuso, J. Hinkel, A. Khattabi, K.L. McInnes, Y. Saito, and A. Sallenger, 2014: Coastal systems and low-lying areas. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 361-409, p. 393.

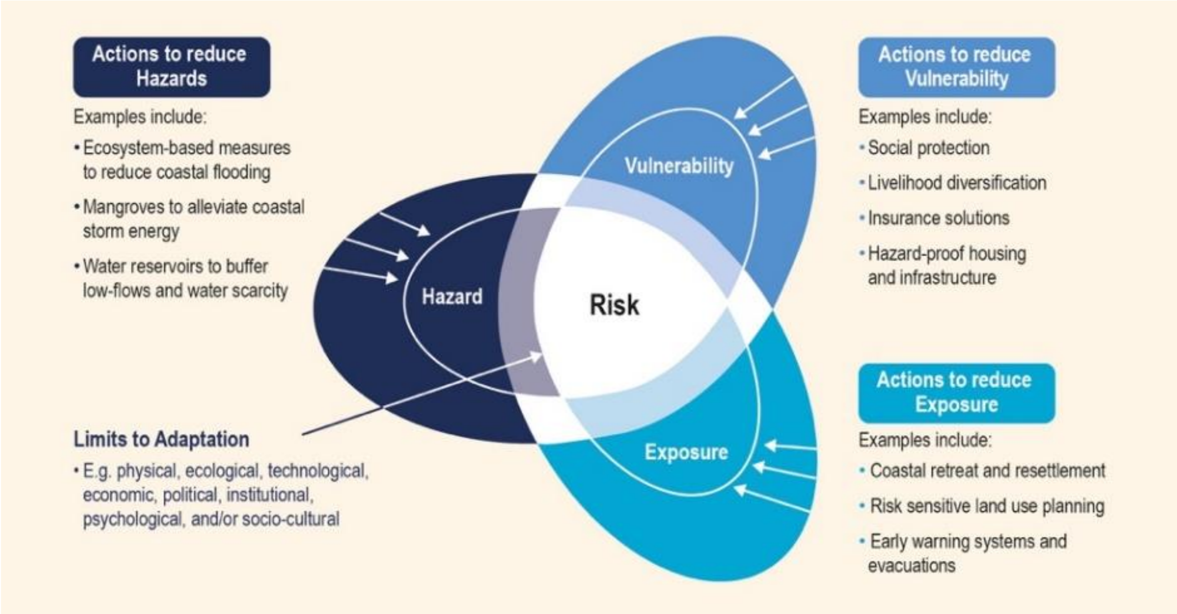


Figure G. Options for risk reduction through adaptation. Adaptation can reduce risk by addressing one or more of three risk factors: reduction of vulnerability, exposure, and/or hazard potential can be achieved through different policy and action choices over time until limits to adaptation are reached.[lvii]

---

[lvii] IPCC, 2019. Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, 2019: Ch. 4 Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge Univ. Press, Cambridge, UK and New York, NY, USA, Technical Summary, Figure TS.4, p. 46.

## 4. Responding to These Risks: Adaptation and Coastal Risk Management

"*Adaptation options that are feasible and effective today will become constrained and less effective with increasing global warming. With increasing global warming, losses and damages will increase and additional human and natural systems will reach adaptation limits*."[lviii]

### 4.1. Coastal Risk Management

Sediment-related pressures on the barrier system can – to some extent in the short-term (next few decades) – be actively managed by replacing with new material the sand supply being trapped behind dams from the longshore sediment transport system by marine-structures, ports or groynes. This can be achieved using soft, hard, or combined coastal protection works that require continued, expensive, ongoing inputs to limit downdrift erosion to maintain the coast in its current position as sea levels rise (Figure H-II, below).

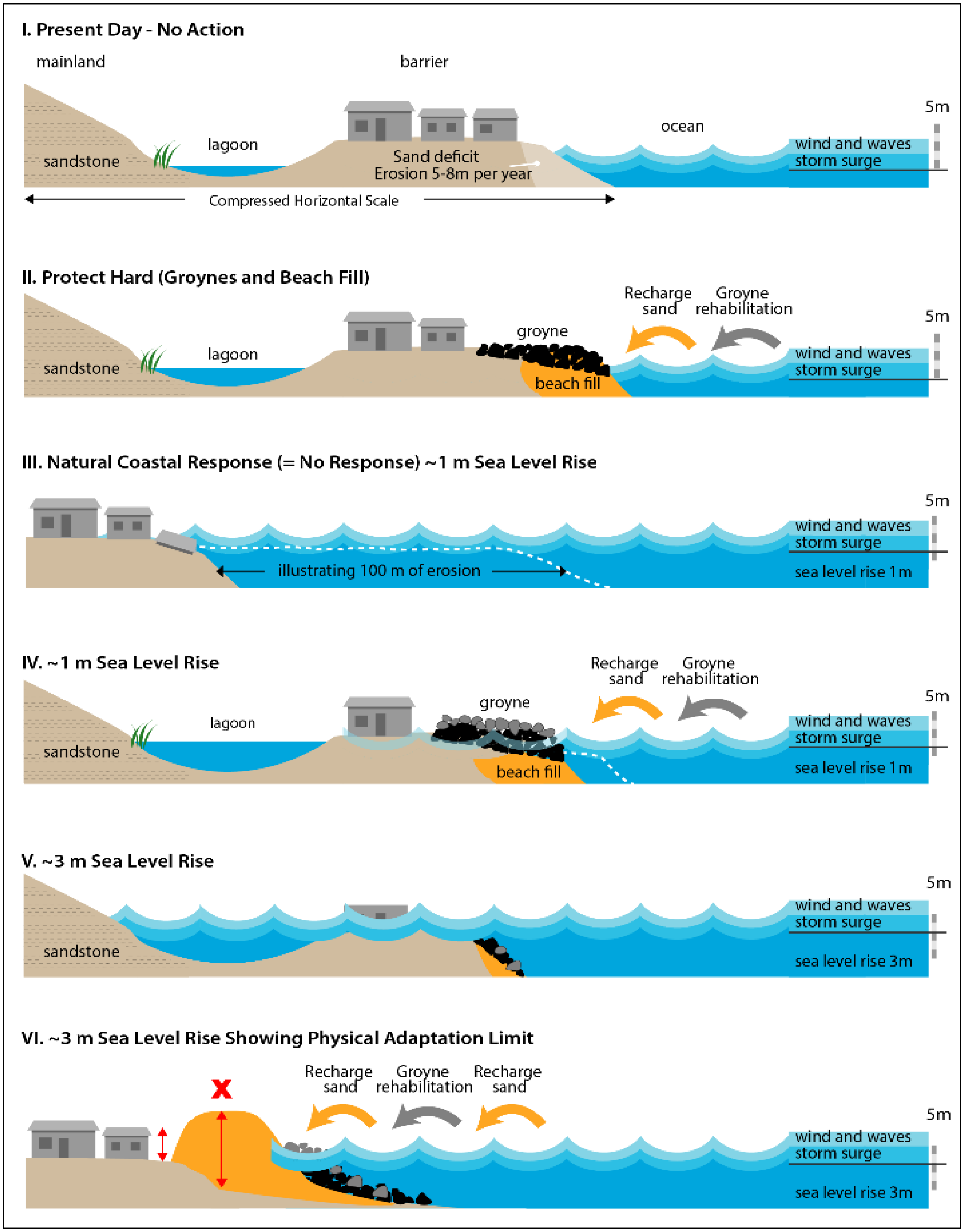
These can be important measures to help buy time to allow communities to implement more resilient adaptation options. Use of groynes plus sediment or massive-sand-recharging is broadly comparable to the effectiveness of a nature-based, coastal wetland solution in relation to SLR where recharged beaches can limit erosion "*until rates of sea-level rise exceed natural adaptive capacity to build sediment (Very high confidence)*."[lix] There is thus a long-term (over 100 year) physical limit to actions to reduce the hazard, after which it will become technically impossible or prohibitively expensive to increase beach and land levels to keep up with future SLR (Figure B, above). This will lead to the landform responses discussed in Section 3.

When these physical limits are exceeded, such as by the sea engulfing the barrier as sea level rises lead to more frequent inundation (Figure H-V and VI, below), it is no longer possible to reduce the hazard in this location (Figure I-I, below). Instead, actions to reduce exposure to the hazard (i.e., coastal retreat and resettlement) and associated vulnerabilities, such as livelihood diversification, are then required (Figure G, above).

---

[lviii] IPCC AR6 Synthesis Report. Headline Statement B.4. Adaptation Options and their Limits in a Warmer World.

[lix] IPCC, 2022: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056, Summary for Policymakers, SPM-C.2.5, p. 24.



I. Present Day - No Action

II. Protect Hard (Groynes and Beach Fill)

III. Natural Coastal Response (= No Response) ~1 m Sea Level Rise

IV. ~1 m Sea Level Rise

V. ~3 m Sea Level Rise

VI. ~3 m Sea Level Rise Showing Physical Adaptation Limit

Figure H – I-VI. Conceptual model of barrier system responses to sea level rises predicted by the IPCC to 2300, illustrating (I) present day and (II) over one meter natural barrier response to combined human and climate change impacts (physical), (III-V) Combined Protection Works under different SLR scenarios, and (VI) the future physical limits to adaptation where land raising and sand recharge cannot physically keep pace with SLR and storm surges.

## 4.2 Adaptation Pathways

Combining long-term adaptation with risk management for improving coastal resilience has thus been considered best practice since the IPCC's Fifth Assessment report. Adaptation pathways are defined as "*a time-independent sequence of actions responding to multiple drivers and uncertainties, and are guided by the magnitude of sea-level rise to determine when and where it is optimum to adapt*."[lx] Effective adaptation pathways require society to choose risk management options, land-use planning, and other policy instruments that can help society create space now, for future adaptation, thereby saving costs and improving long-term societal and ecological resilience.

This twin-track approach to adaptation – often involving reducing harm and improving resilience in the immediate term, such as by using soft or hard coastal risk management options (Figure I-II, below) and producing and implementing policies that allow us to create physical windows of opportunity on land now[lxi] – can make future adaptation feasible, intergenerationally flexible, and just.[lxii]

This can include planned retreat of communities through planning decisions now which restrict human development on land at risk of future erosion and/or flooding. These combined coastal risk and land-based adaptation pathway approaches can give communities time to engage with government and funders to help societies transform and adapt by making climate-resilient development planning decisions. These can minimize future costs of adaptation, losses, and damage by, for example, choosing to avoid increasing future harm (e.g., not adding new development in vulnerable areas).

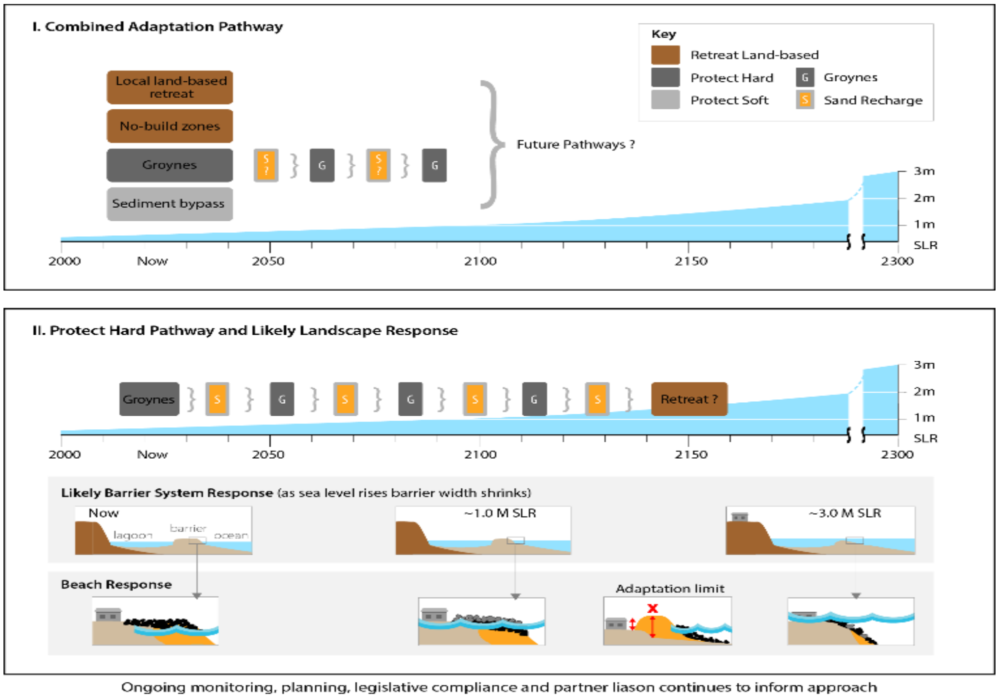


Figure I. Illustrating differences between (I) a coastal protect hard option and (II) a combined adaptation pathway.

---

[lx] Brown, S. Nicholls, R., Hanson, S. *et al.* Shifting perspectives on coastal impacts and adaptation, 2014. Nature Climate Change 4, 752–755, p. 753.

[lxi] Brown, K., Naylor, L. A. and Quinn, T. Making space for proactive adaptation of rapidly changing coasts: a windows of opportunity approach. *Sustainability*, 2017. 9(8), 1408, p. 11.

[lxii] Rennie, AF. *et al.* Dynamic Coast Summary, 2021. Centre of Expertise for Waters, p. 1.

Long-term planning of adaptation options like retreat, or large-scale technical solutions like hard estuarine barriers take decades to be realized – the IPCC's Sixth Assessment Report suggests that planning for this type of adaptation is carried out now together with more immediate-term measures to reduce vulnerability and improve resilience.[lxiii] IPCC's best practice approach for coastal climate change adaptation involves combining coastal protection along with land-based policy and retreat (Figure I-II). The IPCC argues progress on this is urgently needed to close the adaptation gap.[lxiv]

### 4.2.1. West African Coastal Barrier

These approaches for Africa appear in the latest IPCC report: "*Adaptation costs will rise rapidly with global warming (very high confidence) (...) Concessional finance will be required in low-income settings*."[lxv] SLR and extreme weather events were already identified as key climate change risks impacting African coastal communities in the IPPC's Fifth Assessment Report in 2013.[lxvi] Importantly, the Report also stated that a combination of land-use control to reduce both vulnerability and exposure to risks and low-cost, soft, protective coastal infrastructure is considered more feasible and sustainable than hard infrastructure solutions alone.[lxvii]

---

[lxiii] IPCC, 2022: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 Summary for Policymakers, p. 20.

[lxiv] Ibid.

[lxv] Trisos, C.H., I.O.Adelekan, E.Totin, A.Ayanlade, J.Efitre, A.Gemeda, K.Kalaba, C.Lennard, C.Masao, Y.Mgaya, G. Ngaruiya, D. Olago, N.P. Simpson, and S. Zakieldeen, 2022: Africa. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O.Pörtner, D.C.Roberts, M.Tignor, E.S.Poloczanska, K.Mintenbeck, A.Alegría, M.Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1,285–1,455, doi:10.1017/9781009325844.011, {9.4.1}, p. 1,289.

[lxvi] Niang, I., O.C. Ruppel, M.A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. Urquhart, 2014: Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, United Kingdom and New York, NY, USA, p. 1237-1238, Table 22-6, p. 1,235.

[lxvii] Ibid.