Climate risk report for the Central Africa region

Authors: Amy Doherty, Megan Pearce, Roger Calow, Gabrielle Daoust, Adam Higazi, Laura Burgin and Rebecca Osborne

Reviewers: Richard Jones and Jane Strachan

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Lead authors

Amy Doherty, Senior Scientist
Megan Pearce, Scientist
Roger Carlow, Research Officer
Gabrielle Daoust, Research Associate
Adam Higazi, Research Associate
Laura Burgin, Scientific Manager
Rebecca Osborne, Scientific Manager

Reviewed by

Richard Jones, Science Fellow
Jane Strachan, Head International Applied Science

Authorised for issue by

Cindy Somerville, International Development Delivery Manager

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Executive summary

Central Africa is already exposed to a changing climate and its impacts, and these must be considered to ensure climate resilient development planning. This report analyses key risks across the Central Africa region under 6 themes: (1) **biodiversity, ecology and forests** (2) **agriculture and food security**; (3) **water resources and water-dependent services**; (4) **infrastructure and settlements**; (5) **health**; and (6) **coasts, fisheries and the marine environment**. These themes are not comprehensive, and there are many overlaps between them, signposted in the sections that follow.

For this report, Central Africa includes **Cameroon, the Central African Republic, Equatorial Guinea, Gabon, the Republic of Congo, the Democratic Republic of the Congo and Angola**. Climate change is one of several risks to resources, livelihoods, economies, and ecosystems. Central Africa is a dynamic region, experiencing rapid population growth, urbanisation and economic transformation, and assessments of climate risks can only ever provide a partial picture of the role climate change plays in shaping development outcomes. Key climate-related risks for Central Africa have been identified by considering how the current climate interacts with underlying socio-economic conditions, and how further climate change to the 2050s may exacerbate these risks. Seeing the 'bigger picture' where multiple risks compound, interact with one another and drive change will remain important for those charged with designing, monitoring, and evaluating development programmes. Most risks identified in this report are not new for the region, but the frequency, severity and distribution of those risks are changing as the climate changes and economies develop.

The Central Africa region has the highest species diversity on the continent and is globally important for its role as a vast absorber and storer of carbon, and as a source of rainfall and freshwater for the African continent (Section 3.1). Central Africa's rainforests form the second largest rainforest bloc in the world after the Amazon. The region's forests sequester more carbon than any other tropical forest both in the above-ground biomass and in the world's largest peat deposits, located in the Cuvette Centrale of the Republic of the Congo and the Democratic Republic of Congo. Oil and gas exploration, including proposed drilling in the Cuvette Centrale and in areas of intact tropical moist forest, is a challenge to global climate change mitigation agreements and to biodiversity. Other pressures include hunting, which has led to 'defaunation' in some areas, disturbing ecosystems

Central Africa Climate

The region is hot and generally humid, with exceptions in the northern arid Sahelian area (northern Sudano-Sahelian region of Cameroon and northern Central African Republic) and the cooler and drier area in southern Angola. The Congo River Basin and Congo Forest areas are extremely humid containing the second largest tropical rainforest in the world. The region also contains mountains, savannahs, and wetlands. Central Africa's forests play an important role in regulating the world's climate. Central Africa's average annual surface temperatures have increased by between 0.75°C and 1.5°C since 1960. The warming, and associated evapotranspiration will continue to increase in the future and heavy rainfall events will be more intense and more frequent. Average rainfall trends are less clear, however there is some indication of wetter conditions in the northern part of the region by the 2050s and drier conditions in the south, especially in southern Angola which will become more arid. Deforestation of tropical rainforests will lead to reduced evapotranspiration and further warming, with average increases of 0.7°C and up to 1.2 °C locally in deforested areas of the Congo Basin. Complete removal of the forest could lead to 2-3°C of warming in the centre of the basin. Deforestation also alters atmospheric circulation, leading to changes in rainfall of up to 10% in local hotspots. Complete deforestation could see declines of rainfall by around 40% in western areas of Central Africa (Bell et al., 2015). Central Africa's coast is at risk from rising sea levels, sea surface temperatures and increasing ocean acidification.

and threatening iconic species. Logging and forest clearance for agriculture and oil palm plantations also threaten forest ecology and biodiversity, especially if not properly regulated. The ecosystem services of Central Africa's forests are globally essential but undervalued in conventional economic terms, which can lead to destructive land-use changes being deemed more profitable than forest conservation. The climate risks to Central Africa's forests will depend on what happens to rainfall patterns – which models cannot yet predict with confidence. Large increases in temperature and evapotranspiration also pose risks to forest ecology and biodiversity.

Food systems in Central Africa are particularly vulnerable to climate change because most crops are rainfed, and farming and pastoral livelihoods are subsistence-orientated (Section 3.2). Although agricultural production accounts for a relatively low proportion of national GDP in the region, most rural people still depend on farming and livestock to make a living. Livelihoods dependent upon crops, fishing and livestock are already affected by rising temperatures, greater rainfall variability and extremes. Maize, a key staple, is particularly sensitive to rising temperatures; across sub-Saharan Africa, climate change has already reduced yields by 5.8% over the period 1974-2008. By 2050, pasture productivity is projected to decline by 5% in Central Africa. Important crops such as sorghum and cassava are more resilient to increased temperature and variable rainfall. Higher levels of atmospheric CO_2 which can enhance plant growth may offset some crop losses, but this effect is likely to be much smaller with more research required to quantify the offset.

Food security, a broader issue, will become more precarious as food production and food prices - local to regional - becomes more volatile (Section 3.2). Some Central African households may benefit – net sellers of food for example – though much depends on whether rising prices compensate for production losses. Most will be harmed because they are net consumers: subsistence-orientated farmers struggling to meet their own food needs from a single, more unpredictable rainy season, and growing numbers of urban poor dependent on informal wage labour to buy essentials.

Many of the impacts of climate change will be felt through the water cycle (Section 3.3). Central Africa has abundant freshwater resources, but greater rainfall variability and more climate extremes will make the job of harnessing and managing these resources more difficult. More frequent and more intense rainfall events, plus rising temperatures, also pose risks to water quality. Reliance on more climate-resilient groundwater resources will likely increase, particularly for drinking water and small-scale irrigation. Populations lacking access to safe water and sanitation (47% and 73% respectively across Central Africa, mainly rural and poor) are most exposed to water contamination and disease, particularly after heavy rainfall events when pathogens are flushed into unprotected water sources.

More variable river flows may disrupt electricity generation from hydropower – the dominant source of on-grid power supply in Central Africa. This is because managing river flows for power, flood control and environmental objectives will become more difficult. The region has enormous untapped hydropower potential; hydropower development on the Congo River alone could potentially provide 40% of *Africa's* energy needs. Yet roughly 50% of the population, overwhelmingly rural, lack access to electricity. A key risk to be managed is that most big, irreversible infrastructure projects with a long design life are planned for historical, poorly characterised climate conditions, not future climates. More resilient energy systems will need to rely increasingly on multiple options spread across multiple grids – smart, mini, hybrid and cross-border – to mitigate climate risk.

Central Africa's infrastructure deficit in power, transport, housing, and communications hinders economic growth and poverty reduction. Existing infrastructure is also vulnerable to climate extremes, particularly heatwaves and floods (Section 3.4). Climate risk and poverty increasingly coincide in Central Africa's fast-growing informal settlements; over 60% of the region's urban population live in informal settlements and are exposed to multiple hazards, especially floods that damage infrastructure and spread sewage over wide areas. While the severity of natural disasters is often measured in terms of asset loss and damage, secondary impacts on economic activities and output often explain a larger share of impacts as risks cascade across areas, sectors, and users.

Populations and economic assets are concentrated in Central Africa's coastal cities exposed to sea level rise, storm surges, erosion, and flooding. Over half of the region's urban population now lives in coastal cities, attracted by job opportunities in industries linked to oil and gas, mining, agro-processing, and fishing. Most urban expansion is unplanned, opportunistic, and increasingly risky.

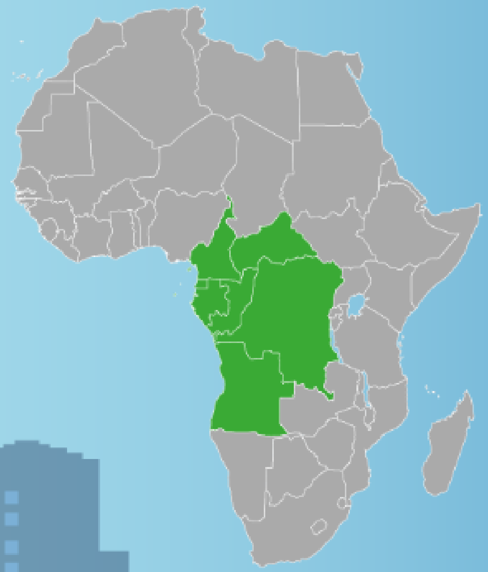
Risks to health are closely linked with rising temperatures, extreme events, and associated increases in communicable and non-communicable disease across Central Africa (Section 3.5). Outbreaks of water-borne diseases such as cholera, diarrhoea and typhoid are already common and likely to increase, particularly after floods and in densely populated informal settlements with poor drainage. Temperature and rainfall changes may also contribute to shifts in the distribution and transmission of vector-borne diseases such as malaria and dengue fever. New malaria areas may emerge at higher altitude; lowland areas experiencing very high temperatures may see a decrease in transmission.

Heat extremes pose a threat to health, particularly when they combine with high humidity and air pollution. Urban areas are typically several degrees hotter than rural neighbourhoods, increasing the risk of potentially fatal heat stress. On average cities in central Africa are expected to see an 89-fold increase in the number of extreme heat events under high emissions by the end of the century. People at elevated risk include the elderly, infants, pregnant women, those living in cramped conditions and those working outside, especially manual labourers. Rising temperatures and heat extremes, combined with air pollution, can also exacerbate non-communicable diseases such as cardiovascular and respiratory illnesses. Assessments of heat-related mortality risks among people aged over 65 on a global scale have identified Central Africa as the region at greatest risk due to the combined effects of severe heat waves, population increase, and aging infrastructure.

Coastal and marine fisheries play an important economic and nutritional role in Central Africa, but they are vulnerable to ocean warming and changing oxygen levels (**Section 3.6**)**.** These trends have already contributed to shifts in the distribution of fish species, and risks associated with rising temperatures and extreme events pose risks to fishery infrastructure and productivity. Marine and coastal ecosystems, including sandy beaches, coastal estuaries and deltas, wetlands, and mangrove systems support rich fauna and flora, and play a vital role in coastal protection. They are threatened by extractive industries, pollution, and urban expansion, as well as by climate change. In particular, **higher marine temperatures, marine heatwaves, sea level rise and increasing ocean acidity threaten the health, function, and productivity of coastal and marine ecosystems and biodiversity.**

Central Africa Climate Risk Report

HEADLINE CLIMATE STATEMENTS



Central Africa has warmed by between 0.75°C and 1.5°C from 1961 to 2015.

Temperatures in Central Africa will increase by at least 1.0˚C by the 2050s, with increases of up to 4.5˚C under high emissions, compared to a 1981-2010 baseline.

The intensity and number of very hot days will increase in the Central African region.

Large variations in the timing and intensity of seasonal rains will continue to be experienced over Central Africa. This variability will increase through to the 2050s resulting in more frequent wetter and drier years and a higher risk of flood and drought events.

The intensity of heavy rainfall events will increase in Central Africa, even in areas where average rainfall decreases.

Annual rainfall totals are expected to increase in northern Central Africa, and reduce in the far south of the region.

There may be a delay to the onset of the rainy season in southern Central Africa with a reduction in the length of the rainy season.

Sea surface temperatures in Central Africa will increase by 0.7-1.8˚C on average under very low emissions and by 0.7-2.5˚C under very high emissions by the 2050s, compared to a 1981-2010 baseline.

Central African sea levels have been rising at a rate of around 3mm a year between 1993-2018. They will continue to rise, by around 0.2 m under very low emissions and 0.3 m under very high emissions by the 2050s compared with 1995-2015 levels.

Central African seas will continue to acidify, and the frequency of marine heatwaves will increase.

Country climate-related risk profiles

Analysis is conducted at the regional level using nine zones. These country summaries are intended to help direct readers towards the relevant sections within the report by country; they are not a complete assessment of the full range of risks at a country level.

Angola country profile

Summary of climate analysis relevant to Angola	**Report section**
Angola experiences a tropical savannah climate in the north and a cooler, semi-arid climate in the south. It has a long coastline and large coastal population, with marine fisheries playing a vital socio-economic role. Angola has already experienced more than 1°C of warming between 1961 and 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. Angola has a rainy season between October and April, which is longer in the north of the country and shorter (November to March) in the south of the country which receives small annual rainfall totals compared to the rest of the region. There has been no significant trend In average precipitation in recent decades. By 2050 there is some indication for wetter conditions in the rainy season and a delay to the onset of the rainy season. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events, and increased evapotranspiration resulting from rising temperatures. Sea levels will continue to rise by the 2050s, exacerbating coastal flooding and erosion. Sea surface temperatures will increase, resulting in increases in the frequency and intensity of marine heatwaves and ocean acidification. The rich marine life off the coast of Angola is under threat as warming temperatures and marine heatwaves affect ocean circulation.	2.2, Technical Reference Document: Section D, Zones 3 and 4
Regional risks relevant to Angola	**Report section**
Risks to crops and livestock due to rising temperatures and heat extremes, water stress, and heavy precipitation events.	3.2
Risks to water resources, including rural and urban water supplies, due to increased rainfall variability, reduction in available water, and contamination from floods and saltwater inundation.	3.3, 3.4
Risks to urban settlements, including coastal cities such as Luanda and Lobito and port infrastructure, due to rising sea levels, rising temperatures and heat extremes and heavy precipitation events and flooding.	3.4
Risks to health including increases in communicable water-borne diseases, vector-borne disease risks, and heat-related risks.	3.5
Risks to fisheries (e.g., declining fish populations) and to coastal ecosystems and biodiversity due to rising sea levels, increased sea surface temperatures, increasing acidification and more frequent marine heatwaves.	3.6

Cameroon country profile

Summary of climate analysis relevant to Cameroon	Report section
Cameroon is characterised by a hot and arid climate in the north, and a humid, tropical climate in the south. The south-east of the country extends into part of the Congo River Basin, and the coastal regions are home to the largest mangrove cover in Central Africa. The south-east and south-west have important blocks of tropical moist forest, including areas of high biodiversity in protected areas. In northern Cameroon there is significant savannah biodiversity and a chain of national parks from the border with Nigeria to the border with Chad, with important megafauna. Agriculture and pastoralism are the main livelihoods in the north and centre and fisheries (coastal and inland) also play an important socio-economic role. Mining, logging, and plantation agriculture are all important for Cameroonian government revenues. Cameroon has already experienced at least 0.75°C of warming between 1961 to 2015. Temperatures will continue to rise in the future, with greater increases likely in the south of the country. Northern Cameroon has a single pronounced rainy season from July to September. To the south, monthly rainfall totals are high year around, with the wettest months occurring from September to November. No trend in seasonal or annual rainfall totals has been observed in Cameroon in recent decades but there is some indication that for higher levels of global warming the intensity of extreme rainfall will increase and there will be increased flooding associated with the monsoon. Sea levels will continue to rise by the 2050s and ocean temperatures will continue to increase resulting in growth in frequency and intensity of marine heatwaves and ocean acidification.	2.2, Technical Reference Document: Section D, Zones 1 and 2

Regional risks relevant to Cameroon	Report section
Risks to forests and associated ecology and biodiversity due to rising temperatures and changing rainfall patterns.	3.1
Risks to crops and livestock due to rising temperatures and heat extremes, water stress, and heavy precipitation events.	3.2
Risks to inland fisheries due to increased water temperatures and changing seasonal water availability patterns.	3.2
Risks to water resources, including rural and urban water supplies, due to increased rainfall variability, reduction in available water. and contamination from floods and saltwater inundation.	3.3, 3.4
Risks to urban settlements, including coastal cities such as Douala and port infrastructure, due to rising temperatures and heat extremes and heavy rainfall events and flooding.	3.4
Risks to health including increases in communicable water-borne diseases, vector-borne disease risks, and heat-related risks.	3.5

Risks to fisheries and to coastal ecosystems and biodiversity (including mangrove systems) due to rising sea levels, increased sea surface temperatures, increasing acidification and more frequent marine heatwaves.	3.6

Central African Republic country profile

Summary of climate analysis relevant to Central African Republic	Report section
Central African Republic experiences an arid/semi-arid climate in the north and savannah woodland and patches of tropical forest in the south. It is the only landlocked country in the Central Africa region. Agropastoralism and cereal-root crop mixed systems are the main livelihood systems in the north, while root and tuber crop systems dominate in the south. Central African Republic has already experienced at least 0.75°C of warming between 1961 to 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. Central African Republic experiences a rainy season between July and September. There has been no significant trend in average precipitation in recent decades and by the 2050s there is some indication that the rainy season will lengthen, and Central African Republic will see wetter conditions during September to November (start of the rainy season). Frequency and intensity of heavy rainfall events will increase. Due to increased warming, levels of evaporation and evapotranspiration will rise, even if there is no decrease in rainfall totals availability of water will decrease.	2.2, Technical Reference Document: Section D, Zone 1

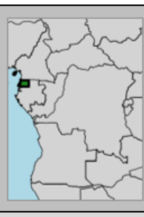
Regional risks relevant to Central African Republic	Report section
Risks to crops and livestock due to rising temperatures and heat extremes, water stress, and heavy precipitation events.	3.2
Risks to inland (e.g., river) fisheries due to increased water temperatures and changing seasonal water availability patterns.	3.2
Risks to water resources, including rural and urban water supplies due to increased rainfall variability, reduction in available water, and contamination from floods and saltwater inundation.	3.3, 3.4
Risks to urban settlements due to rising temperatures and heat extremes and heavy precipitation events and flooding.	3.4
Risks to health including increases in communicable water-borne diseases, vector-borne disease risks, and heat-related risks.	3.5

Democratic Republic of the Congo country profile

Summary of climate analysis relevant to Democratic Republic of the Congo	Report section
Democratic Republic of the Congo experiences a mix of climates. The DRC has by far the largest block of tropical moist forest in Central Africa, as well as areas of savannah, wetland swamp forest, and montane forest. The centre of the Democratic Republic of Congo contains the largest area of tropical moist forest, and this radiates out in all directions. The far north of Democratic Republic of Congo is savannah, as is Katanga in the south-east. Democratic Republic of the Congo has a narrow stretch of coastline defined by the Congo River estuary and mangrove forests and by the capital city, Kinshasa, Crucially, the DRC has very biodiverse inland fisheries in the Congo River Basin. Democratic Republic of the Congo has already experienced more than 0.75°C of warming between 1961 to 2015. Temperatures will continue to increase in the future with increases in the frequency and intensity of hot extremes. The forested area of Democratic Republic of the Congo in the north sees rainfall throughout the year, with drier conditions in the south of the country which has a distinct rainy season from October to March. There has been no significant trend in average precipitation in recent decades. The rainy season may become wetter by the 2050s and there is some evidence for a delay to the start of the rainy season in the south of the country. Flood events are likely to become more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events, and increased evapotranspiration resulting from rising temperatures. Sea level rise, more frequent inundation, and rising sea surface temperatures by the 2050s pose threats to the Congo estuary ecosystems including the mangrove forests.	2.2, Technical Reference Document: Section D, Zones 2, 3 and 4

Regional risks relevant to Democratic Republic of the Congo	Report section
Risks to forests and associated ecology and biodiversity due to rising temperatures and changing rainfall patterns.	3.1
Risks to crops and livestock due to rising temperatures and heat extremes, water stress, and heavy precipitation events.	3.2
Risks to inland fisheries (e.g., Congo River, Lake Tanganyika) due to increased water temperatures and changing seasonal water availability patterns.	3.2
Risks to water resources, including rural and urban water supplies, due to increased rainfall variability, reduction in available water, and contamination from floods and saltwater inundation.	3.3, 3.4
Risks to urban settlements, including coastal settlements, due to rising temperatures and heat extremes and heavy precipitation events and flooding.	3.4
Risks to health including increases in communicable water-borne diseases, vector-borne disease risks, and heat-related risks.	3.5
Risks to fisheries and to coastal ecosystems and biodiversity (including mangrove systems) due to rising sea levels, increased sea surface temperatures, increasing acidification and more frequent marine heatwaves.	3.6

Equatorial Guinea country profile



Summary of climate analysis relevant to Equatorial Guinea	Report section
Equatorial Guinea borders Cameroon and Gabon and has substantial tropical forests and includes two islands: the small island of Annobón and the larger Bioko. Both islands have high biodiversity and endemic species, and Bioko is the site of the capital city Malabo. Marine fisheries are important economically for the country. Equatorial Guinea has the highest GDP of all the countries in Central Africa and the highest population growth rate (3.4%). Equatorial Guinea has already experienced at least 0.75°C of warming between 1961 to 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. The wettest periods of the year in Equatorial Guinea occur during March/April and October. There has been no significant trend in average precipitation in recent decades but there is some indication that conditions will be wetter by the 2050s. Frequency and intensity of heavy rainfall events will increase leading to more frequent flood events, and increased evapotranspiration resulting from rising temperatures reducing water availability. Sea levels will continue to rise by the 2050s and temperatures will continue to increase. Both the mainland and islands of Equatorial Guinea are vulnerable to beach erosion and shoreline retreat affecting fisheries as well as wildlife (e.g., turtle) habitats.	2.2, Technical Reference Document: Section D, Zone 2

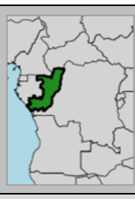
Regional risks relevant to Equatorial Guinea	Report section
Risks to forests and associated ecology and biodiversity due to rising temperatures and changing rainfall patterns.	3.1
Risks to crops due to rising temperatures and heat extremes, water stress, and heavy precipitation events.	3.2
Risks to water resources, including rural and urban water supplies, due to increased rainfall variability, reduction in available water, and contamination from floods and saltwater inundation.	3.3, 3.4
Risks to urban settlements, including coastal cities such as Malabo and port infrastructure, due to rising temperatures and heat extremes and heavy precipitation events and flooding.	3.4
Risks to health including increases in communicable water-borne diseases, vector-borne disease risks, and heat-related risks.	3.5
Risks to fisheries and to coastal ecosystems and biodiversity (e.g., sandy beaches and protected areas such as the Reserva Natural del Estuario del Muni) due to rising sea levels, increased ocean temperatures, increasing acidification and more frequent marine heatwaves.	3.6

Gabon country profile

Summary of climate analysis relevant to Gabon	Report section
Gabon experiences a humid tropical climate. Fisheries, oil and gas, regulated commercial logging, and high-end tourism in its national parks, are important economically. Gabon is one of the more prosperous countries in the Central African region. Gabon has experienced more than 0.75°C of warming between 1961 to 2015. Temperatures will continue to rise in the future resulting in an increase in the frequency and intensity of hot extremes. Gabon receives rainfall throughout the year with peaks in March and October. There has been no significant trend in average precipitation in recent decades, though there is some indication of wetter conditions annually by the 2050s. Frequency and intensity of heavy rainfall events will increase leading to higher frequency of flood events. Due to increased warming, levels of evaporation and evapotranspiration will rise, meaning that even if there is no decrease in rainfall totals, availability of water will decrease. Sea levels will continue to rise, and sea surface temperatures will continue to increase. The coast of Gabon hosts the capital Libreville, beaches, and estuaries, including mangroves, that are at risk from flooding, erosion and shoreline retreat, and water supplies are threatened by salination from saltwater inundation.	2.2, Technical Reference Document: Section D, Zone 2

Regional risks relevant to Gabon	Report section
Risks to forests and associated ecology and biodiversity due to rising temperatures and changing rainfall patterns.	3.1
Risks to crops due to rising temperatures and heat extremes, water stress, and heavy precipitation events.	3.2
Risks to water resources, including rural and urban water supplies, due to increased rainfall variability, reduction in available water, and contamination from floods and saltwater inundation.	3.3, 3.4
Risks to urban settlements, including coastal cities such as Libreville and port infrastructure, due to rising temperatures and heat extremes and heavy precipitation events and flooding.	3.4
Risks to health including increases in communicable water-borne diseases, vector-borne disease risks, and heat-related risks.	3.5
Risks to fisheries and to coastal ecosystems and biodiversity (including mangrove systems and the Bas Ogooué Delta) due to rising sea levels, increased sea surface temperatures, increasing acidification and more frequent marine heatwaves.	3.6

Republic of the Congo country profile



Summary of climate analysis relevant to Republic of Congo	Report section
The Republic of Congo has a humid tropical climate to the north and a tropical savannah climate to the south. Deforestation rates have historically been much higher in the south than in the north. The northern region contains large and biologically important tropical moist forest and vital protected areas. Agriculture in the north is typified by tree crop and forest-based systems while in the south it is dominated by root and tuber systems. Inland and marine fisheries are important across the country. The Republic of Congo has already experienced more than 0.75°C of warming between 1961 to 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. Republic of Congo has two peaks in precipitation occurring in March and October. There has been no significant trend in average precipitation in recent decades and by the 2050s the country will be wetter on average across the year. Frequency and intensity of heavy rainfall events will increase causing increased flooding and due to increased evapotranspiration resulting from rising temperatures water availability will decrease. Sea levels will continue to rise, and sea surface temperatures will continue to increase threatening marine life and causing flooding and coastal inundation.	2.2, Technical Reference Document: Section D, Zones 2 and 3

Regional risks relevant to Republic of Congo	Report section
Risks to forests and associated ecology and biodiversity due to rising temperatures and changing rainfall patterns.	3.1
Risks to crops due to rising temperatures and heat extremes, water stress, and heavy precipitation events.	3.2
Risks to inland (e.g., Congo River) fisheries due to increased water temperatures and changing seasonal water availability patterns.	3.2
Risks to water resources, including rural and urban water supplies, due to increased rainfall variability, reduction in available water, and contamination from floods and saltwater inundation.	3.3, 3.4
Risks to urban settlements, including coastal cities such as Pointe-Noir and port infrastructure, due to rising temperatures and heat extremes and heavy precipitation events and flooding.	3.4
Risks to health including increases in communicable water-borne diseases, vector-borne disease risks, and heat-related risks.	3.5
Risks to fisheries and to coastal ecosystems and biodiversity due to rising sea levels, increased sea surface temperatures, increasing acidification and more frequent marine heatwaves.	3.6

Image location: Equatorial Guinea

1 Introduction

1.1 Purpose of this report

This report provides an evidence base on the Central Africa region's changing climate and how these changes could impact socio-economic development across the region. The aim is to inform development programming and policy dialogue for Central Africa. It forms part of a of a series of climate risk reports commissioned by the UK Government's Foreign, Commonwealth & Development Office (FCDO) which interpret climate, socio-economic and environmental information to support FCDO regional development planning.

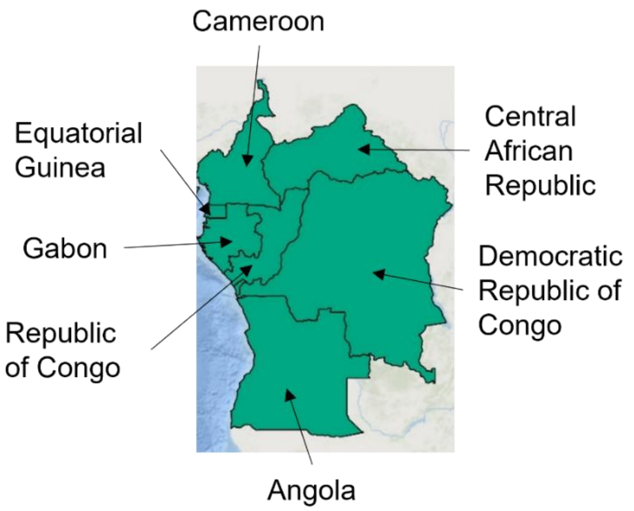


Figure 1: Countries included in the Central Africa region for this report.

For the geographic scope of this report, Central Africa includes **Cameroon, the Central African Republic, Equatorial Guinea, Gabon, the Republic of Congo, the Democratic Republic of the Congo and Angola** (Figure 1). Key aspects of the region, such as the elevation of the region and population densities, are also shown in Figure 2 (middle and right panels)

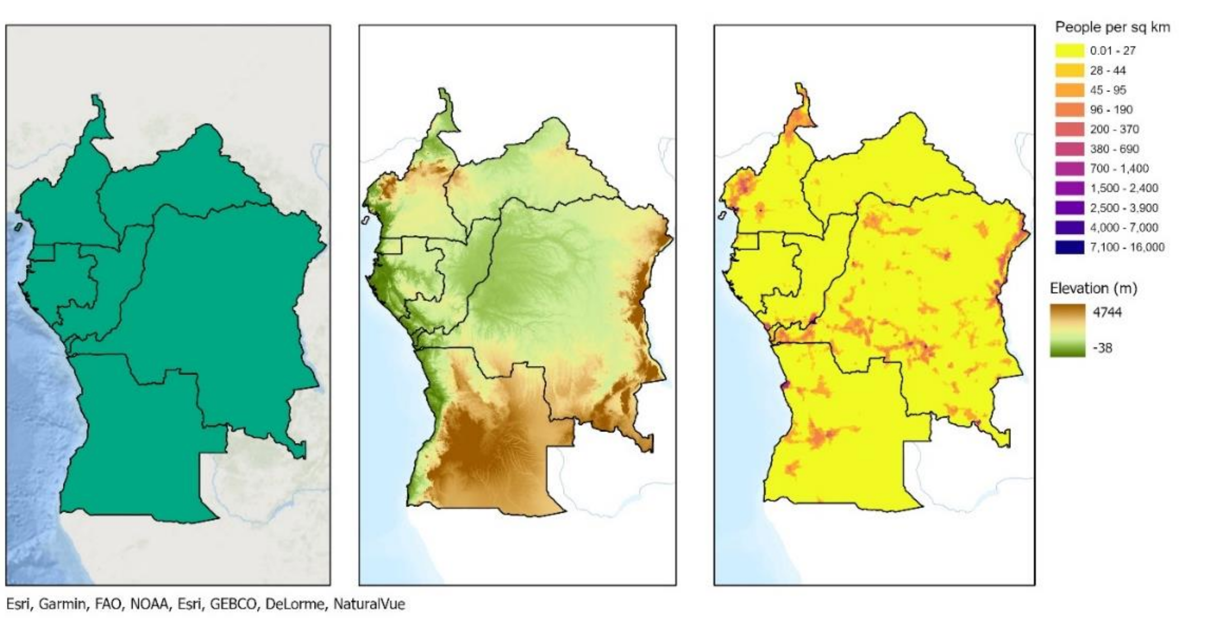


Figure 2: The Central Africa region considered in this report. Left panel: countries included in the analysis, middle panel: elevation of the region, right panel: population density.

1.2 Methodological approach

This report presents an analysis of climate risk in the Central Africa region, combining climate with social and economic analysis to identify key threats to production systems, resources, economies, services, and livelihoods. The report aims to guide development planners to areas requiring attention, providing an overview of key risks and uncertainties, bringing prominent regional risks to the fore.

Current climate has been analysed for geographical regions which share similar climate characteristics, such as the timing of rainy seasons or similar seasonal temperature ranges. This climate analysis is brought together with regional socio-economic information to contextualise our knowledge of future regional climate change, known as climate projections.

The interpretation of knowledge of future climate in this report is informed by six issues that run through analysis of several themes:

- Economic growth and infrastructure, including disparities in income/wealth distribution.
- Capacity and human capital, including ways in which climate risks are shaped by gender and differences in power, rights, and opportunities.
- Population and demography, including rapid urbanisation and the growth of informal settlements where climate risks are amplified.
- Livelihood systems and key crops, with a focus on more exposed (rainfed) agricultural and pastoral systems.
- Disaster risks, given projected increases in the frequency and magnitude of extreme events such as floods and droughts.
- Conflict and migration in a region where political instability and violence undermines efforts to build resilience.

Further information regarding the data used and detailed methodology can be found in Section A of the Technical Reference Document and on the Met Office website[1].

Focus Box 1 explains why it is necessary to consider both exposure and vulnerability to climate hazards, and the need for an interdisciplinary approach when interpreting compound risks associated with, or exacerbated by, climate change.

[1] https://www.metoffice.gov.uk/services/government/international-development/climate-risk-reports

Focus Box 1: Exposure, vulnerability, response and development

A climate or disaster hazard does not in itself create risk. Risk is a function of both an individual's or community's exposure and vulnerability to a hazard, and also its ability to respond (Figure 3, Begum et al., 2022). Exposure and vulnerability are separate, yet both emerge from socio-economic contexts and are exacerbated by uneven development dynamics such as: rapid urbanisation and demographic change, environmental degradation, weak governance, and lack of economic opportunity. IPCC AR6 also now considers response as an important component of risk and examines the effectiveness of adaptation solutions, the management of risks at higher levels of warming if climate change mitigation is unsuccessful and the benefits of mitigation and emissions reductions (Begum et al., 2022).

The components of risk (hazard, vulnerability, exposure and response) interact in complex ways (Figure 3, Begum et al., 2022). They can compound in single or multiple directions, cascade (e.g., with one event triggering another) and aggregate (e.g. more than one component occurring simultaneously).

Climate vulnerability and poverty are often mutually reinforcing; a growing body of evidence highlights the role of climate risk in persistent poverty and poverty traps (Hansen et al, 2019; Sachs et al., 2004). This is a challenge exacerbated by the political marginalisation of many poor and climate vulnerable people (Wisner et al., 2003).

Climate change is interwoven with development challenges across the Sustainable Development Goals (SDGs). As factors such as economic inequality, education, gender, nutrition and health shape the risk profile of individuals and communities, supporting sustainable development indirectly supports their capacity for managing climate risk (Wisner et al., 2003; Schipper and Pelling, 2006).

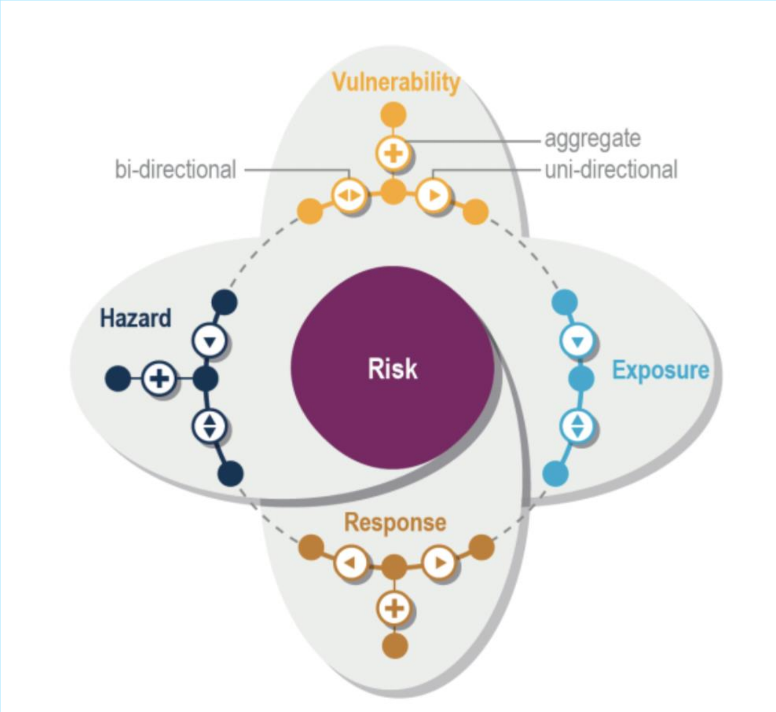


Figure 3: Climate risk is the product of the hazard, vulnerability and exposure to the hazard and the response to the hazard which interact in complex ways: compounding in single or multiple directions, cascading and/or aggregating. Image adapted from IPCC AR6 Working Group 2 (Begum et al, 2022).

1.3 Report structure

The current climate already includes significant changes in climate to which some aspects of human and ecological systems are not well adapted. Section 2 provides an assessment of the current climate resilience and vulnerability across the Central Africa region, as well as a summary of our knowledge about the current climate and its future evolution at the regional scale. This information is brought together to present assessments of the current and future climate in the context of the prevailing socio-economic conditions in newly identified zones defined by their main climate characteristics. Section 3 interprets this knowledge on future climate presented in Section 2 in terms of risks across six key themes: biodiversity, ecology and forests; agriculture and food security; water resources and water-dependent services; infrastructure and settlements; health; and coasts, fisheries, and the marine environment.

Country summaries have been provided in Appendix A to outline prominent climate risks for that location within the regional context. The summaries do not provide a national level analysis and there will be additional climate risks pertinent at a national scale that should also be considered in a national or subnational development plan. Where relevant risks are identified, or where national or sub-national scale risk information is required, additional climate and socio-economic analysis would be required.

The Technical Reference Document accompanies this report to provide more detail on the methods, data and analysis that supports the assessment presented here.

Image location: River Congo, Republic of Congo

2 Climate in context: current and future climate in the Central Africa region in the context of socio-economic dynamics

2.1 Climate resilience and vulnerability overview for the Central Africa region

Central Africa is rich in natural resources and home to the world's second largest tropical rainforest, with rare biodiversity and crucial climate regulating and carbon capture/sink functions. However, the region is characterised by high levels of wealth inequality, poor infrastructure, and political instability and conflict.[2] Understanding the nature and distribution of poverty and other inequalities remains crucial to any understanding of climate risk. Recent analyses demonstrate how climate shocks keep people in poverty and push people back into poverty (Hallegatte et al., 2016, 2017; World Bank, 2020). Poorer people are typically more exposed and more vulnerable to hazards that destroy assets and income streams; to water-borne diseases and pests that become more prevalent during heat waves, floods or droughts; to crop failure and livestock mortality; and to spikes in food prices that often follow local production failures or, at present, shocks to international trade (ODI, 2022).

Central Africa's coastal environments, including low sandy beaches and mangrove forests vital for biodiversity, are vulnerable to sea level rise and erosion. Central Africa is the most water-abundant region of Africa, with DRC alone accounting for 23% of Africa's renewable water resources. All seven focus countries fall within the low or no 'water stress' categories. Climate change is unlikely to have a detrimental impact on overall water availability.

All countries in the region export mostly primary commodities rather than manufactured goods. Agricultural production (including forestry and fishing) accounts for a relatively low proportion of national GDP, although high rates of agricultural employment highlight the sector's importance to people's livelihoods, food security, and socio-economic wellbeing. The majority of the region's poverty-affected populations live in rural areas and depend, directly or indirectly, on rainfed agriculture leaving them vulnerable to rising temperatures and rainfall variability.

Rapid urbanisation is changing the exposure and vulnerability landscape. The urban population across the seven countries increased from roughly 20 million in 1990 to an estimated 87 million in 2020 and is projected to rise to over 243 million by 2050. Infrastructure provision (water and sanitation, housing, etc.) lags behind urban expansion.

A full summary of the socio-economic context of climate risk in Central Africa is provided in Section B of the Technical Reference Document.

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[2] Four of the seven focus countries are included in the World Bank's latest list of fragile and conflict-effected 'situations': Cameroon, the Central African Republic, DRC (because of medium-intensity conflict), and the Republic of Congo (for high institutional and social fragility) (https://www.worldbank.org/en/topic/fragilityconflictviolence/brief/harmonized-list-of-fragile-situations)

2.2 Climate overview for the Central Africa region

The Central Africa region has a hot, mainly humid climate (Figure 4) with drier areas in the far north and south. The region has uniform temperatures throughout the year (mean temperatures in the range of 22-28°C) without much seasonal variability and is characterised by large variations in timing and intensity of seasonal rainfall.

The far north of Central Africa (northern Cameroon and all of the Central African Republic) is part of the arid Sahelian region with a seasonal rainfall cycle characterised by a single rainy season during April-October and a distinct dry season.

The main part of the Congo River Basin and Congolian Rainforests are located in the northern/central band of the Central Africa region including northern DRC, northern Republic of Congo, southern Cameroon, Equatorial Guinea and Gabon. This is a humid region; it has rainfall year round with peaks in April and October.

The southern half of the region (south Republic of Congo and DRC, and Angola) has rains October to April with a distinct dry season which lengthens as you move further south. Southern Angola is cooler than the rest of the region, with a cool, dry season during April to August, known as the Cacimbo. And, whereas the Central Africa region as a whole has fairly uniform temperatures throughout the year, southern Angola sees a significant drop in mean temperature (down to 18-20°C) and particularly minimum daily temperature (11-13°C) during the dry season (May-August).

Central Africa has already warmed by 0.75-1.05°C since 1960, with the south of the region warming more rapidly than the north. Minimum temperatures have increased more quickly than maximum temperatures in the northern zones and the frequency of hot extremes has increased across the region (IPCC WGI, 2021).

Central African has a coast on the Atlantic Ocean. Off the coast of Angola the confluence of the Angola current and the Benguela current causes upwelling, creating conditions for rich fisheries. Observed marine trends for Central Africa show an increase in sea surface temperatures and an increase in sea level of 3 mm per year in recent decades, consistent with the global mean (IPCC, 2021). There is also an observed upward trend in frequency of marine heatwaves (Arias et al., 2021). Shoreline retreat is a particular risk in Central Africa due to the profusion of low-lying sandy beaches; a 2018 study identified erosion hotspots in Gabon and Angola and two accretion hotspots in Angola/DRC (Luijendijk et al., 2018).

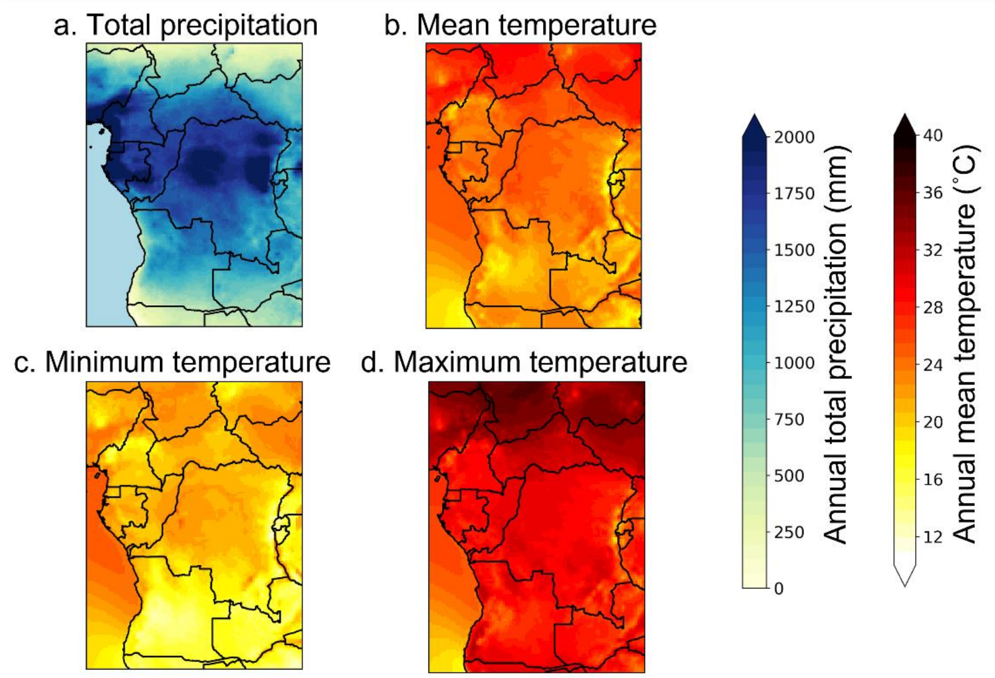

Figure 3: Baseline climate for the Central Africa region for the period 1981-2010. Maps show climatological average values of annual mean a) total precipitation (mm/year), b) mean temperature (°C), c) minimum temperature (°C) and d) maximum temperature. Temperature and precipitation data come from the ERA5 and CHIRPS datasets respectively[3].

2.2.1 Future Climate over Central Africa

Temperatures across the Central Africa region will continue to increase by at least 1.0˚C by the 2050s, with increases of up to 4.5˚C under high emissions, compared to a 1980-2010 baseline (Ranasinghe et al., 2021). The intensity and frequency of hot extremes will also increase (IPCC, 2021) as will the frequency of days above 35°C for multiple areas across the region. There is large uncertainty in future projections of fire risk in Central Africa (Senande-Rivera et al., 2022, Yu et al. 2022) arising partly from uncertainty in population growth, which generally increases ignitions, and land use change to managed agriculture, which suppresses fire spread.

Year-to-year variability will continue to be a dominant feature of rainfall across Central Africa to the 2050s. Year-to-year variability in seasonal rain amounts and timings will increase in the future climate, larger-scale influences such as ENSO and NAO remain active. Annual mean rainfall projections for the Central Africa region show no consensus in signal, with projections a mix of drying/no robust change in the south (Angola) and no robust change/wetting in the north (Arias et al., 2021). There is large uncertainty in the direction and magnitude of future changes, with CMIP6, CMIP5 and CORDEX climate models indicating that both increases and decreases in annual mean precipitation are plausible across the region, although a larger number of models indicate an increase, except in Angola. The recent

[3] Temperature data are from the ERA5 reanalysis (Hersbach et al., 2020) which includes air temperature values over the oceans. Precipitation data are from the CHIRPS reanalysis which includes land-based data only (Funk et al., 2015).

CMIP6 climate model projections show better representation of the Central Africa climate compared to CMIP5 (Ayugi et al., 2021) and generally project increases in mean precipitation, giving more confidence in an upward trend (IPCC, 2021).

The length of the rainy season may get shorter for Central African regions south of the equator. Most models project a shorter rainy season with delayed onset south of the equator. An increase in annual rainfall totals is projected but with less certainty (Dunning et al., 2018). ENSO events are projected to become more frequent (Cai et al., 2021) resulting in increased variability. Thus, there will be an increase in wetter and drier years relative to the mean despite a lack of clear signal in average rainfall totals.

For northern Central African regions, annual rainfall totals are expected to increase. Most models project an increase in rainfall totals north of the equator. A decrease in rainy season length is also projected in the north of Central Africa but with less confidence. Projected precipitation trends for northern Central Africa include more frequent ENSO events (Cai et al., 2021), increased frequency and intensity of heavy precipitation events (IPCC, 2021; Kendon et al., 2019), and increased heavy precipitation leading to flood risk (IPCC Interactive Atlas, 2021).

Dry spells and conditions associated with drought may increase in Central Africa in the future, although more research is needed. A recent study to analyse future African climate using a higher resolution model that can more accurately capture rainfall characteristics, including extremes, has indicated that the duration of dry spells during the wet season could significantly increase in Central Africa, which is not robustly projected in coarser resolution models (Kendon et al., 2019). In 1980-2012 the Sudano-Sahelian area of Cameroon (far north of Central African region) experienced higher than average humidity in the northern and south-eastern parts, however a significant drying trend was seen in the south-west with risk to maize and peanut crops (Njouenwet et al., 2021). Due to high model uncertainty for precipitation projections there is low confidence in the direction of change for hydrological, agricultural and ecological drought in the Central Africa region as a whole (IPCC Interactive Atlas, 2021). Further research across Africa using higher resolution models is necessary to better quantify the uncertainty associated with these projections and assess the subsequent socio-economic impacts.

Central Africa is likely to experience more frequent river flooding, with the majority of the region (apart from northern Angola) projected to see an increase in the frequency of 1 in 100-year high river flow events (Ranasinghe et al., 2021). For the Central Africa region, although global climate models are at present too coarse to adequately resolve local, convective rainfall events, the dynamics of the hydrological system mean that in a warmer world the frequency and intensity of heavy precipitation events are projected to increase (IPCC, 2021; Kendon, 2019). Most African regions, including Central Africa, are also projected to experience increases in heavy precipitation that can lead to pluvial (surface) floods. Under all scenarios of greenhouse gas emissions, widespread flooding is projected to increase across Central Africa before, during and after the monsoon season, associated with increased intensity of heavy rainfall (Ranasinghe et al., 2021).

Sea levels along the coastal regions to the west of Central Africa will continue to rise with projected increases of 0.2-0.4m by 2041-2060, and 0.5-1.1m by 2081-2100, relative to 1995-2014 levels, under a very high emissions scenario (0.1-0.3m and 0.3-0.7m in a low emissions scenario, respectively) (IPCC Interactive Atlas, 2021). These increases in relative sea level rise and extreme water levels will result in increased coastal flood risk in low lying areas and increased coastal erosion along sandy shorelines (Arias et al., 2021). Average shoreline retreat of around 65m is projected along the west coast of Central Africa region by mid-century and greater than 150m by 2100, under a high emissions scenario most significantly along the Gabon and southern Republic of Congo coast (Ranasinghe et al., 2021).

Sea surface temperatures for the west coast of Central Africa will increase by at least 0.7 ˚C and up to 1.8˚C warmer by the 2050s in a low emissions scenario, or 0.7 to 2.5˚C in a very high emissions scenario (IPCC Interactive Atlas, 2021). As a result, marine heat waves will also increase in frequency and intensity, and ocean acidification will increase further as a result of rising atmospheric CO_2 levels. The continued ocean acidification will causes changes in seawater chemistry, with negative implications for a variety of marine organisms. Marine heatwaves (periods of extremely high ocean temperatures which negatively impact marine ecosystems) will increase in frequency, intensity, spatial extent and duration for all coastal zones (IPCC, 2021).

2.3 Climate analysis by zone

To assess the magnitude and direction of projected climate trends at a sub-regional scale the region is divided into four sub-regional spatial analysis zones that reflect the different climate types, as shown in Figure 4. The projected trends in these zones are summarised in Table 1. Further detail on the selection of zones and the zonal climate analysis is provided in Section D of the Technical Reference Document.

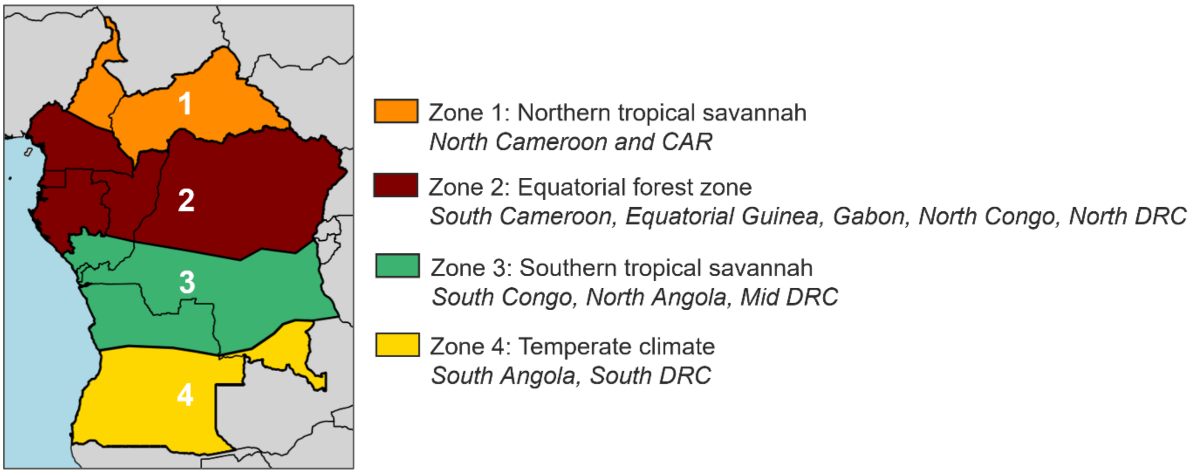

Figure 4: The four spatial analysis zones across the Central Africa region.

Table 1: Summary of the zonal analysis f. More detail is provided in Section D of the Technical Reference Document.

Zone	Countries included	Current climate type	Future projections for the 2050s: headline messages
Zone 1	Northern Cameroon and Central African Republic	Tropical savannah climate, semi-arid in the north and more rainfall in the south.	• Annual mean temperatures will increase. • Some evidence that the zone will become wetter during September to November. • Heavy rainfall events will become more intense.
Zone 2	Southern Cameroon, Equatorial Guinea, Gabon, northern Congo and northern Democratic Republic of Congo	Humid tropical climate	• Annual mean temperatures will increase. • Some evidence that the zone will become wetter during September to March. • Heavy rainfall events will become more intense. • Sea levels, sea surface temperatures, marine heat waves and ocean acidity will increase.
Zone 3	Southern Congo, northern Angola and	Tropical savannah climate	• Annual mean temperatures will increase.

	mid Democratic Republic of Congo		• Some evidence that the zone will become drier September to November and wetter during December to March. • Heavy rainfall events will become more intense. • Sea levels, sea surface temperatures, marine heat waves and ocean acidity will increase.
Zone 4	Southern Angola and southern Democratic Republic of Congo	Temperate climate	• Annual mean temperatures will increase. • Some evidence that the zone will become wetter during December to March. • Heavy rainfall events will become more intense. • Sea levels, sea surface temperatures, marine heat waves and ocean acidity will increase.

Met Office Hadley Centre ODI UKaid

Image location: Democratic Republic of Congo

3 Climate risk impacts and interpretation for the Central Africa region

This section examines some key climate risks relevant to development themes. The themes analysed include biodiversity, ecology, and forests (4.1), agriculture and food security (4.2), water resources and water-dependent services (4.3), health (4.4), infrastructure and settlements (4.5) and coasts, fisheries and marine environments (4.6).

3.1 Biodiversity, ecology, and forests

Summary of risks to biodiversity, ecology, and forests

- Biodiversity in Central Africa is threatened by a combination of climate change and habitat loss. More research is needed to understand how rising temperatures and increased rainfall variability will affect Central Africa's globally important ecosystems.
- As the Central African forests and peatlands are a major carbon sink and part of the regional water cycle, their loss would cause widespread droughts on the African continent and have negative implications for climate change and greenhouse gas concentrations globally.
- Reduced flowering, fruit production and mast seedings of some plant species will occur due to higher temperatures and reduced water availability, with knock-on effects on the entire ecosystem. It is not currently known which species are most vulnerable to these climatic changes.
- Overall, forests of Central Africa may be more naturally resilient to climate change than those of the Amazon, but this resilience is reduced by human activities which lead to forest fragmentation and biodiversity loss.

3.1.1 Context

Central Africa is home to the second largest rainforest block in the world after the Amazon and, crucially, its tropical forests now store and absorb more carbon than any other tropical forest in the world (Eba'a Atyi et al., 2022). The region's forests are of great importance for the biodiversity and climate of the African continent and for Earth as a whole. The resilience of these rainforests to climate change depends on (a) the magnitude of temperature increases and changes in precipitation, and (b) ecosystem and forest health – notably whether ecosystems are intact or fragmented and damaged. Climate risks need to be defined where possible at the species level and in relation to the biodiversity and ecology of specific areas. Halting deforestation and hunting (the cause of defaunation) is essential for forest resilience to climate change.

The Central African Forest Initiative agreed at COP26 in Glasgow with the DRC promises an investment of USD 500 million over the first five years with the aim of capping forest loss at 2014-18 levels (UN, 2021).[4] Other conservation initiatives in Central Africa include the Central African Forests Initiative (CAFI), launched in 2015, and UN-REDD+ – the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Degradation – among several others, involving international partnerships with countries in the region (see Eba'a Atyi et al., 2022). The issue is whether sufficient resources will be forthcoming to meet the scale of need and incentivise conservation over competing interests that would result in deforestation and biodiversity loss.

Central Africa consists of four floristic bioregions. The largest is the Guineo-Congolian biome, which is bounded by fragments of Guineo-Sudanian vegetation to the north, Albertine Rift Montane to the east and the Central Zambezian bioregion to the south (Droissart et al, 2018 – see Figure 6). Each bioregion is defined by patterns of regionalisation, diversity, and endemism (see Technical Reference, Annex E) in the flora (Droissart, et al. 2018). Data for these flora are limited, with many species in Central Africa still undocumented, but what does exist provide an important baseline for measuring changes in the distribution and population of species due to climate change and other pressures (Dauby, et al., 2016; Sosef et al., 2017).

[4] 'COP26: Landmark USD 500M agreement launched to protect the DR Congo's forest', 2 November 2021.https://www.un.org/africarenewal/magazine/december-2021/cop26-landmark-500-million-agreement-launched-protect-dr-congo's-forest.

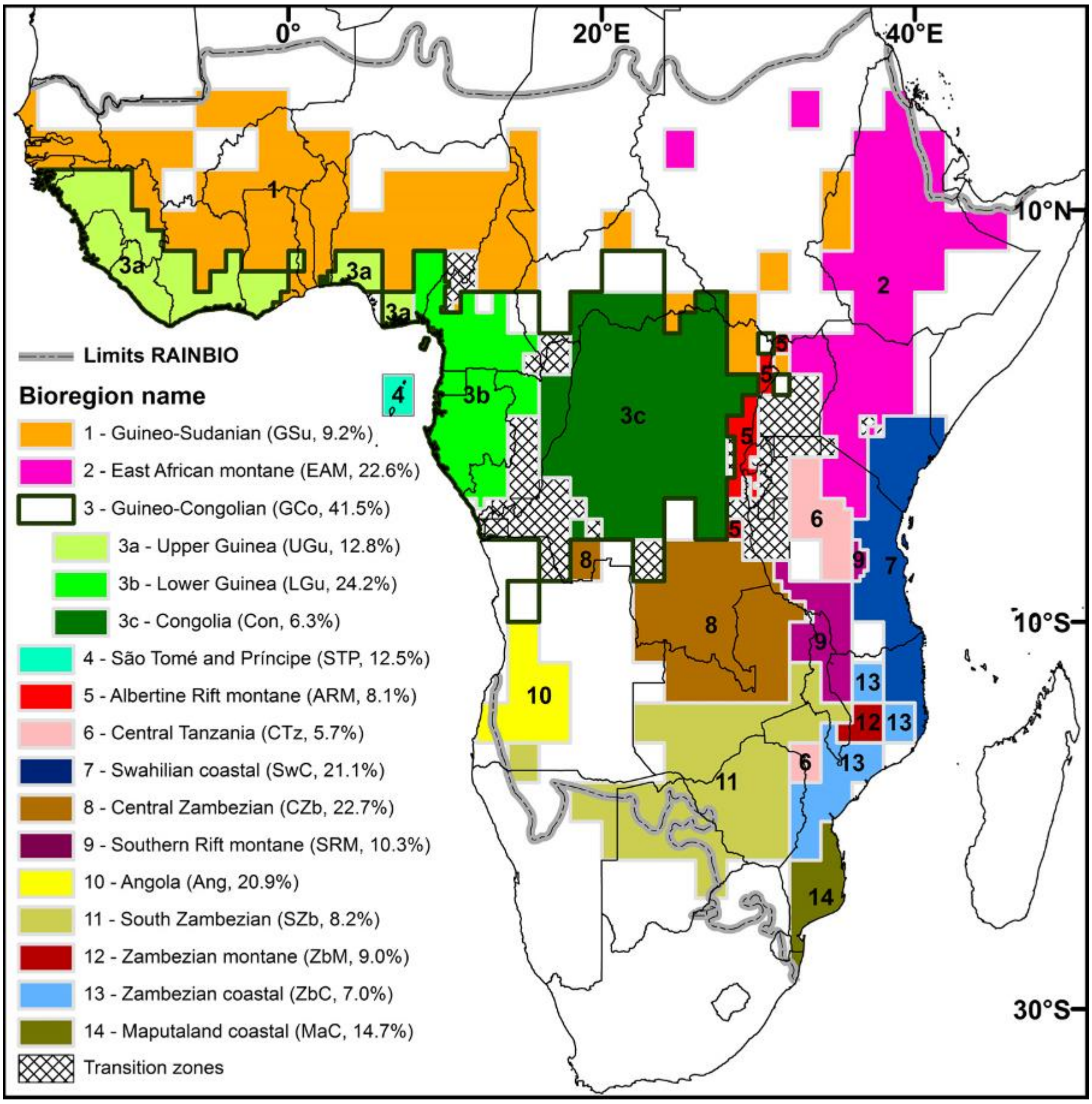

Figure 6: Map drawn by Droissart et al. (2018), p. 1157, with designation of floristic bioregions and transition zones in tropical Africa.

3.1.2 Tropical rainforest

Central Africa has the highest diversity of flora and fauna on the continent. Old refugia forests (those which survived the Pleistocene ice ages) – including parts of the Lower Guinea forest - are among the most diverse and whilst they remain intact, they are possibly the most resilient of the region's forests to climate change (Abernethy et al., 2016). The policy implication is that those areas of old, diverse forest should be protected as a conservation priority, because they are more likely to withstand the impacts of climate change. However, some forest areas thought to be resilient to climate change are less biodiverse, notably tropical monodominant forest, parts of which are shown by pollen analysis to be 2700 years old but with a canopy dominated by a single tree species, *Gilbertiodendron dewevrei* (Tovar et al., 2019). Central Africa's forests are thus heterogeneous in composition (Réjou-Méchain et al., 2021; Dalimier et al., 2022, Sosef, 2017) and will respond to climate change in different ways (Réjou-Méchain et al., 2021).

Defaunation is an acute threat in parts of Central Africa, caused by the hunting of animals for the bushmeat trade and 'traditional' medicine markets (Benitez-Lopez et al., 2019, Dirzo et al., 2014, Abernethy et al, 2013). Elimination of megafauna and top predators can trigger trophic cascades (ecological imbalances that impact numerous species in the food chain), diminishing the whole ecosystem. This is compounded by anthropic impacts from illegal logging (for timber, charcoal, and firewood), agriculture, roads (which facilitate incursions further into forests for hunting, illegal logging etc.), mining, and oil and gas exploration (Abernethy et al., 2016, Benitez-Lopez et al., 2019, Wilkie et al., 2000). Disruptions from climate change to already strained ecosystems could lead to further reductions in biodiversity, or ecosystem collapse in the worst affected areas. However, at present Central Africa still has a high percentage of intact habitats and forests, with remarkable flora and fauna, some of which are in protected areas (Breuer et al, 2021). Others are in relatively undisturbed areas of unprotected forest, potentially vulnerable to land-use change (Eba'a Atyi et al., 2022).

Central African tropical moist forests, in general, survive on lower rainfall than other tropical rainforests, although rainfall varies across the region and between seasons. In an ecological study of rainforest trees, Turner (2004) notes that tropical forests generally receive annual precipitation of at least 2000mm. The lowland forests of the central Congo Basin exist near the minimum threshold, with annual mean rainfall of 1500-2000mm (Asefi-Najafabady & Saatchi, 2013). Mean annual precipitation recorded in the Cuvette Centrale peatlands is 1700mm (Sonwa et al., 2022; Dargie et al., 2017). There is higher precipitation in Lower Guinean forests of Gabon, Cameroon and Equatorial Guinea, where the annual mean ranges from 2500-3000mm (Asefi-Najafabady & Saatchi, 2013).

As current precipitation in the Congo Basin is close to the minimum required for a rainforest to thrive, Réjou-Méchain et al. (2021) found that **large areas of Central Africa's forests have high vulnerability to climate change.** The most vulnerable areas are the rainforest margins in the north and south, the coastal forests near the Atlantic seaboard, and most of DRC's forests, threatened by a combination of climatic and anthropogenic pressures. These conclusions were reached by studying tree species composition and phylogeny and specific vulnerabilities to projected changes in temperature and rainfall (Réjou-Méchain et al., 2021). Current precipitation levels and the seasonally variable climate of Central African forests makes them vulnerable to lower rainfall. Zhou et al. (2014) reported a long-term drying trend and a decline in forest greenness[5] between 2000-2012, especially in northern areas of the Congo Basin Forest, attributable to a reduction in rainfall. In situ rainfall records indicate a drying trend in areas of forest in Gabon (Bush et al., 2020) and Salonga National Park in DRC (Bessone et al., 2021) although there is no clear trend across the region as a whole. A reduction in cumulative rainfall, or a persistent prolongation of the dry season, could lead to a retraction of evergreen forest and expansion of savannah woodland. At the same time, due to physiognomic and evolutionary features, there are areas of forest in Central Africa that could be adapted to changes in rainfall and more resilient to climate change (see mapping in Réjou-Méchain et al., 2021; and for classifications Dalimier et al. 2022).

Large-scale tropical deforestation in Central Africa would alter weather patterns including precipitation beyond the region itself (Abernethy, 2016). The Congo Rainforest generates precipitation across Central Africa and is an important source of rainfall for other parts of Africa, from the Sahel to Ethiopia (Abernethy et al., 2016; de Wasseige et al., 2015). Tropical forests are 'water pumps' that release moisture into the atmosphere through evapotranspiration, stimulating and increasing regional rainfall, while deforestation reduces rainfall (Aragão, 2012; Spracklen et al., 2012). Loss of forest cover would cause feedback loops reducing rainfall in other parts of Africa and have impacts across the entire Earth system (Abernethy, 2016, Spracklen et al., 2018 (and references therein)). The Central African forests also now absorb and store more carbon than any other tropical forest area, in the above-ground biomass and in below ground peat deposits. The region has a high number of big old trees with a high wood density and large basal area, known to sequester much more carbon than smaller trees (Harris et al., 2020; Sullivan et al., 2017; Poorter et al., 2015). So, as well as the size of the rainforest (including how many trees it has) it is also the age, species composition and prevalence of big trees that determines forest carbon storage.

Increasing temperatures and declining rainfall may be reducing the reproductivity of tropical rainforest. A longitudinal study in Lopé National Park in Gabon shows a steep decline in the fruiting of tropical trees since observations began in 1986 linked to increased temperatures and an observed 75 mm reduction in precipitation per decade since the 1980s (Bush, et al., 2020). Increased temperatures can also put plant reproduction at risk through disruptions to mast seedings (synchronous mass seeding events every 2-3 years – a defensive strategy against predators) (Hacket-Pain, 2021). This would potentially reduce seed production and dispersal in some tree species. Any disturbance to pollination or fruit production and the dispersal of seeds will disrupt the entire ecosystem, compromising plants and animals and overall biodiversity.

The elimination of pollinators and seed dispersers, which at present is caused primarily by hunting and poaching, has calamitous effects on plants. The eradication of much of the critically endangered forest elephant (*Loxodonta cyclotis*) population in the central DRC due to hunting has been shown to have led to direct and steep declines in at least 18 tree species whose seeds were solely or primarily dependent on elephant seed dispersal (Beaune et al., 2013, Bush et al., 2020a, 2020b; Beirne et al., 2020). Gabon has the largest remaining

[5] Zhou et al (2014: 86) specify that vegetation greenness was calculated using Enhanced Vegetation Index (EVI) data, derived from satellite imaging, and it measures leaf area, canopy photosynthetic activity, and primary productivity.

population of forest elephants in Africa (approximately 35,000), and they play a vital role in forest ecology through seed dispersal, nutrient recycling, herbivory, and in structuring the composition of the forest (Beirne, et al., 2021). There are comparable impacts caused by the hunting of duikers, primates, and other animals in Central Africa’s forests (Abernethy et al., 2013). Climate change risks exacerbating existing anthropic pressures on ecosystems and creating new disturbances.

3.1.3 Savannah woodlands and grasslands

Climate change could alter the natural distribution of Central Africa’s savannah plants and animals. The vegetation of savannah biomes in Central Africa ranges from grassland to woodland, supporting diverse and often endangered fauna. The ranges and populations of large carnivores and megafauna have been reduced due to habitat loss and hunting, with some species becoming extinct and many listed as endangered or critically endangered (see Annex E of Technical Reference for further details). In places with a lower human population density and more intact ecosystems, shifts in the species distribution of plants and animals in response to climate change may be possible, but in many areas human land-use pressures will constrain this natural migration. Protected Areas in the savannahs must be joined up and extended to increase the viable range for wildlife distribution shifts. A non-exhaustive list of Protected Areas in the Guineo-Sudanian Savannah of Central Africa is given in Section E of the Technical Reference Document.

Increased risk of fire weather during dry periods could pose threats to savannah woodlands, with potential for fire to spread from savannah to tropical forest in transition zones. The savannahs have longer dry seasons and lower cumulative rainfall than the tropical rainforest and the vegetation has to some extent adapted to fire, but extreme heat and diminished precipitation could lead to overly destructive fires. This could be a particular problem in areas of savannah woodland, including along the savannah-forest boundary, a mosaic where vegetation shifts over time depending on climatic trends, rather than a fixed line (Cuni-Sanchez et al., 2016). Savannahs store substantial amounts of carbon in their vegetation and soils, and increased risk of fire increases the risk of carbon release. How these ecosystems will respond to climate change requires further research (Cuni-Sanchez et al., 2016). In Upper Katanga Province of south-east DRC, which includes Afro-montane ecosystems and the diverse Upper Zambezian flora, the adjacent Kundelungu National Park and Upemba National Park are important savannah conservation areas but have come under considerable pressure, including from armed groups.

3.1.4 Wetlands

The Cuvette Centrale: the largest Tropical Peatland in the world

The peatlands of the DRC and the Republic of Congo are situated in the Cuvette Centrale depression in the central Congo Basin. This are the largest tropical peatland complex in the world, a vast swamp forest composed of hardwood trees and palms covering 145,500km^2 and accounting for an estimated 29% of total tropical peat stocks (Dargie et al., 2017; Dargie et al., 2019). The peatlands in the DRC cover about 90,800km^2 and the ROC about 54,700km^2 (Dargie et al., 2017: 88).

In total the Congo Basin contains approximately 36% of the world's tropical peatland area and stores about 28% of the world's tropical peat carbon (Crezee et al., 2022). The peatlands in the central Congo Basin accumulated over the past 17,500 years, but with a drying from approximately 5000 to 2000 years ago that decomposed the deposits from 7500 to 2000 years ago (Garcin et al., 2022). There has been an accelerated rate of peat formation over the past 2000 years with the return of wetter conditions (Dargie et al., 2019, Garcin et al., 2022). The peatlands of the Cuvette Centrale contain about the same amount of carbon as is stored in all the biomass of the above-ground forest in the Congo Basin (Crezee et al., 2022, Dargie et al., 2017), making them a globally important carbon sink.

Peat soils exist in waterlogged, anoxic conditions that inhibit the decomposition of organic matter, with peat defined as having an organic matter content of at least 65% to a depth of at least 0.3m (Dargie et al., 2017). Rainfall is vital in keeping the Congo Basin peatlands wet (Davenport et al., 2020), and river flow into extensive areas has also recently been identified as crucial (Crezee et al., 2022). The Cuvette Centrale peatlands are large but shallow, with a mean depth measured at 1.7 ± 0.9m and a maximum depth measured at 6.4m (Crezee et al., 2022). This is much shallower than other tropical peat deposits, possibly the result of lower rainfall, which reduces the rate of peat accumulation (the annual rainfall in peatlands in northwest Amazonia and southeast Asia is 2500-3000 mm) (Crezee et al., 2022, Davenport et al., 2020).

The Congo Basin peatlands are largely intact at present, but climate change is a real threat to the stability of their carbon stocks (Dargie et al., 2019). Drying out of the Congo Basin's peat deposits could lead to the release of huge quantities of carbon and methane with global impacts (Garcin et al., 2022) This is due to the sheer volume of carbon they store – 30 gigatonnes (Dargie et al., 2017), equivalent to 15 years of carbon emissions from the US economy (Sonwa & Lewis, et al., 2022). The Congo Basin's peat deposits lie in inter-fluvial areas and depend on rainfall (currently c. 1700mm p/a) and river flows to remain waterlogged (Crezee et al., 2022, Dargie et al., 2019). A reduction in precipitation or erratic precipitation that creates longer dry spells could lead to the drying out of peat deposits and associated release of carbon into the atmosphere, as occurred 5000-2000 years ago (Garcin et al., 2022). Climate models cannot reliably predict future rainfall in the Congo Basin, partly because there is such little ground-level observational data (see Bush et al., 2020a, for the use and importance of on-the-ground climatic datasets), so how climate change will affect the seasonality and volume of rainfall in the peatlands is uncertain (Sonwa & Lewis, et al., 2022: 252).

Land-use change in the Congo Basin peatlands greatly increases the risk of converting them from major carbon stores and absorbers to vast emitters of greenhouse gases (Sonwa & Lewis, et al., 2022; Dargie et al., 2019). The greatest immediate risk to the peatlands is from land-use change. Palm oil plantations, hydrocarbon exploration and drilling, logging, large dam projects, and the proposed diversion of rivers to Lake Chad are all serious emerging and present threats to the peatlands (see Dargie et al., 2019, for detailed information, and Sonwa & Lewis, et al., 2022). The Cuvette Centrale peatlands include areas designated as Ramsar sites - Wetlands of International Importance - under the 1971 Ramsar Convention, some of which overlap with protected areas (reserves and national parks) (Dargie et al., 2019: 679-80). But this recognition does not necessarily translate into protection on the ground, and the protected area network in the DRC and ROC covers only 11% of the peatlands (Dargie et al., 2019, Crezee et al, 2022). As well as accelerating global climate change, the destruction of these wetland forests and peat deposits would impact the area's biodiversity and endangered species such as western lowland gorillas and forest elephants (Crezee et al, 2022).

Congo Basin peatlands will experience heightened risk from fire with increasing temperatures (Dargie et al., 2019). Higher temperatures will increase evaporation and evapotranspiration from the peat soils. This would increase the rate of decomposition of organic matter, releasing carbon, and fire would become a real threat to the drying peat landscape (Dargie et al., 2019). Evaporation rates would be much higher if there is logging or clearance of the swamp forest, as this would remove shade and expose the peat to direct solar radiation and increased heat. Forest clearance would also drastically reduce the amount of organic matter going into the peat. In periods of heavy rainfall, there could be more flooding if the forest has been cleared causing further erosion of the peat soils.

The swamp forests have unique biodiversity that needs to be safeguarded. This includes substantial populations of highly endangered great apes (western lowland gorillas, chimpanzees, bonobos) and forest elephants. There is much more to discover: much of the flora and fauna of the area remains to be researched and documented (Dargie et al., 2019).

The local population in the Cuvette Centrale has broadly conserved the forest, so the main threat is from climate change – especially reduced precipitation combined with higher temperatures - and from the potential for large-scale destruction from oil and gas drilling and plantation agriculture. Dargie et al. (2018) argue that climate change mitigation funding to protect the peatlands for their importance in storing and absorbing carbon would benefit the livelihoods of local communities. In contrast, the destruction of such a large carbon store would have very damaging global climatic consequences.

3.1.5 Marine and Freshwater Ecosystems

The main climate risks to marine ecosystems in Central Africa are from sea level rise, warming oceans, acidification and changes in the ocean currents which bring upwellings of nutrients. Iconic species inhabiting the offshore waters of Central Africa include whales and dolphins.

Marine diversity, already under pressure from over-fishing, will be affected by the warming of the ocean, including increases in the frequency and intensity of marine heat waves. Higher surface temperatures disrupt ocean circulation and hence ocean currents, which in turn will disrupt and reduce marine life, with direct impacts on pelagic fish species. For example, the Angolan coast is 1650km long and marine life there is enriched by the Angola and Benguela Currents (Hutchings et al., 2009). Reduced oxygen in the upper ocean or reduced upwelling of nutrients from changes to these important currents would diminish or shift marine ecosystems and biodiversity, compounding pressures from overfishing (see also Section 3.6).

Central Africa's highly diverse freshwater ecosystems will be damaged by increasing temperatures. Warmer water temperatures will reduce oxygen levels of the upper layers of lakes, with a detrimental effect on life in those important layers of water near the surface (Cohen et al., 2016). As warming changes freshwater environments beyond conditions previously encountered, this will endanger endemic species that are highly adapted to existing conditions and possibly benefit invasive species. In terms of building resilience to climate change, protecting marine and freshwater habitats from over-exploitation, degradation and pollution is important. The gene pools of species need to be sustained, with diversity within species as well as overall biodiversity, because the larger the population of a species the higher the chances of it adapting to changing conditions.

3.1.6 Montane Ecosystems

The montane ecosystems of Central Africa include those in the Cameroon Highlands, Eastern DRC, the Rwenzori Mountains, and Virunga National Park (see Technical Reference, Annex E for further details). Climate change is likely to be more intensely felt in montane ecosystems, including the Albertine Rift (Ayebare et al., 2018) which has high rates of biodiversity and endemism (Droissart, 2018).

As global warming continues all the remaining glaciers and snowfields in the Rwenzori Mountains will disappear before 2050 (Mackay et al., 2020). The glaciers of the Rwenzori Mountains are very sensitive to changes in temperature and have already retreated in extent from 6.5km^2 in 1906, to about 2km^2 in 1987, and measuring less than 1.0km^2 in 2003, due to rising air temperatures (Taylor et al., 2006). The loss of these glaciers and snowfields will alter terrestrial and aquatic montane ecosystems, especially at higher altitudes, and the biology and geochemistry of glacial lakes will change, although further research is needed to characterise these changes (Mackay et al., 2021). Evidence indicates that glacial retreat in the Rwenzori will not substantially reduce river flows in the mountains or change the hydrology, as glaciers contribute only a small amount to river discharge, most of which comes from precipitation (Taylor et al., 2009).

The unique plants and animals adapted to the Rwenzori Mountains could be lost when alpine conditions disappear due to rising temperatures. A redistribution of some plant species as a result of glacial recession has already been observed (Oyana and Nakileza, 2016). Some mosses, algae and lichen could be threatened by glacial retreat, even as other plants colonise ice-free areas (Mackay, Lee & Russell, 2020; Oyana and Nakileza, 2016; Linder & Gehrke, 2006, for a plant inventory; Osmaston, 2006). The loss of species adapted to Afro-alpine conditions is possible if temperature increases lead to the disappearance of alpine conditions, as plants there have evolved to cope with freezing temperatures. There is large uncertainty in future projections of fire risk in Central Africa (Senande-Rivera et al., 2022, Yu et al. 2022). Fires have been observed in the Rwenzori Mountains since the early twentieth century (Osmaston, 2006), and the damage they cause would likely increase with higher temperatures during the dry months.

The vegetation and habitats of mountain gorillas living in Virunga National Park are threatened by rising temperatures. Mountain gorillas (g*orilla beringei beringei*) are an endangered species threatened by poaching, habitat loss, and potentially climate change. Some live at altitudes above 3000m, and as they have a preference for cooler conditions, there are signs that gorillas could move to higher altitude areas of the forest in response to elevated temperatures (UNEP, 2020). However, the ability of gorillas to shift their range in response to climate change would be constrained by the size of Virunga National Park and human pressure at the boundaries, which is increasing as deforestation and land use change intensify (Christensen & Arsanjani, 2020). Some studies indicate that mountain gorillas show resilience to climatic variability, but this needs further research (UNEP, 2020).

The climate impacts on Virunga and on mountain gorillas will depend on the severity of climate change and on the continued protection of the park. The former depends on cutting greenhouse gas emissions while the latter hinges on improving the productivity and sustainability of agricultural livelihoods outside the park, on peace and security, and on preventing poaching, habitat loss, and oil and gas exploration inside the park (on the latter, see Tchoumba et al., 2021). If local agriculture is compromised by changes in climate, the pressure on the park will increase as people either seek new farmland or intensify exploitation of natural resources in the protected area. Options for improving local livelihoods and the protection of Virunga National Park include increasing food security, access to clean water, switching to more efficient energy sources, and protection of the park the buffer zone (UNEP, 2020).

3.1.7 Ecosystem services

Central Africa's diverse biomes provide important ecosystem services, including those providing direct revenue such as tourism and international investment. They are also include the maintenance of biological diversity, rainfall and water regulation, and the provision of forest timber and non-timber products (fodder, fuel, fibres, medicines, wild foods) for local communities (Eba'a Atyi et al., 2022; IPBES, 2019). For climate change mitigation, preserving Central Africa's forests and ecosystems is globally essential (Sonwa & Lewis, et al., 2022, Abernethy et al., 2016, Crezee et al, 2022), but the financial incentives to destroy such places are still much higher than the investments needed to protect them. The financial flows required for effective conservation, including from carbon prices, remain insufficient (Eba'a Atyi et al., 2022, IPBES, 2019: 98).

Carbon is priced far too low for REDD+ policies to have a transformative impact on forest and biodiversity conservation, even while there are some potential benefits (for analysis, see Eba'a Atyi et al., 2022, and IPBES, 2019). Civil insecurity and political instability in parts of the region also hinder REDD+ implementation and other conservation efforts (Brown, 2017). Consequently, there are strong revenue incentives for sweeping land-use changes through agricultural expansion, palm oil plantations, uncontrolled logging, large hydropower projects, mining, and oil and gas exploration, including in protected areas and intact forests (Tchoumba et al., 2021; Dargie et al., 2019; Sonwa & Lewis, et al., 2022).

In Central Africa climate change risks can be mitigated by protecting forests and ecosystems. The Central African forests generate rainfall across large expanses of the continent (Worden et al., 2021), feeding the rivers and the ecosystems on which people and wildlife depend (Malhi et al., 2013) and in turn affecting the global water cycle. The destruction of the Central African forests will have a negative impact on this water cycle (Sonwa et al., 2020; Gou et al., 2022).

3.2 Agriculture and food security

Summary of risks relevant to agriculture and food security

- Greater rainfall variability, more extremes and rising temperatures will have broadly negative impacts on agricultural yields, output variability, prices, and food security, including via disease vectors and rising pest populations. Impacts across food systems and areas will be profoundly gendered given women's central role in the region's agriculture.
- Increasing average and extreme temperatures will generate periodic heat and water stress for important staples such as maize and increase reliance on more heat-tolerant staples such sorghum and cassava. Increases in heavy rainfall may damage crops, cause waterlogging and threaten storage and processing facilities.
- Warming and heat extremes will negatively affect pastoral and agropastoral livelihoods through direct heat stress, impacts on pasture and fodder, water needs and access, and livestock mobility. Vulnerabilities will be intensified and possibilities for adaptations limited by agricultural expansion and other non-climatic pressures.
- Inland fisheries will be negatively affected through rising water temperatures and heavy rainfall and flood events, with impacts on water quality and fishery productivity. Climate risks will amplify other pressures from deforestation, dam construction, and industrial and agricultural development.

3.2.1 Context

Agricultural production, including crop production, forestry, and fishing, accounted for an average of 14% of national GDP in Central Africa in 2020, ranging from 3% in Equatorial Guinea to 32% in Central African Republic (World Bank, 2022 - see Annex F and H of Technical Reference). The significance of agriculture to national GDP has declined over recent decades, in part due to expanding petroleum and mineral exports (Dixon et al., 2020a). However, agricultural employment as a proportion of total employment highlights the sector's continuing importance to regional livelihoods, ranging from roughly 30% in Republic of Congo and Gabon, to 60-70% in DRC and Central African Republic in 2019 (Annex F, Technical Reference). Agricultural occupations account for a higher proportion of female employment (with the exception of Republic of Congo), and women account for most domestic agricultural traders in the region (World Bank, 2018, 2022). This highlights the gendered implications of climate change impacts on agricultural livelihoods.

Central Africa is characterised by diverse agricultural systems adapted to specific ecological, social, and economic contexts (see Figure 8, and Annex G, Technical Reference). Root and tuber crops and forest-based systems cover the largest areas, but agropastoral livelihoods are also significant, especially in northern regions of Cameroon, Central African Republic, and DRC and southern Angola. Inland fisheries in lakes and rivers also play a key role in providing food and income, particularly for poorer households (Harrod et al., 2018a).

3.2.2 Farming systems and livelihoods

Climate change directly affects crop production via increasing average and extreme temperatures, changing rainfall patterns and water availability. Crop cultivation in Central Africa is overwhelmingly rainfed and subsistence-oriented (Dixon et al., 2020a), making crop production and the people who depend on it vulnerable to climate variability and change. Climate change poses direct risks to crop cultivation because crops are sensitive to temperature changes and heat extremes as well as rainfall amounts and timings. The interaction between rainfall and temperature is also important because it affects soil moisture conditions, plant evapotranspiration and the risk of periodic water stress or waterlogging. Levels of atmospheric CO_2 also affect plant growth. The amount of CO_2 in the atmosphere is increasing and this could have positive impacts on crop productivity, but there is considerable uncertainty about this response (Trisos et al, 2022).

*Figure **8:** Agricultural systems in Africa (source: Dixon et al., 2020a).*

Impacts of combined rising temperatures, variable rainfall and rising CO_2 on crop production will continue to be broadly negative, though evidence remains patchy. Most of the comprehensive studies that have looked at the impacts of climate change on crop production have been limited to key staples (maize, rice, wheat) and some important cash crops such as tea and coffee (Trisos et al, 2022). Over the period 1974-2008, climate change decreased maize and wheat yields in sub-Saharan Africa by 5.8% and 2.3%, respectively (Ray et al, 2019). This is mainly because of the limited heat tolerance of these staples: in tropical regions yields are projected to decline by 5% with every degree of global warming (Franke et al, 2020).

Where temperatures exceed 30-35°C for longer periods, maize-mixed cultivation will suffer more than cereal-root crop systems based around millet, sorghum, and cassava because in contrast to wheat and maize, millet and sorghum are more resilient to rising temperatures and drought, as are root and tuber crops such as cassava (Thornton and Cramer, 2012; Jarvis et al., 2012; Hadebe et al., 2017; Adjei-Nsiah et al., 2020; Manners et al., 2021). However, relatively few studies have looked at the response of root and tuber crops to hot and dry conditions beyond individual country sites.

Important regional cash crops such as coffee are also expected to be impacted by changes in temperature and rainfall. With rising temperatures (under RCP 4.5), some areas suitable for Arabica and Robusta coffee cultivation will decline in eastern and western Central Africa by 2050, although areas suitable for Robusta may expand in some central parts, including in Southern Cameroon, Equatorial Guinea, Gabon, northern Congo and northern DRC. (Magrach and Ghazoul, 2015). Rising temperatures will reduce areas where coffee can be cultivated, restricting cultivation to higher altitudes (Downie, 2018). Other cash crops such as cocoa, with an optimal maximum growing temperature of 32°C, will see declines in production through rising temperatures (Schroth et al., 2016; Downie, 2018). Favourable conditions for banana and plantain production may increase through rising temperatures (Calberto et al., 2015; Varma and Bebber, 2019; Manners et al., 2021). However, extended exposure to extreme temperatures (above 30-35°C) and low soil moisture can reduce banana and plantain production (Thornton and Cramer 2012; Calberto et al., 2015).

Increasing temperatures and more variable rainfall are likely to increase periodic water stress for crop production and increase irrigation demand across Central Africa. Higher temperatures lead to increased evapotranspiration and reduced soil moisture, increasing water requirements for certain crops, especially in regions where drier conditions are projected. Irrigation development remains limited in Central Africa: in 2018, irrigated land accounted for less than 1% of all cultivated land in all Central African countries (FAO AQUASTAT, 2022 – see Annex H, Technical Reference), although these figures may not capture much small-scale, farmer-led irrigation (Wiggins and Lankford, 2019).

While irrigation offers potential to respond to some of the climate-related impacts on cultivation, it brings its own risks. National adaptation plans in Cameroon and the Central African Republic, for example, identify irrigation as a priority in responding to climate-related risks (République du Cameroun, 2015; République Centrafricaine, 2022). However, irrigation can increase pressure on and competition for ground and surface water resources and intensify inequalities in access to water sources and irrigated land (e.g., based on gender or wealth). Flood-based farming is also practiced in the region, notably floodplain/flood recession agriculture in the Logone and Chari floodplain, around Lake Chad, and along the Congo River (Comptour et al., 2020; Puertas et al., 2021). While flood-based farming is also less dependent on local rainfall variability, flood patterns (and in turn planting, growth, harvesting, and so on) will be affected by changes in river flows and lake levels, and flood dynamics linked to seasonal rainfall patterns and rainfall extremes, in turn affecting the dependability of flood-based farming

More frequent and intense heavy rainfall events will damage crops and agricultural infrastructure and increase soil erosion. Heavy rains and floods already cause widespread damage to crops across Central Africa contributing to food security crises (FSIN and GNAFC, 2021). Different crops have different levels of tolerance to waterlogging: sorghum is more resilient, while key staples such as millet and maize are far less tolerant (Hadebe et al., 2017). Cassava is not well-adapted to excess water, so projected increases in flooding present risks to production (Thornton and Cramer, 2012). While most climate change studies focus on production only, crop processing, storage and distribution are also likely to be impacted by heavy rain and floods (Trisos et al, 2022).

Changes in temperature and rainfall can create favourable conditions for plant pests and diseases in new locations throughout Central Africa. These changes have already contributed to the expanded distribution of pests such as the desert locust and fall armyworm and are anticipated to increase risks from banana wilt, cassava mosaic virus, brown streak disease, and coffee leaf rust (Jarvis et al., 2012; Thornton and Cramer, 2012; Downie, 2018; USAID, 2018). In 2021, infestations of migratory locusts across more arid parts of the region (northern Cameroon, the Central African Republic, south-eastern Angola) caused widespread damage to crops (FSIN and GNAFC, 2021). Under projected climatic changes, Central Africa may become a regional 'hotspot' for the fall armyworm, threatening cereal crops such as sorghum and maize (Tepa-Yotto et al., 2021; Timilsena et al., 2022). Across Sub-Saharan Africa, pests and diseases are attributed to cause between 10-35% of yield losses for key staples (Savary et al, 2019). The costs of pests and diseases control could also be expected to increase as favourable conditions expand.

Climate-related risks to crops will be compounded by deforestation and the broader degradation of ecosystems and biodiversity. Native forests can help reduce surface water runoff (at least for smaller-moderate rainfall events) and, at scale, generate precipitation (Lan et al., 2019; Acreman et al, 2021), while biodiversity protects and enriches soils and enables crop pollination (Malhi et al., 2013). Deforestation and ecosystem loss will likely contribute to the degradation of watersheds from more intense rainfall events, flooding, and soil erosion (Kumagai et al., 2004).

Coping and adaptation responses have been adopted or proposed but remain limited in coverage and uptake. Adaptation responses employed in Central Africa and globally cover changes to crops and cropping patterns, adoption of new cultivation systems (e.g., flood-recession agriculture, conservation agriculture), water/soil conservation and irrigation, income diversification, and seasonal migration (see e.g. Bele et al., 2014; Azibo and Kimengsi, 2015; Schut et al., 2016; Zieba et al., 2017; Evariste et al., 2018; Nguimalet, 2018; Comptour et al., 2020; Amani et al., 2022; Chimi et al., 2022). However, barriers include insufficient and unequal financial resources, insecure land rights, and access to information, inputs, and extension support (see e.g., Bele et al., 2014; Azibo and Kimengsi, 2015; Schut et al., 2016; Bate et al., 2019; Mbuli et al., 2021; Amani et al., 2022; Chimi et al., 2022).

Agricultural responses to climate-related changes may themselves present risks of negative impacts on local environments. These include the intensification of agricultural activities and effects on land and soil quality as well as disruptions to existing land use patterns (e.g., livestock grazing), use of farm inputs (e.g., fertilisers) and increases in water pollution, water use for irrigation and livestock, and use of forest resources for income diversification. While adaptation initiatives may have positive environmental impacts, the risks they present must also be considered.

3.2.3 Pastoral and agropastoral livelihoods

Pastoralism and livestock are important for rural economies and food security in northern regions of Cameroon, Central African Republic, Democratic Republic of the Congo and southern Angola. Livestock numbers in this region have increased dramatically since the 1990s (Huchon et al., 2021) and illustrate the sector's continuing importance. Pastoral systems manage about 80% of the region's livestock (Huchon et al., 2021) and are characterised by mobility within and across country borders, linked to extensive trade networks across the Chad Basin and wider Sahel (Moritz et al., 2013; de Leeuw et al., 2020; Huchon et al., 2021; Oluwasanya et al., 2022a). Note that regional livestock networks are discussed in the climate risk reports for West Africa and the Sahel (Doherty et al, 2022; Holmes et al, 2022).

Central Africa pastoralists have already begun moving southward in response to multiple pressures. Those pressures include the expansion of cultivated land in regional and neighbouring countries and associated loss of grazing land and migration routes, changing access to water sources, and more abundant pasture and water resources in destination regions (ICG, 2014; Nagabhatla et al., 2021; Huchon et al., 2021; RICC, 2021; Oluwasanya et al., 2022a). Escalating southward movements may increase pressures on savannah and forest environments.

Climate change will negatively affect livestock through impacts on fodder availability and quality, livestock food supply chains, access to drinking water, direct heat stress and tolerance, prevalence of livestock diseases, and livestock mobility (Nardone et al., 2010; Rojas-Downing et al., 2017; de Leeuw et al., 2020; Godde et al., 2021; Trisos et al., 2022). Direct heat stress increases risks to livestock health and mortality, impairs livestock reproduction and milk production, and increases needs for drinking water. Rising temperatures may negatively affect feed crops and the availability of suitable pasture and drinking water. By 2050, pasture productivity is projected to decline by 5% in Central Africa under RCP8.5 (2.4^{o}C warming) (Boone et al, 2018). Higher temperatures are also likely to reduce the health and reproduction of goats, even if they are less vulnerable to heat stress compared to cattle and sheep (Thornton and Cramer, 2012; Sejian et al., 2021).

Increases in heavy precipitation events and flooding may result in losses of livestock feed crops and stores and livestock displacement and deaths. Extreme rainfall affects forage yield (de Leeuw et al., 2020) and may also affect the quality of water sources (e.g., through contaminated runoff – see Section 3.3). By contributing to changes in water levels and flooding patterns and timing, temperature and rainfall changes may also have detrimental impacts on floodplains that are central to transboundary pastoral systems such as the Logone floodplain, an important dry season grazing land for pastoralists in Cameroon, the Central African Republic, and Chad (Haller et al., 2013; Moritz et al., 2013; Moritz, 2017). Projected climatic changes could also increase pressures on existing common-pool resource management systems (Moritz, 2017).

Policies restricting nomadic lifestyles and which fragment and appropriate resources currently place pressures on pastoralists which are accentuated by the impacts of climate change. Current pressures, displacement, and tensions in Central Africa are linked to changes in land use policies, land enclosure, and agricultural expansion, which fragment and reduce grazing land, migration routes and livestock grazing corridors, alongside taxes on access to pasture and floodplain areas (Moritz, 2012; Haller et al., 2013; Moritz et al., 2013; ICG, 2014; Ntangti et al., 2019; Feldt et al., 2020; Mbih, 2020; Huchon et al., 2021; Schareika et al., 2021). These also limit possibilities for adaptations to climatic changes, for example through access to new pasture or water sources.

Climate-related risks will also be shaped by changes to the organisation of livestock economies throughout Central Africa. These include the expansion of 'contract herding', where absentee owners contract hired herders to care for animals (Moritz et al., 2011; Moritz et al., 2015) and shifts from pastoralism to ranching (e.g., in north-central Cameroon) (Huchon et al., 2021; Schareika et al., 2021). Policies and development interventions have tended to favour crop-based agriculture and sedentary livestock production at the expense of pastoral livelihoods and mobility rights (Boffa et al., 2020; de Leeuw et al., 2020; Oluwasanya et al., 2022a). However, projected temperatures increases and effects on pasture and water resources may put sedentary livestock raising at risk.

Violent conflicts in Cameroon and Central African Republic have negatively affected pastoral livelihoods in the region. Impacts include the targeting of livestock and taxation of pastoralists by armed groups, disruption and loss of migration routes and access to pasture, changes in transhumance destinations, and disruption of access to veterinary services and medication (ICG, 2014; Betabelet et al., 2015; de Vries, 2020; Huchon et al., 2021). Together, the broader political and economic dynamics described in these paragraphs will interact with, and intensify vulnerability to, the impacts of future climatic changes.

3.2.4 Freshwater fisheries

Inland fisheries play an important role in supporting livelihoods in Central Africa, particularly for poorer households. Inland fisheries include floodplain and lake-based systems (Hamerlynck et al., 2020). Floodplain-based fisheries include major river basins, notably the Congo River and the Oubangui and Sangha Rivers. Lake-based fisheries are concentrated around major lakes such as Lakes Tanganyika, Mweru, Kivu, Edward, and Albert in eastern DRC, Lake Mai-Ndombe in western DRC, and Lake Chad in northern Cameroon. Lake Tanganyika is the world's second-largest freshwater lake by volume and depth and ranks second among African lakes in terms of fish production, with over one million people relying on its fisheries (Alsdorf et al., 2016; Harrod et al., 2018a).

Central African countries may be among the most vulnerable to the impacts of climate change on fisheries due to the combined effects of warming, the importance of fisheries to national economies and diets, and limited capacity to adapt (Allison et al., 2009). In a study of 132 countries, DRC was identified as the second-most vulnerable country due to its dependence on inland fisheries (Allison et al., 2009). For inland fisheries, areas where fish are caught mostly in rivers and floodplains are more likely to experience climate change related reductions in fish catches than areas reliant on lakes (Trisos et al., 2022), as river-based fishery productivity is more vulnerable to variable rainfall and its effects on flood dynamics (Hamerlynck et al., 2020).

Increases in annual temperatures and heat extremes will also occur in freshwater systems, posing risks to fish distribution and productivity in lakes and rivers (Trisos et al., 2022). Lake surface temperatures are expected to rise with increasing global warming (Kraemer et al., 2021). Higher water temperatures reduce oxygen content and vertical mixing of the water column (Cohen et al., 2016), negatively affecting aquatic biodiversity, habitats, and water quality, and fish health and stocks (Kraemer et al., 2021). Thermal stress can affect fish distribution and individual and population health and mortality (Harrod et al., 2018b). In Lake Tanganyika, rising air and water temperatures have been linked to declines in fish and mollusc species and to decreases in fish catches and fishery productivity (Alsdorf et al., 2016; Cohen et al., 2016). Rising temperatures will also increase evaporation rates, potentially reducing the extent and depth of freshwater bodies. This could contribute to the loss of spawning, nursery, and foraging habitats (Harrod et al., 2018b).

Increases in the intensity and frequency of heavy rainfall will likely increase sediment and pollution loads, contributing to habitat degradation and fish kills (Harrod et al., 2018b; Plisnier et al., 2018). Flood events may also result in damage to or loss of fishing equipment and landing sites, as well as posing risks to fishers (Harrod et al., 2018b).

Climate-related risks to inland fisheries will interact with and be amplified by the impacts of human activities on lakes and rivers. Freshwater fisheries are threatened by multiple pressures, including over-fishing, soil erosion and siltation, water withdrawals for irrigation, and pollution from industrial and agricultural sectors (for different pressures, see Sarvala et al., 2006; Mbih et al., 2014; Cohen et al., 2016; Branchet et al., 2018; Harrod et al., 2018a; Plisnier et al., 2018). In Cameroon for example, gold mining is damaging and polluting rivers (Ngounouno et al., 2021; Ngueyep et al., 2021).

Climate adaptation responses that rely on freshwater resources (e.g., hydroelectric power generation, agricultural irrigation) may present risks to inland fisheries, through impacts on flow regimes, water levels, and runoff (Harrod et al., 2018b). In Cameroon, for instance, hydroelectric dams have had detrimental impacts on riverine fish habitats and diversity (Nyom et al., 2020; Nemba et al., 2022).

3.2.5 Food security

Links between climate change and broader food security are more difficult to predict because pathways are complex. Food security[6] is shaped by access to and uptake of food, not just production and availability. Nonetheless, most studies to date have focused on output

[6] Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (World Food Summit, 1996). For further information on the four dimensions of food security flagged here (availability, access, utilisation and stability), see: https://www.worldbank.org/en/topic/agriculture/brief/food-security-update/what-is-food-security

and output variability only (Trisos et al, 2022). Food security may be threatened by a combination of (1) declining output and availability; (2) lower access due to declining household incomes and price variability; (3) changing uptake/utilisation of food within the body affected by (for example) disease; and (4) lower stability as a result of more variable output, prices, and incomes. Untangling the climate signal across each of these four areas is difficult, but a growing body of evidence indicates that yield losses are likely to translate into higher agricultural prices and much greater output and price volatility. These impacts will, in turn, affect the purchasing power and real income of households (Hallegatte et al, 2016).

In 2018-2020, more than half of the populations of Cameroon, Central African Republic, Republic of Congo, DRC, and Angola faced moderate or severe food insecurity, ranging from 56% in Cameroon to 88% in Republic of Congo (FAOSTAT, 2022 - see Annex H, Technical Reference). In 2020, DRC was the country most affected by food insecurity globally, with nearly 22 million people (33% of the population) facing at least crisis-level food insecurity and nearly six million facing at least emergency-level food insecurity (FSIN and GNAFC, 2021). In the Central African Republic, 51% of the population faced at least crisis-level food insecurity and 16% faced at least emergency-level food insecurity, the highest proportion of any country (FSIN and GNAFC, 2021). Food security crises in the region are driven by a combination of weather extremes (drought, heavy rains, floods), agricultural pests and diseases, conflict and security crises, and economic shocks linked to COVID-19 restrictions, border closures, declining oil prices, and rising food prices (FSIN and GNAFC, 2021).

The impacts of production and price volatility on poverty will depend on how vulnerable households make a living. Net sellers of food and those dependent on agricultural wages *may* benefit, though much depends on the interplay between prices, output and incomes. Net consumers of food will be harmed, while those who depend on agricultural wages and profits are likely to experience mixed impacts. Poorer consumers – the growing numbers of households living in informal urban settlements and subsistence-orientated[7] farmers who struggle to feed themselves from own production – will be worst affected (Hallegatte, 2016; Trisos et al, 2022). Poorer urban households typically spend at least 40% of their incomes on food (Wiggins, 2022).

Links between climate-induced ecosystem change, food security and poverty have not been systematically assessed but are likely to be important. Poorer rural households are more likely to depend on foraging and wild foods to meet food and income needs, smoothing consumption between season and years. Incomes from resource stocks that grow *continuously* over years (e.g. timber and fish) also play a key 'buffering' role as they are less sensitive to weather fluctuations than those that depend on annual cycles, like crops (Naidoo et al, 2013; Hallegatte, 2016). Although the safety net function of ecosystems is well-known, few studies have looked at links between climate-induced ecosystem change and poverty in Central Africa, or in sub-Saharan Africa more broadly (Trisos et al, 2022).

The impacts of climatic changes on food imports required to meet national food demands may intensify household vulnerabilities to global market volatility and

[7] Smallholders who depend on a single rainy season for most of their staple food needs and practise low input, low output agriculture. Their farming is subsistence-orientated, but they are not 'subsistence' farmers because they rely on diversified sources of income and because they struggle to achieve self-sufficiency in most years (Devereux, 2009; Ellis, 2013).

changes in food prices. Some countries in Central Africa are highly reliant on food imports. In 2017-2021, cereal import dependency ratios (ratio of imported vs domestically produced food supplies) ranged from 22% in DRC and 42% in Angola, to 83% in Republic of Congo, 91% in Gabon, and 100% in Equatorial Guinea (FAOSTAT, 2022 – see Annex H, Technical Reference). However, agricultural production in Central Africa may have the potential to meet regional staple food demands, especially via increased cereals production in Cameroon with its wide range of agroecological zones allowing the cultivation of numerous key crops (Bricas et al., 2016; World Bank, 2018).

3.3 Water resources and water-dependent services

Summary of risks relevant to water and water-dependent services

- Central Africa as a whole has abundant surface and groundwater resources, and climate change is unlikely to have negative impacts on the overall availability of fresh water for different uses and users.
- Greater rainfall variability and more extremes will make mobilising and manging water for key sectors more difficult, though groundwater development can provide cost-effective, climate-resilient supply for urban and rural users.
- Central Africa has enormous hydropower potential, but planning and management for power, flood control and environmental objectives will become more difficult as rainfall becomes more variable and river flows fluctuate.
- Climate-induced changes in water quality, exacerbated by flooding, pose the biggest threat to drinking water and health in countries with very limited access to safe water and sanitation.

3.3.1 Context

The countries of Central Africa collectively form the most water-abundant region of Africa. The Congo Basin, covering an area of roughly 3.7 million km^2, is the second-largest river basin in the world after the Amazon Basin. The basin extends across nine countries - most of the Republic of Congo and DRC, the Central African Republic, eastern Zambia, northern Angola, Rwanda, Burundi and parts of Cameroon and Tanzania - before flowing into the Atlantic Ocean southwest of Kinshasa. The DRC alone accounts for 23% of Africa's internal renewable water resources (Karam et al, 2022).

Although water is abundant, use of water for Central Africa's economic and social sectors is extremely low. All countries fall within the low or no 'water stress' categories used for monitoring Sustainable Development Goal (SDG) 6.4.2.[8] Low levels of water use reflect modest levels of investment in water development, storage, and distribution. This is mainly because the big water-using sectors, particularly irrigation and hydropower, remain under-developed (ADB, 2016; Shah et al, 2020). For example, although the region has huge hydropower potential, investment to date has been limited, constrained by huge investment costs needed, the reluctance of banks to invest in challenging political environments, and weak market integration through regional power pools (ADB, 2016). Many projects developed to the pre-feasibility stage have not been progressed further because their generating capacity exceeds national power requirements (ADB, 2016).

In the sections below, we look at risks across three areas: water resources, including water quality; rural water supply and sanitation; and electricity generation from hydropower as this

[8] Water stress measured as water withdrawals as a percentage of available water. FAO (2018) data – see Annex H, Technical Reference.

is a region where hydropower development *potentially* offers the opportunity to power not just Central Africa, but other regions in Africa as well. Urban water supply and sanitation, and risks to other types of power, are covered under Infrastructure and Settlements in Section 3.4.

3.3.2 Water resources – availability and quality

Many of the impacts of climate change will be felt through the hydrological cycle. In contrast to Eastern, Western and Southern Africa, rainfall and river flows in Central Africa have remained fairly stable from year to year in recent decades (Conway et al, 2009). Throughout Central Africa rainfall variability is expected to increase as global temperatures rise, with more frequent and intense extreme rainfall events and more extreme peak (wet season) river flows and floods. It is unclear if annual total rainfall amounts will increase or decrease, however the latest model simulations suggest that increases are more likely, with greater confidence in these rises in the north-west of Central Africa. Increasing variability could also result in an increase in the frequency, severity and duration of drought conditions, particularly agricultural and ecological droughts, given rising temperatures and higher rates of evapotranspiration. In broad terms, however, climate change is unlikely to have negative impacts on the overall, long-term *availability* of water in the region's rivers and lakes to 2050 and beyond.

Groundwater resources provide climate-resilient water supply at relatively low cost for millions of dispersed, rural residents throughout Central Africa. Although the region's groundwater resources remain poorly characterised, a growing body of research[9] highlights their significance in terms of spatial extent (compared with more isolated rivers and lakes) and storage, with groundwater providing climate-resilient water supply at relatively low cost for millions of dispersed rural residents (Calow et al, 2018; Cobbing, 2020; MacDonald et al, 2021). In particular, the storage groundwater aquifers provide makes groundwater less sensitive to annual and multiannual rainfall variability (Taylor et al, 2013; Cuthbert et al, 2019; Caretta et al, 2022). Groundwater is also shielded to some degree from pollution because of the filtration effect of overlying soils and rocks. Nonetheless, local contamination occurs through poor construction of water and sanitation systems especially during heavy rainfall events and floods (Lapworth, 2020).

Threats to water quality rather than overall availability are likely to be the most pressing concern for Central Africa. The combination of reduced streamflow and rising temperatures will have broadly negative impacts on freshwater ecosystems and surface water quality (Cisneros et al, 2014; Caretta et al, 2022). Higher water temperatures encourage algal blooms and increase risks from toxins and natural organic matter in water sources. Increased runoff results in greater loads of fertilisers, animal wastes and particulates. Periods of low streamflows, meanwhile, reduce the capacity of rivers to dilute, attenuate and remove pollution and sediment. Reductions in raw water quality pose risks to drinking water quality, even with conventional treatment, though the extent and nature of changes remain uncertain and very dependent on rainfall seasonality, land cover and soil management practices (Howard et al, 2016; Calow et al, 2018).

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[9] Including those using Gravity Recovery and Climate Experiment (GRACE) satellite data to assess spatiotemporal variability in water storage, and those drawing on (limited) ground-based monitoring. See Scanlon et al (2022) for the most recent review of the evidence.

3.3.3 Rural water supply and sanitation

Secure water, sanitation, and hygiene (WASH) provides a vital buffer against climate variability (Howard et al, 2016; Calow et al, 2018). Investments in safe water and sanitation are risk-reducing (or resilience *multiplying*) since they lessen people's dependence on more climate-vulnerable, poorer quality sources, and free up time – particularly for women and girls – for more productive activities (Howard et al, 2016; Calow et al, 2018). They also have a well-documented role in improving long-term health and nutrition (Howard et al, 2016; Calow et al, 2018).

Climate change is more of a significant factor for water *quality* than availability in Central Africa. Specifically, the link between flood risk, poor sanitation, and water contamination in environments where water sources are poorly constructed, and sanitation is rudimentary or non-existent. Projected increases in fluvial, pluvial, and coastal flooding are likely to present increased risks to water and sanitation infrastructure and supply systems, and in turn water quality, through damage to and destruction of latrines, spreading of faecal matter, and widespread (and enduring) contamination of the surface environment, soils, water resources and water sources. Impacts on health, direct and indirect, can be severe. For example, a growing literature shows how poor WASH contributes to malnutrition by transmitting pathogens and infections that inhibit nutritional uptake through diarrhoea, parasites and enteric inflammation and dysfunction (Cumming and Cairncross, 2016; Howard et al, 2016; Nijhawan and Howard, 2022).

Countries and areas with limited sanitation and safe water are most exposed to climate risk. An initial assessment of climate risk therefore needs to consider how countries and regions perform in terms of extending and sustaining services. In Central Africa, the data paint a bleak picture overall, albeit with some bright spots (Table 2). Four key points emerge. First, rural populations are more poorly served than urban ones. Second, within both urban and rural areas, the poorest wealth groups (the bottom 40%) have the poorest services. Third, sanitation coverage lags well behind water - a significant issue in terms of contamination-linked flood risk. Finally, the Central African region as a whole is not on-track to meet SDG 6 for WASH, potentially leaving millions without access to safer, more resilient services and contributing to state fragility (World Bank, 2017; Sadoff et al, 2017; WHO/UNICEF, 2021).

Table 2: Population, WASH, electricity, and hydropower data Central Africa. Sources/notes: Country classifications: L (low income), LM (lower-middle income), UM (upper-middle income) World Bank classification 2022; Population (2020 data): World Bank, World Development Indicators; Access to drinking water (DW) & sanitation (San): (2020 data): UNICEF/WHO 2021; Hydropower as a % of total installed capacity (hydro instal cap): various sources. See Annex H of Technical Reference for further data and notes. (CAR = Central African Republic, Cam = Cameroon, E. Guin = Equatorial Guinea, R. Congo = Republic of Congo, DRC = Democratic Republic of Congo)

	Population		DW Access		San Access		Elec Access		Hydro
Country	Total (M)	Rural (%)	Total (%)	Rural (%)	Total (%)	Rural (%)	Total (%)	Rural (%)	Instal cap (%)
CAR (L)	4.8	58	37	28	14	6	15	2	88
Cam (LM)	26	42	66	44	45	23	65	25	54
E.Guin (UM)	1.4	28	64	31	66	57	67	1	20
Gabon (UM)	2.2	10	85	45	50	40	92	28	40-50
R.Congo (LM)	5.5	32	74	46	20	6	50	15	ND
DRC (L)	89.5	54	46	22	15	11	19	1	98
Angola (LM)	32.9	33	57	28	52	24	47	7	56

There are significant differences in WASH-related climate exposure across the Central African region. Looking at the latest country data and setting the bar low in terms of access to at least *basic* services[10], there are significant differences across the region. The Central African Republic and DRC have the lowest levels of water and sanitation coverage and, by implication, the most *exposure* to climate-related (WASH) hazards. Middle-income Gabon and the Republic of Congo have the highest levels of drinking water coverage, though the Republic of Congo fares much less well on sanitation.[11]

The evidence linking climate change with service outcomes is thin, but most sustainability problems are probably attributable to poor design, construction, and maintenance rather than climate change. Across Sub-Saharan Africa, anywhere between 10% and 65% of water points are 'non-functional' at a given time. In-depth functionality surveys conducted in Uganda, Malawi, and Ethiopia - countries adopting a similar mix of technologies to those in Central Africa - indicate that most functionality problems are attributable to poor design, siting, construction, and maintenance rather than climate change (Calow et al., 2017). In Central Africa, a detailed diagnostic of WASH performance in DRC highlighted the 'silent' emergency of malnutrition linked to poor WASH, with low coverage and poor construction of systems leading to widespread pollution of water by *E. coli*. This was common across improved and unimproved sources, high in the capital Kinshasa, and near universal in some rural areas (World Bank, 2017). Clear links between water supply disruptions and the outbreaks of cholera in DRC have also been observed (Jeandron et al, 2015). A key conclusion is that most existing technologies are resilient to climate change

[10] An improved source with collection times of less than 30 minutes.
[11] According to the latest World Bank country classifications for FY 2023, the Central African Republic and DRC fall into the low-income category (< USD 1085/capita). Cameroon, the Republic of Congo and Angola are classified as lower-middle income (USD 1086 - 4255/capita). Equatorial Guinea and Gabon are in the upper-middle income grouping (USD 4256 – 13,205/capita).

provided systems are built and maintained to higher standards (Howard et al, 2016; Calow et al, 2018).

3.3.4 Hydropower

Access to reliable electricity is a problem across Central Africa. For the seven focus countries, access to electricity averages 34%, below the average for Central Africa (53%). The Central African Republic and DRC report the lowest access at 15% and 19%, respectively, overwhelmingly urban (World Bank 2022 - see Annex H of Technical Reference). Lack of access to reliable electricity results in poorer social and economic outcomes, and contributes to serious environmental degradation as rural people meet their energy needs with charcoal and firewood (Hallegatte et al, 2016, 2019; Rozenberg and Fey, 2019).

Hydropower makes up a significant share of Central Africa's electricity production and the share is growing. With the exception of Equatorial Guinea (20%), hydropower accounts for over 50% of installed electricity generation capacity in each country (various sources – see Annex H, Technical Reference). Hydropower potential is significant, and development of hydropower is ramping up in Cameroon, Gabon, Equatorial Guinea, and Angola[12]. Angola aside, new developments are now drawing on Chinese financing (Brautigam and Huang, 2017)[13].

Although hydropower is much cleaner than fossil fuel alternatives, its green credentials are sometimes over-hyped. Many hydroelectric schemes require large areas to be flooded to create dams or reservoirs that supply the water that powers turbines. The greenhouse gas emissions from tropical reservoirs can be significant (though less than fossil fuel equivalents) because of the decomposition of flooded organic material. Emissions tend to be highest in the first 10-20 years following reservoir impoundment. Emissions relating to construction and operation depend on reservoir type, size, and location (IHA, 2020).

Hydropower development on the Congo River, focussed largely on the Inga schemes in DRC, could potentially provide around 40% of Africa's energy needs (Trefon, 2016; Moran et al, 2018). The Grand Inga scheme, a combined series of dams adding to completed Inga 1 and Inga 2 developments, would constitute the largest hydropower complex in the world at 40 GW (40,000 MW), generating almost twice as much as the Three Gorges dam in China if fully developed, over eight times the power of Ethiopia's Grand Renaissance dam, and more than one third of current electricity production in Africa (Trefon, 2016; Gnassou, 2019; Moran et al, 2018). As it stands, the enormous cost of the scheme, and the lack of an accessible market for power beyond DRC, blocks development (Gnassou, 2019 - see below).

Hydropower potential is under-exploited, but more variable river flows and droughts may disrupt power supply in the future. Greater annual and inter-annual variability in rainfall and river flow can make electricity production less reliable (albeit with more high-flow peak power), and challenges dam management because the balance between flood prevention and

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[12] Cameroon, for example, has the third largest hydropower potential in Africa after DRC and Ethiopia, yet only 3% has been exploited to date, mainly in the Sanaga river basin. By 2025, an additional 3000 MW will have been added to the grid (IHA, 2020).
[13] Financing estimates based on >75% funding for major (> 50 MW) projects, with funding all from the Export-Import Bank of China (Eximbank), China's official export credit agency (Brautigam and Huang, 2017).

power production becomes more difficult to navigate (Ludwig et al, 2013; Hallegatte et al, 2019). In larger river basins this is less of an issue because the effect of heavy rainfall or drought on river flow in one area can be 'smoothed' by low/high rainfall in another. In the Congo Basin, for example, there is always at least one part of the catchment experiencing a rainy season because the drainage basin straddles the equator on its north and south sides, and because it is also fed by 'baseflow' release from wetlands and groundwater (Trefon, 2016). In smaller, more responsive ('flashier') catchments, reliable power generation and flood control is more of an issue. For run-of-river hydropower with little or no reservoir storage, power generation is directly linked to seasonal river flows. Hence while off-grid 'micro-hydro' can provide much needed power in disconnected rural areas, it is much more sensitive to rainfall and stream/river flow variability.

Most big infrastructure projects have been planned for historical climates not future ones. Hydropower is dominated by large, irreversible schemes with a design life of at least 50 years. However the storage capacity and management regimes for most reservoir schemes in Sub-Saharan Africa are designed for *historical* patterns of (poorly characterised) hydrological variability. This poses significant risks to performance and maintaining *reliable* power production and flood control from reservoirs may require increases in storage capacity and cost to build and maintain (Conway et al, 2015; Sridharan et al, 2019; Siderius et al, 2021). The risks associated with under-designing for future climate change are manifold, and include those associated with soil erosion and resevoir sedimentation in catchments experiencing greater runoff and flooding[14]. Guidance on factoring-in climate change into hydropower planning has only recently been published under the auspices of the International Hydropower Association (IHA) with technical support from the World Bank and other donors (see IHA, 2019).

Chinese financing may turbo-charge hydropower development in Central Africa but carries risks. The slow pace of hydropower development in the region reflects, in part, social and environmental conditionalities attached to financing from the 'traditional' multilaterals that have historically bankrolled large infrastructure (e.g. IBRD). But countries now have other options to turn to, not least Chinese investment. While China's engagement in African hydropower is often exaggerated in the media (Brautigam and Huang, 2017), major new investment – already significant - may be incentivised by energy-intensive mining. Specifically, the opportunity to develop (and export) the region's rich natural resources, increasingly focussed on the copper, cobalt and lithium needed for batteries/electric vehicles. The institutions financing hydropower, particularly China's Eximbank, are not signatories to the (voluntary) international Hydropower Sustainability Assesment Protocol (HSAP), or the IHA guidelines on addressing climate risk (see IHA, 2019). A recent study by IIED concluded that Chinese hydropower is starting to address social and environmental safeguarding norms, but that progress remains patchy (Buckley et al, 2022) and very dependent on financing and construction modalities[15].

[14] Existing hydropower schemes on the Congo River run well below intended generation targets because of maintenance and repair issues, but also because of siltation.
[15] In particular the financing package, the way it is structured, and the funding mix - bilateral or a mix of bilateral-multilateral (IIED, personal communication).

Regional cooperation and power sharing offer the potential to accelerate hydropower development and mitigate climate risks. Ongoing interest in hydropower development on the Congo River reflects concern in Southern Africa about greater climate variability and (in some areas) declining rainfall in key hydropower basins. This prompted South Africa's decision in 2014 to ratify an agreement with DRC to purchase over half of the output of (proposed) Inga 3, significantly strengthening the bankability of the project (Gnassou, 2019). Long distance power transfers to Egypt and Nigeria have also been mooted (Gnassou, 2019).

Trading between regions facing different climate risks reduces the threat of concurrent low flows and load shedding, but the costs involved (including transmission) have so far proved prohibitive. The Central Africa Power Pool (CAPP) currently supports only minimal trading beyond a few bilateral arrangements (ADF, 2021), Moreover, after initial feasibility funding, the World Bank suspended support for Inga 3 in 2016 citing differences of opinion over the project's 'strategic direction'.[16] The current status of the Inga 3 hydroelectric scheme is unclear after the withdrawal of the Chinese consortia and unilateral reallocation by DRC to Australian resources company Fortescue (Reuters, 2021).

[16] World Bank Press Release, July 2016: HYPERLINK "https://www.worldbank.org/en/news/press-release/2016/07/25/world-bank-group-suspends-financing-to-the-inga-3-basse-chute-technical-assistance-project"https://www.worldbank.org/en/news/press-release/2016/07/25/world-bank-group-suspends-financing-to-the-inga-3-basse-chute-technical-assistance-project)

3.4 Infrastructure and settlements

Summary of risks relevant to infrastructure and settlements

- More intense rainfall events will increase flood risk in settlements of all sizes, with densely populated, low-lying, and fast-growing informal settlements most exposed and vulnerable.
- Increasing temperatures and heat extremes, in combination with rapid urbanisation, will increase demand for water and electricity, intensifying pressure on fragile and overstretched infrastructure.
- Rising temperatures, heat extremes and floods will have negative impacts on power generation of all types and may also damage or disrupt electricity transmission.
- Rising sea levels, storm surges and floods threaten the region's coasts where people and economic assets are increasingly concentrated.

3.4.1 Context

The region's urban population increased from 20 million in 1990 to nearly 70 million in 2015 and 87 million in 2020, while settlements of more than 10,000 people rose from 272 in 1990 to 881 in 2015 (most in DRC) (OECD/SWAC, 2020; UN Habitat, 2021). The urban population across the seven countries is projected to reach over 243 million by 2050, representing 76% of the region's population (UN Habitat, 2021). Annual urban growth rates in Central Africa were higher than most other regions in 2000-2010 (4.9%) and 2010-2015 (6.2%), second only to East Africa (OECD/SWAC, 2020). In 2018, an average of 61% of urban populations in the region lived in informal settlements (higher than the world average of 24%), ranging from roughly 35% in Cameroon and Gabon to nearly 50% in Republic of Congo and Angola, to 95% in Central African Republic (UN Habitat, 2021).

Table 3. *Urbanisation indicators in Central Africa (sources: OECD/SWAC, 2020; UN Habitat, 2021). CAR is the Central African Republic, R. Congo is Republic of Congo, DRC is Democratic Republic of the Congo, E.Guinea is Equatorial Guinea.*

	Urban population (millions)				**Population residing in urban areas (%)**				**No. of agglomerations (>10,000 people)**	
	1990	**2015**	**2020**	**2050**	**1990**	**2015**	**2020**	**2050**	**1990**	**2015**
Cameroon	4.1	12.8	14.9	36.4	35	55	58	73	70	147
CAR	0.9	1.8	2.1	5.3	33	37	42	60	22	31
R. Congo	1.3	3.1	3.9	9.2	60	66	68	80	15	27
DRC	10.6	32	40.8	125.9	29	45	46	64	130	553
E. Guinea	0.1	0.8	1	2.4	26	62	73	83	2	13
Gabon	0.5	1.5	1.9	3.3	55	81	90	95	7	14
Angola	2.6	15.9	21.9	61.1	26	63	67	80	26	96

Urban populations and urbanisation levels have increased dramatically in Central Africa in recent decades (see Table 3). Pressures on over-stretched infrastructure including energy, water and sanitation will grow as urban settlements expand. Climate risks will affect both rural and urban areas but may be most obvious and intense in areas where infrastructure provision (decent housing, safe water and sanitation, drainage, power) lags behind urban growth. Although climate risks to infrastructure may be addressed in National Adaptation Plans of Action, insufficient human and financial resources impedes risk preparedness and response (Nkiaka and Lovett, 2018).

The impacts of climatic changes on settlements and infrastructure will present the most severe risks for populations already exposed to conditions of vulnerability (Trisos et al., 2022). A large proportion of urban residents in Central Africa reside in informal settlements often located on the peripheries of cities, with inadequate water, sanitation, and waste management services and drainage systems (OECD, 2021). Rapid urban development since the 1980s has meant that many people, especially poorer populations, have settled in areas at risk of flooding such as swamps and floodplains, and hillside areas at risk of landslides (Kometa and Akoh, 2012; Cain, 2017; Yengoh et al., 2017; Ovono and Pottier, 2019). These are areas where climate risk and poverty will increasingly coincide.

3.4.2 Housing and transport

Increases in extreme rainfall events and floods will damage housing, transport infrastructure and other service and supply systems in urban and rural settlements. Flooding is already a key risk in Central Africa. In 2021, floods affected over 450,000 people in DRC, Republic of Congo, and the Central African Republic, with 53,000 people displaced and over 50,000 homes destroyed (OCHA, 2022). Central Africa is among the regions globally at greatest risk of increased flood displacement in the second half of this century due to a projected increase in the frequency of river floods with a flood-water depth exceeding one metre, in combination with growing populations (Kam et al., 2021).

Increased flood risks and damage will combine with increasing demands on already inadequate infrastructure to amplify risks in urban settings. Vulnerabilities to flood risks across Central Africa will be intensified if urban areas expand in unplanned ways, especially where new urban areas lack adequate drainage (Tshimanga et al., 2016). Rapid urbanisation has meant that informal settlements have extended into areas at substantial risk of climate-related hazards such as floods (e.g., low-lying floodplain areas) (OECD, 2021), and these risks may intensify with expected increases in rainfall extremes. Risks may be particularly high in north-western parts of Central Africa where total rainfall levels may be more likely to increase. Settlements close to major rivers and lakes are particularly exposed, such as Kousseri, Maroua, Garoua, and Douala (Cameroon), Bangui (the Central African Republic), Brazzaville (Republic of Congo), and Kinshasa and Kisangani (DRC).

Flood risk is shaped by many factors, not just climate. Large-scale deforestation, mining and rapid urbanisation have all intensified flooding in the Congo River Basin (Tshimanga et al., 2016). Flood risks and vulnerabilities are also exacerbated by inadequate institutional flood management capacities, including weak and poorly enforced risk assessment and management frameworks, limited drainage and flood prevention measures, and barriers to flood response and evacuation (Tshimanga et al., 2016; Bang et al., 2017, 2018; Nguimalet, 2018; Tangan et al., 2018; Wanie and Ndi, 2018; Bang et al., 2019). In Douala (Cameroon) and Libreville (Gabon), for example, increased flood risks have been attributed not to changing rainfall patterns but to poor urban planning and infrastructure investment in the face of population increase, resulting in the occupation of flood-prone areas (Yengoh et al., 2017; Ovono and Pottier, 2019).

Floods and heat extremes may disrupt Central African transport infrastructure and networks via damage to roads, bridges, rail infrastructure, and airport runways, with impacts that extend across areas and sectors (Cervigni et al., 2017; Koks et al., 2019). This can have severe consequences for food security, communication, and wider economies in the region (Trisos et al., 2022). A recent global assessment of projected damage to transport infrastructure due to surface and river flooding reports that Central Africa is among the regions globally at greatest risk of disruption and damage to road and rail infrastructure, with Central African Republic the country most at risk on a global scale (Koks et al., 2019). Increases in heat extremes could also have major impacts on transport networks through damage to roads, railways, and airport runways (e.g., buckling, accelerated aging) (Cervigni et al., 2017). In rural areas, loss of individual road links or bridges can leave large areas and large numbers of people without a connection to markets, supply chains, and essential services. While the severity of natural disasters is often measured in terms of asset loss and damage, it is the secondary impacts on economic activities and output that often explain a larger share of impacts as risks cascade across areas and sectors (Hallegatte et al, 2019).

3.4.3 Power and communications

Heat extremes pose a range of risks to power infrastructure, particularly electricity generation and distribution systems in both urban and rural areas of Central Africa. Direct impacts include the overheating of electricity generators, transmission lines, and substations, which can result in power outages. Rising temperatures and temperature extremes will also increase energy demands for cooling technologies across domestic, industrial and health sectors (Parkes et al., 2019), with demands already increasing with rapid urbanisation. DRC is projected to face the second-greatest increase in cooling demand of all African countries under 2°C and 4°C warming, due to the combination of heat stress and population density, while Central African Republic is expected to face particular challenges related to cooling demands due to low GDP per capita (Parkes et al., 2019). A recent study in seven cities in Central Africa – including Yaoundé, Bangui, Brazzaville, Kinshasa, Malabo, and Libreville – projects energy demand for cooling to almost double (82%) at 2.5-3°C of warming and increase by more than two and a half times (167%) under 3-5°C of warming between 2016 and 2100 (Nematchoua et al., 2019).

The region has significant solar (and wind) power potential, though development to date has been limited. Solar potential especially is significant, though evidence linking climate change with solar photovoltaic (PV) output across Sub-Saharan Africa remains limited. Solar power is sensitive to climate because PV output depends on shortwave irradiance from the sun, which is in turn affected by aerosols and clouds (Feron et al, 2021). Output is also affected by air temperature, with hotter conditions generally reducing the efficiency of PV panels and lowering output (Feron et al, 2021). One study suggests moderate impacts on PV solar potential (±3%) for most of the continent by mid-century, with uncertainties linked mainly to changes in cloud cover.[17]

3.4.4 Urban water supply and sanitation

Access to at least basic water and sanitation services is far higher in urban areas than in rural areas in Central Africa, although rates vary widely across countries (see Section 3.3). The proportion of urban populations with basic drinking water access in 2020 ranged from 50% in the Central African Republic, to between roughly 70-80% in Cameroon, DRC, Equatorial Guinea, and Angola, to roughly 90% in Republic of Congo and Gabon. Urban access to basic sanitation was lower, ranging from about 20-25% in the Central African Republic, Republic of Congo, and DRC to 60-70% in Cameroon, Equatorial Guinea, and Gabon (World Bank, 2022 – see Annex H, Technical Reference). **Water-related insecurities persist in urban and peri-urban areas in the region, associated with aging or inadequate water and sanitation infrastructure, reliance on informal water provision, high water prices, water pollution and contamination, and increasing urban population growth outpacing supply systems** (UNEP, 2011; OECD, 2021). The pace of urbanisation means that many urban residents, particularly those living in unplanned, informal settlements, have neither a piped water supply nor a safe means of waste disposal.

Many urban populations, especially in peri-urban areas and informal settlements, rely on patchy and unregulated water supply and sanitation services, increasing exposure to climate risks. National water access rates mask disparities across and within urban settlements, including limited investments in basic services for informal settlements and areas far city centres (Cain, 2018; OECD, 2021). In Cameroon, DRC, and Angola, many urban and peri-urban residents rely on shallow wells, untreated water (e.g., from streams or rivers), or rainwater collection for drinking, bathing, washing, and cultivation (Kapembo et al., 2016; Nienie et al., 2017; Silva et al., 2017; Kayembe et al., 2018; Tume, 2021). In parts of Kinshasa, DRC, more than 70% of people rely on polluted shallow wells for domestic water (Kapembo et al., 2016). In Luanda, Angola, a third of residents rely on expensive, poor quality informal supply mechanisms such as tanker trucks supplying river water (Cain, 2018).

Projected increases in heavy precipitation events can lead to pluvial (surface) floods, while the impacts of sea level rise can lead to coastal flooding (see Section 2.2). **Urban flooding and inadequate sanitation combine to create major health risks.** This is because of the link between flooding and damage to onsite sanitation, problems gaining vehicular access to flooded areas to empty on-site systems, and because the mixing of flood water and sewage over wide areas can contaminate the environment and water supply. Sanitation, wastewater and faecal sludge management remain insufficient and largely unregulated in Central Africa (Silva et al., 2017; Kayembe et al., 2018; Bisimwa et al., 2022). Studies in DRC and Angola report that faecal contamination of well and river water in urban centres, which contributes to water-borne diseases, is especially high in the wet season due to higher runoff and floods (Kapembo et al., 2016; Nienie et al., 2017; Silva et al., 2017; Kayembe et al., 2018). A systematic review of the health evidence highlights strong links between flood events and

[17] Under RCP4.5 – an intermediate emissions scenario under which global temperatures rise by 2-3oC by 2100 (Feron et al, 2021).

outbreaks of water-related disease, including cholera, hepatitis A and E, and pathogenic *E.coli* (Alderman et al, 2012).

Risks associated with urban water and sanitation services (or the lack of them) will be shaped by institutional and system-level dynamics as well as climate change. These include wide disparities in investments in water and sanitation infrastructure within urban centres. Studies in Central Africa show that urban water crises are due to insufficient and unreliable supplies via municipal distribution networks, reliance on community water provision schemes, uncoordinated national policies, and poorly conceived privatisation schemes for water utilities (Fonjong and Ngekwi, 2014; Sally et al., 2014; Fonjong and Fokum, 2017; Cain, 2018; Tantoh and Simatele, 2018; Tume, 2021).

3.4.5 Coastal settlements and infrastructure

Roughly 60-70% of the population of coastal Central African countries (excluding Central African Republic but including Sao Tome and Principe) is located in coastal zones. Over half of the region's urban population lives in coastal cities, and coastal communities are growing faster than those inland (UNESCO/IOC, 2020). Angola has the largest coastal population in the region with over half the country's population (and nearly two-thirds of its urban population) living in coastal settlements (Cain, 2017; UNESCO/IOC, 2020).

Rising sea levels will amplify threats from storm surges, coastal flooding, coastal erosion, and shoreline retreat (UNESCO/IOC, 2020). Sea levels have been rising in Central Africa and this is expected to continue (Cooley et al, 2022). Compound hazards associated with sea level rise affecting coastal cities include extreme coastal high tides, storm surges, and flooding (Moftakhari et al., 2018). Risks may be particularly acute for large coastal cities (e.g., Pointe-Noir, Republic of Congo; Libreville, Gabon; Malabo, Equatorial Guinea; Douala, Cameroon), cities along steeper coastlines (e.g., Luanda, Angola), and countries and locales with low-lying beaches (e.g., Gabon) (Hinkel et al., 2012). Gabon has been identified as particularly vulnerable to sea level rise given the concentration of populations and economic activities in coastal areas (Hinkel et al., 2012). Vulnerabilities are intensified by inadequate disaster risk assessment and management plans (Cain, 2017; Yengoh et al., 2017; Maes et al., 2019).

Rising sea levels and coastal flooding may also increase the risk of saltwater (saline) intrusion into coastal groundwater aquifers. Saline intrusion has affected groundwater quality along the Cameroon and Angola coasts (UNESCO/IOC, 2020). In the coastal town of Limbe in south-western Cameroon, saline intrusion is already affecting coastal aquifers and groundwater quality (Motchemien and Fonteh, 2020). Few studies have looked at this topic or attempted to untangle the climate signal from other drivers of change. While the problem is likely exacerbated by sea level rise, the main cause is likely to be intensive groundwater extraction on the coast for domestic, industrial, and agricultural uses. This 'pulls' saline water from the sea into coastal aquifers as freshwater is pumped out (UNESCO/IOC, 2020).

Urban expansion, the growth of extractive industries and ecosystem degradation have contributed to coastal erosion in Central Africa, alongside climate change (UNESCO/IOC, 2020). Sand and aggregate mining for construction contributes to the degradation of natural coastal defences in the region (UNESCO/IOC, 2020). Furthermore, coastal ecosystems that play an important role in protecting coasts are being damaged and destroyed through human activity. Coastal mangrove ecosystems in Central Africa which play a key role in flood and erosion defence have declined due to wood harvesting, agricultural expansion, and infrastructure development for oil production (Feka and Ajonina, 2011; Ellison and Zouh, 2012; Munji et al., 2013; G. N. Ajonina et al., 2014a; Munji et al., 2014; Fendoung et al., 2017; Nemba et al., 2022).

Sea level rise, storm surges and floods may damage port structures and vessels, while rising temperatures and heat extremes may affect mechanical equipment and power supplies (Izaguirre et al., 2021). Coastal areas in Central Africa are home to important transport and trade infrastructure, notably port facilities, and shipping routes (UNESCO/IOC, 2020). Key ports in the region include Douala and Kribi (Cameroon), Pointe Noire (Republic of Congo), Malabo, Bata, and Luba (Equatorial Guinea), Libreville and Port Gentil (Gabon), and Luanda and Lobito (Angola). These will be increasingly exposed to damage from sea level rise, storm surges and floods.

Households have adopted a range of strategies to cope with and adapt to coastal risks. These include modifying and reinforcing housing (e.g., through elevation, roof protection), establishing flood barriers (e.g., sandbags, tree planting, other flood-proofing techniques), or relocating (Molua, 2009a; Munji et al., 2013, 2014; Evariste et al., 2018). However, most are reactive individual- or household-level actions that are unlikely to contribute to longer-term sustainability, and are limited by a lack of financial resources, technical know-how, and institutional support (Munji et al., 2013). Initiatives to counter the impacts of sea level rise, coastal erosion, and coastal flooding are being implemented in Central African countries, including construction and expansion of embankments, dikes, and seawalls (World Bank, 2021). However, these types of 'hard' infrastructure defences may exacerbate risks elsewhere and, if they fail, can have rapid and catastrophic impacts (Goussard and Ducrocq, 2017).

3.5 Health

Summary of risks relevant to health

- Increases in extreme precipitation events and flood risks, combined with increases in temperature, may contribute to increases in the prevalence of communicable water-borne diseases such as cholera and diarrhoeal diseases through contamination of drinking water sources.
- Increasing temperatures and changing rainfall patterns will likely affect the geographic range and incidence of vector-borne diseases such as malaria and dengue fever, including in highland areas that are currently not suitable for transmission.
- Increasing temperature extremes, and combinations of increased heat and humidity, will result in more days of the year exceeding critical heat stress thresholds, intensifying existing heat risks and reduce labour productivity. Poverty-affected households, residents of informal settlements, outdoor workers, children, and elderly people, especially in urban settlements, are the most vulnerable to heat risks.

3.5.1 Context

In 2020 the mortality rate for children under five years old ranged from 42 per 1,000 live births in Gabon, to 72 in both Cameroon and Angola, to 103 in the Central African Republic, compared to a global average of 38. In 2019, the average life expectancy in the region was 62 years (ranging from 53 in Central African Republic to 67 in Gabon), compared to a world average of 73 years (WHO, 2022).

In 2016, the average mortality rate attributed to unsafe water, sanitation, and hygiene (WASH) conditions in Central Africa was 45 per 100,000 people (ranging from 21 in Gabon to 82 in the Central African Republic), compared to a world average of 14 (World Bank, 2022) (see Table 4). In 2019, communicable diseases and maternal, prenatal, and nutrition conditions accounted for an average of 55% of deaths in the seven countries vs a world average of 33% (WHO, 2022).

Table 4: *Diseases and mortality in Central Africa (source: World Bank, 2022). CAR is the Central African Republic, R. Congo is Republic of Congo, DRC is Democratic Republic of the Congo, E.Guinea is Equatorial Guinea.*

	Mortality from unsafe WASH, 2016 (per 100,000 people)	Mortality from air pollution, 2016 (per 100,000 people)	Deaths from communicable diseases and nutrition, 2019 (% of total)	Deaths from non-communicable diseases, 2019 (% of total)
Cameroon	45	208	52	38
CAR	82	212	59	32
R. Congo	39	131	52	39
DRC	60	164	56	34
E. Guinea	22	178	60	33
Gabon	21	76	46	45
Angola	49	119	59	32

Communicable diseases such as diarrhoea and malaria are some of the main causes of death in Central Africa. Between 2000-2019, malaria was the leading cause of death among 5-19-year-olds in the region (Liu et al., 2022). In 2016 the average mortality rate attributed to household and ambient air pollution was 155 per 100,000 people (ranging from 76 in Gabon to 212 in the Central African Republic), slightly lower than the world average of 211 (World Bank, 2022).

Health expenditure in the region has increased in recent decades but per capita spending differs hugely across countries, ranging from about USD 21 per capita per year in DRC to USD 255 in Equatorial Guinea in 2019 (USD 37 in the Central African Republic, USD 49 in Republic of Congo, USD 54 in Cameroon, USD 71 in Angola, USD 215 in Gabon) (WHO, 2022).

Human health outcomes in Central Africa have improved over the past two decades, with all countries experiencing an increase in life expectancy at birth and a decline in infant, child, and adult mortality rates (WHO, 2022). However, key health indicators remain below global averages. Health systems are affected by insufficient health infrastructure, staff, and financial and material resources, and gaps in geographic access and quality (Munster et al., 2018; Falchetta et al., 2020). Considering other environmental impacts on health, across Central Africa air pollution is associated with higher mortality rates than unsafe WASH conditions (World Bank, 2022; see Table 4). Climate change impacts will exacerbate existing inequalities in health outcomes and access to services, shaped by socio-economic determinants of health linked to economic status (e.g., poverty), location (e.g., rural location, informal settlements), and social position (gender, age, etc.) (Trisos et al., 2022).

3.5.2 Communicable and non-communicable diseases

More intense rainfall events and flooding, combined with low access to safe water and sanitation, will increase the risk of water-borne diseases in Central Africa. Outbreaks and transmission of water-borne disease such as cholera, typhoid, hepatitis E, and diarrhoea occur through contamination of water sources and irregular water supply (Nsagha et al., 2015). Faecal contamination of well and river water in urban centres is especially high in the Central African wet season due to higher volumes of runoff (Kapembo et al., 2016; Nienie et al., 2017; Silva et al., 2017; Kayembe et al., 2018). Cholera risks have increased in recent years: in 2021, the Central (and West) Africa region recorded its largest cholera epidemic in five years (Cholera Platform, 2021). Risks are higher for households with limited water, sanitation and hygiene (WASH) facilities, prioritising water for drinking and cooking rather than handwashing and cleaning, while recycling of water for multiple uses (e.g., cleaning, handwashing) can increase infection risks (Nounkeu and Dharod, 2020; Dharod et al., 2021; Nounkeu et al., 2019, 2021).

Temperature and rainfall changes may contribute to shifts in vector-borne diseases. Across Central Africa, rising temperatures and changing rainfall totals may change the distribution of suitable habitat for mosquito development and decrease virus incubation time, in turn increasing transmission – though very high temperatures may increase mosquito mortality and decrease transmission risk (mosquito populations decline as temperatures rise, especially approaching 40°C) (Ngarakana-Gwasira et al., 2014; Sintayehu et al., 2020). Heavy rainfall may increase suitable breeding sites but disrupt mosquito eggs and larvae (Sintayehu et al., 2020).

Rising temperatures may lead to increases in malaria transmission and prevalence in Central Africa, especially higher elevation areas (Tonnang et al., 2014; Mordecai et al., 2020; Ryan et al., 2020). Northern Angola and southern DRC may become new malaria hotspots by 2030, extending to western Angola by 2080 (Ryan et al., 2020). New seasonal malaria regions may emerge in central Angola and coastal Gabon and Republic of Congo by the 2030s (Zermoglio et al., 2019). Increases in temperatures and rainfall may increase and expand dengue fever incidence, especially in Cameroon, Equatorial Guinea, and Gabon (Sintayehu et al., 2020) and in the Central African Republic, northern Republic of Congo, and central and northern DRC (Campbell et al., 2015; Attaway et al., 2016).

However, temperature and rainfall changes could lead to a decrease in malaria transmission in some areas (e.g., parts of Cameroon, the Central African Republic, DRC, Angola) due to declining environmental suitability and the breaching of mosquito thermal limits (Egbendewe-Mondzozo et al., 2011; Drake and Beier, 2014; Yu et al., 2015; Semakula et al., 2017; Ryan et al., 2019; Trisos et al., 2022). In parts of Central Africa where temperatures are currently regularly between 25-29°C, areas experiencing rising temperatures may become less suitable for malaria but more suitable for dengue, chikungunya, and other insect-borne viruses (Mordecai et al., 2020). However, evidence on the links between climate change and infectious disease in Central Africa remains limited (Heaney et al., 2016).

Climatic factors have been identified as contributors to the transmission of the monkeypox virus (Thomassen et al., 2013)**.** The monkeypox virus can cause serious smallpox-like illness in humans and is transmitted from wildlife to humans in tropical forest areas of the Congo Basin. Temperature and rainfall changes may contribute to shifts in monkeypox range into new regions, especially in eastern DRC and in south-eastern Cameroon, northern Gabon, and Equatorial Guinea, while drying trends may disperse mammals into human settlements to forage. However, forest clearing will likely be a more important factor in transmission trends, leading to more frequent contact between humans and wildlife carriers (Thomassen et al., 2013).

Increases in annual temperatures and hot extremes combined with air pollution could increase prevalence of non-communicable diseases such as respiratory and cardiovascular illnesses throughout Central Africa. High temperatures can exacerbate cardiovascular disease, stroke, renal diseases, neurodegenerative diseases, and type-2 diabetes (Cook et al., 2011; Cosselman et al., 2015; Barraclough et al., 2017; Killin et al., 2016). These risks, especially to urban populations, will be intensified as extreme weather conditions increase. Climate change may contribute to an increase in the concentration of air pollutants, especially fine particulate matter associated with lung cancer and cardiopulmonary disease (Park et al., 2020).

3.5.3 Heat stress

Increases in the intensity and frequency of hot extremes across Central Africa are likely to have significant impacts on human health. Impacts include dehydration, heat-stroke, reduced productivity and exacerbation of respiratory conditions. Heat extremes, heat stress and other heat-related risks (e.g., heat cramps, heat exhaustion, heat stroke) are likely to affect all of Central Africa but may vary regionally in severity (Fotso-Nguemo et al., 2022). Coastal, northern, and central areas of Central Africa are likely to be exposed more frequently to higher heat-related risks, notably southern Cameroon, Central African Republic, Republic of Congo, Equatorial Guinea, Gabon, northern and western DRC, and northern Angola. Risks may be especially high in coastal areas due to increases in both temperature and humidity (Fotso-Nguemo et al., 2022).

Risks from extreme heat will be especially severe in Central African urban centres due to the 'urban heat island' effect and the combination of heat and humidity. Wet bulb temperatures (a combination of heat and humidity) above 34-35°C pose severe risks to human health and productivity, with wet bulb temperatures of 35°C identified in some studies as a limit for human survivability (Andrews et al., 2018; Coffel et al., 2018; Speizer et al., 2022). Humidity is likely to be higher in urban areas near rivers and lakes, increasing the likelihood of dangerous wet bulb temperatures. Cities in Central Africa are projected to experience an 89-fold increase in exposure to heat extremes under high emissions by the 2090s on average, with Luanda, Angola projected to have a 181-fold increase in exposure (Rohat et al., 2019). The number of days projected to exceed potentially lethal (i.e., contributing to excess mortality) heat thresholds could reach 100 to 150 days per year in Central Africa and over 200 to 300 days in some parts of the region between 2090 and 2100 under RCP 8.5 (Mora et al., 2017).

Heat-related health risks will be particularly acute for poverty-affected individuals and households with limited access to cooling technologies, including those in informal urban settlements. Children (especially those under age five), elderly people (over age 64), and people with disabilities also face greater vulnerabilities to heat-related health risks (Trisos et al., 2022). Assessments of heat-related mortality risks among people aged over 65 on a global scale have identified Central Africa as the region at greatest risk due to the combined effects of severe heat waves, population increase, and aging infrastructure (Ahmadalipour et al., 2019; Fan et al., 2022). Outdoor laborers, especially agricultural workers, construction workers, utility and other service workers, and workers in the informal sector, are particularly exposed.

3.6 Coasts, fisheries, and the marine environment

Summary of risks relevant to coastal fisheries and the marine environment

- Over half of the region's urban population now live in coastal cities, increasingly exposed to sea level rise, coastal erosion, and flooding.
- Marine fisheries are at risk from increases in sea surface temperatures, the impacts of sea level rise, ocean acidification, and marine heat waves.
- Increases in coastal flooding and erosion threaten coastal ecosystems, including sandy beaches, estuaries, deltas, and wetlands. Mangroves offer protection against floods and act as carbon sinks but are threatened by rising sea levels and anthropogenic pressures.
- Climate change will act with and amplify other pressures from rapid coastal urbanisation, industrial development and pollution, agro-industrial development, mining and oil exploration.

3.6.1 Context

People and economic assets are increasingly concentrated in Central Africa's coastal areas. Over half of the region's urban population now lives in coastal cities (see Section 3.4), attracted by job opportunities with industries linked to exports, oil and gas, fishing and agro-industries such as palm oil production. Coastal development is not unique to the region; globally, people are attracted to risky coastal areas because of the jobs on offer (Hallegatte et al, 2017).

Urban and industrial expansion, alongside climate change poses risks to important coastal ecosystems and the services they provide. Those include coastal estuaries and deltas, such as Gabon's massive Ogooué freshwater delta, which supports rich flora and fauna, and coastal mangrove systems (the largest off the coast of Cameroon) that serve as sea defences, fish nurseries and carbon stores.

3.6.2 Coastal and marine fisheries

Coastal fisheries play an important economic role in Central Africa and also provide an important source of food and nutrition. Marine fisheries and aquaculture production reached about 5,000 metric tonnes in Equatorial Guinea in 2019, nearly 10,000 tonnes in DRC, nearly 20,000 tonnes in Gabon, over 30,000 tonnes in Republic of Congo, nearly 270,000 tonnes in Cameroon, and nearly 390,000 tonnes in Angola (FAO, 2021a). The scale of production may also be significantly underestimated (Belhabib et al., 2016a; Nsangue et al., 2018). Coastal fisheries are also an important nutritional source (Trisos et al., 2022). In Cameroon, coastal fisheries account for over 25% of animal protein consumption (Ngoande and Yongbi, 2014; Nemba et al., 2022). Climate risks to coastal fisheries therefore affect livelihoods, incomes, and food security.

Countries in Central Africa are among the most vulnerable globally to future climate change, with Angola the most vulnerable due to its dependence on coastal fisheries in

a study of 132 countries (Allison et al., 2009). Fisheries include small-scale artisanal fishing (Mbock et al., 2020; Nemba et al., 2022) and larger-scale industrial fishing (e.g., shrimp and tuna), mainly for export to Europe and Asia (Ndjambou and Ndong, 2020; Nemba et al., 2022). Coastal fisheries in Central Africa include a sandy coast system comprising Equatorial Guinea and parts of Gabon, Republic of Congo, and Angola coasts, and an estuarine/deltaic and mangrove system across coastal Cameroon, Gabon, DRC, and northern Angola. These provide important habitat and nutrition to fish, mollusc, and crustacean species (Hamerlynck et al., 2020). Rising sea levels, coastal flooding, and erosion, could all have significant impacts on estuarine/deltaic and mangrove systems.

Increases in sea surface temperatures and in the frequency and intensity of marine heat waves will have negative impacts on Central African coastal marine ecosystems and fisheries (IPCC AR6, 2021). These changes can negatively affect the physiology, behaviour, population dynamics, and distribution of marine fish and crustacean species (Potts et al., 2014; Belhabib et al., 2016b). Ocean warming and changing oxygen levels off the coast of Angola have already contributed to shifts in fish species distribution (Potts et al., 2014). Rising temperatures are projected to contribute to declining marine fish production in Central Africa, particularly off the Angolan coast (Lam et al., 2012; Barange et al., 2014). Shifts in species distribution across economic zones could also contribute to tensions in fisheries management between Central African countries (Potts et al., 2014).

Sea level rise, coastal flooding, and coastal erosion pose risks to fishery infrastructure, including ports and harbours (see Section 3.4.5), **launching and landing sites, and processing facilities, including through physical damage or destruction, and barriers to access.** Increases in temperature and increased rainfall variability may also affect fish processing techniques such as sun drying (Nemba et al., 2022), and rising temperatures may increase needs for refrigeration and cold storage.

Climate-induced pressures to marine ecosystems will exacerbate disruption caused by anthropogenic pressures such as the overexploitation of fish stocks. Intense pressure on fish stocks from unregulated fishing and overexploitation is already a significant problem for coastal Central Africa (Ngoande and Yongbi, 2014; Ngoran et al., 2016; Mbock et al., 2020; UNESCO/IOC, 2020), with effects on reduced biodiversity. The intensification and expansion of industrial commercial fishing – dominated by international ships – has negatively affected local fishing livelihoods in the region (Mikolo, 2014; Ngoande and Yongbi, 2014; Ndjambou and Ndong, 2020; Ndjambou et al., 2020; Nemba et al., 2022). Industrial fishing has contributed to reduced fish catches for artisanal fishers (Mbock et al., 2020; Ndjambou and Ndong, 2020).

3.6.3 Coastal environments

Storm surges, coastal flooding, coastal erosion, shoreline retreat and saline intrusion into coastal aquifers are all exacerbated by climate change. These changes can in turn present risks to ecosystems as well as to human populations and their livelihoods. Risks may vary across types of coastal environments: sandy beaches, wetlands, mangrove systems, and forests.

Sea level rise, storm surges, and coastal flooding contribute to the loss of sandy beaches, damaging or destroying habitats for coastal bird, turtle, and other species.

Sandy beaches are important nesting ecosystems in Central Africa, especially for sea turtles (Diop et al., 2014). Risks may be particularly acute for countries with low-lying beaches (e.g., Gabon), and shoreline retreat is projected to be most significant along the Gabon and southern Republic of Congo coasts. Coastal erosion is already having damaging effects on biodiversity in the region, and these effects may intensify with rising sea levels (UNESCO/IOC, 2020). In Equatorial Guinea's Reserva Natural del Estuario del Muni, home to at least 20,000 migrating bird species, coastal erosion will have negative effects on bird biodiversity (UNESCO/IOC, 2020). On Bioko Island (Equatorial Guinea), coastal erosion has diminished areas of mangroves and tall vegetation reducing nesting habitats for green turtles, with the combination of coastal erosion and sea level rise projected to lead to a nesting habitat loss of 62% by 2046-2065 and 87% by 2081-2100 (UNESCO/IOC, 2020).

Central African coastal estuaries and deltas are at risk from sea level rise, threatening habitats for fish, bird, amphibian, mammal, plant, and other species. Risks associated with sea level rise include shoreline retreat, coastal erosion, increased wetland flooding, and saline intrusion (Diop et al., 2014). Gabon's Bas Ogooué Delta, for example, is the third largest freshwater delta in Africa (World Bank, 2021). Coastal flooding, erosion, subsidence, saline intrusion and increasing salinity, and sedimentation are already contributing to damage to regional estuaries and wetlands in Central Africa (Munji et al., 2013; UNESCO/IOC, 2020).

Climate-related risks to estuary environments are intensified by human activities, already disrupting coastal aquatic habitats. Dams and deforestation along many Central African rivers have affected hydrology and sediment flows, with downstream impacts on siltation and accelerated erosion (Diop et al., 2014; Goussard and Ducrocq, 2017). Agricultural runoff (e.g., fertilisers, pesticides) also contributes to increased eutrophication (loading of nutrients causing algal blooms and low-oxygen water) in the estuaries, deltas, and other coastal environments, affecting flora and fauna (Diop et al., 2014; Goussard and Ducrocq, 2017).

Central African mangrove systems provide a number of important services and are threatened by sea level rise and storm surges. Mangroves play an important role in protecting and stabilising coastal zones, act as carbon sinks and provide habitat and nutrition to numerous fish, mollusc, crustacean, turtle, and bird species (Ellison and Zouh, 2012; G. N. Ajonina et al., 2014a; Fendoung et al., 2017; Ajonina, 2022; Nemba et al., 2022). Many waterbird and other species in Central Africa are found only in estuarine and mangrove forests (Feka and Morrison, 2017). Deltas and estuaries in Cameroon and Gabon are home to the largest blocks of mangroves in West and Central Africa, and Cameroon is home to the largest mangrove cover (over 220,000-230,000 hectares) in Central Africa, and the sixth largest in Africa (G. N. Ajonina et al., 2014a; Fendoung et al., 2017; Ajonina, 2022). Mangrove systems provide a means of subsistence – via wood, fishery products, and more – to over 30% of Cameroon's population (Ajonina, 2022). Coastal erosion due to sea level rise and human activities is already contributing to a reduction in mangrove cover in Central Africa (Ellison and Zouh, 2012; Fendoung et al., 2017; UNESCO/IOC, 2020). Rising sea levels pose the biggest threat to mangrove systems (Munji et al., 2013, 2014; Ellison, 2015; Fendoung et al., 2017).

Damage to and loss of mangrove systems will impact coastal biodiversity, as well as increasing risks of coastal hazards and releasing stored carbon (Munji et al., 2013; 2014; Fendoung et al., 2017). However, coastal mangrove ecosystems in Central Africa have declined due to wood harvesting, agriculture expansion, and oil development (e.g. Ajonina et al., 2014a; Munji et al., 2014; Fendoung et al., 2017; Nemba et al., 2022). Mangrove exploitation increases during periods of flooding, as floodwaters grant access to forest areas inaccessible during non-flood periods (Munji et al., 2013, 2014). These risks may be intensified by expected increases in coastal flooding into the future. Mangrove conservation initiatives have been implemented in Central Africa, often using community-based management to support conservation and rehabilitation/restoration (Feka and Morrison, 2017; Zebedee and Isaac, 2017). Although these interventions *may* be slowing mangrove loss, their focus is often on tree-planting only (as opposed to broader restoration strategies) and there is little evidence on their long-term effectiveness (Feka and Morrison, 2017; Zebedee and Isaac, 2017).

Climate change also poses risks to Central African coastal urban and agricultural livelihoods. In Cameroon, banana and palm plantations have expanded in coastal regions (Fonteh et al., 2009; P. U. Ajonina et al., 2014b) and may be affected by increases in temperature and precipitation (see Section 3.2). Alongside flooding of coastal croplands and damage to crops, rising sea levels, coastal flooding and groundwater pumping also increase the risk of saline intrusion into freshwater aquifers and soils, reducing agricultural productivity (Molua, 2009a; Munji et al., 2013; Evariste et al., 2018). Mangrove loss in coastal areas renders coastal agriculture more susceptible coastal flooding. Agricultural developments have in turn contributed to coastal vulnerabilities through widespread destruction of coastal estuarine forests, soil and water pollution, and reductions on plant and animal biodiversity (P. U. Ajonina et al., 2014b).

Coastal conservation and protection efforts in Central Africa are hampered by weak institutions and continued urban expansion. Protected areas have been established in coastal mangroves, wetlands, and forests, such as Campo Ma'an National Park and Douala-Edéa National Park in Cameroon and Pongara National Park and Loango National Park in Gabon. Coastal environments named as Ramsar sites (wetlands of international importance) include mangroves, marshes, swampy forests, and coastal plains and lakes in Cameroon (e.g., Estuaire du Rio Del Rey), Equatorial Guinea (e.g., Reserva Natural del Estuario del Muni), Republic of Congo (e.g., Bas-Kouilou-Yombo, Conkouati-Dou), DRC (e.g., Parc National des Mangroves), and Gabon (e.g., Bas Ogooue, Petit Loango, Wonga-Wongué) (Ramsar Convention, 2022). However, conservation efforts are hindered by gaps in broader coastal ecosystem management (linked to bureaucratic and governance tensions) and pressures from urban expansion (Ngoran et al., 2016; Goussard and Ducrocq, 2017; Zebedee and Isaac, 2017).

3.6.4 Ocean ecology and biodiversity

Increases in sea surface temperatures and marine heat waves, reduced oxygen content, and increasing ocean acidification will have negative impacts on marine biodiversity, affecting the physiology, behaviour, population dynamics, and distribution of individual species, including marine fish and crustaceans. For example, higher surface temperatures disrupt ocean circulation and hence ocean currents, which in turn will disrupt and reduce marine life, with direct impacts on pelagic fish species (see Section 3.1.4).

Climatic changes will interact with a range of human activities to affect Central African coastal environments and ocean ecology and biodiversity, intensifying vulnerability to changes associated with sea level rise and warming ocean temperatures. Marine and coastal environments (including species habitats) and livelihoods (including coastal fisheries) in Central Africa are already being negatively affected by rapid urban expansion and pollution, infrastructure development, agro-industrial development (e.g., palm plantations) and agricultural runoff, construction of ports and hydroelectric dams, and environmental damage and pollution from mining and oil development (Aysissi et al., 2014; Diop et al., 2014; Fendoung et al., 2017; UNESCO/IOC, 2020; Ajonina, 2022; Nemba et al., 2022). Fisheries, especially industrial fisheries, also present risks to marine animals when they become caught in fishing gear (Aysissi et al., 2014; Honarvar et al., 2016).

Offshore oil exploration in the Gulf of Guinea – mainly off Angola and Cameroon, as well as Equatorial Guinea, Gabon, and the Republic of Congo – has led to pollution of marine and coastal environments in Central Africa (Bassou, 2016). Angola is the second largest oil producer in Africa, second only to Nigeria (Bassou, 2016). Offshore oil platforms and refineries and other production facilities along the coast and transport vessels present risks to marine health from oil spills, ship discharge, and more (UNESCO/IOC, 2020). Areas around oil production, refining, and transport facilities in Cameroon and Angola are some of the most polluted areas of the Central African coast (UNESCO/IOC, 2020). Expected future sea level rise will damage oil, mining, ports, and other industrial infrastructure and operations via storm surges, flooding, and coastal erosion resulting in harmful environmental impacts such as oil or chemical leakage or spills.

Met Office Hadley Centre ODI UKaid

Image location: Luanda, Angola

Image location: Loango National Park, Gabon

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