FROM RISK TO RESILIENCE

A strategic assessment of challenges and solutions to scaling climate mitigation and adaptation in the Democratic Republic of Congo

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Woodwell Climate Research Center

MINISTÈRE DE L'ENVIRONNEMENT ET DÉVELOPPEMENT DURABLE

Who we are

[a] **Woodwell Climate Research Center**
Woodwell Climate Research Center conducts scientific research to find solutions at the intersection of climate, people and nature. We work in partnership with leaders and communities to make a fair and meaningful impact on the climate crisis. Our scientists helped launch the United Nations Framework Convention on Climate Change in 1992 and, in 2007, Woodwell Climate scientists shared the Nobel Prize awarded to the Intergovernmental Panel on Climate Change. For over 35 years, Woodwell Climate has combined practical experience and political impact to identify and support society-wide solutions that can be implemented immediately. This includes working with communities on the front line of the climate crisis.

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[c] **Ministry of the Environment and Sustainable Development (MEDD) of the Democratic Republic of Congo**

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Table of contents

Table of figures

1.0 Introduction

The impacts of climate change on the frequency and severity of physical hazards are putting many communities at risk. As the threat of climate change grows, so too does the need for accessible information, tools, and expertise to support climate-resilient decision making across multiple scales, from communities to countries. Woodwell Climate Research Center believes there is a need to localize and customize climate risk assessments. This information is critical for government leaders as they make planning decisions, but it is not available to all that need it. Woodwell Climate believes that this science should be freely and widely available. To address this gap, Woodwell Climate works with communities and countries across the world, including the Democratic Republic of the Congo, to provide climate risk assessments, free of charge.

1.1 Policy context

The Democratic Republic of Congo (DRC), straddles the equator, covering 2,345,409 km^2 (905,567 square miles) and covers most of the Congo Basin. The population is estimated to be more than 90 million inhabitants, with an annual population growth rate of 3.1%. The DRC has said that it is committed to the United Nations' 2030 Agenda for Sustainable Development and has adopted its National Strategic Development Plan for the period 2019-2023 (NSDP), which is aligned with the Sustainable Development Goals (SDGs).

The NSDP outlines key phases of development to 2050 and is structured around five main pillars:

Pillar 1 | Development of human capital, social and cultural development;

Pillar 2 | Strengthening governance, restoring state authority and consolidating peace;

Pillar 3 | Consolidation of economic growth, diversification and transformation of the economy;

Pillar 4 | Land use planning, reconstruction and modernization of infrastructure; and

Pillar 5 | Environmental protection, the fight against climate change and sustainable and balanced development.

The environmental protection and climate change pillar (Pillar 5) is cross-cutting and aims to integrate environmental issues and climate change concerns across government in order to achieve resilient and low-carbon development. Tropical forest conservation, in particular, is key to national efforts to reduce emissions. To achieve these goals, the Ministry of Environment and Sustainable Development (MEDD) coordinated the development of the Climate Change Policy, Strategy and Action Plan.

The National Adaptation Plan (NAP), for the period 2022–2026, was developed to strengthen the country's resilience and to integrate climate change adaptation into planning and budgeting at both the national and provincial levels.

1.2 Policy alignment

In 2022, Woodwell Climate began consultations with officials in the Ministry of Environment and Sustainable Development (MEDD) and the University of Kinshasa to identify climate resiliency priorities. Climate change threats to forests and forest carbon were identified as critical because of DRC's plans to engage in global carbon markets and because of the key role that forests play in the country's nationally determined contribution.

Those discussions identified how a climate risk assessment could be made relevant to the DRC's policy priorities of forest conservation and sustainable development. The DRC National Adaptation Plan 2022–2026 (2021; Section 3.4) identifies the connection between climate risk and other environmental goals. Nature-based Climate Solutions (NbCS) encompass a range of landscape protection, improved management, and restoration activities that are essential to deliver on global emissions reduction targets. Many nature-based opportunities exist across the DRC, spanning the economically and socially diverse provinces. The ways in which climate risk intersects spatially with this potential is a key focus of this risk assessment.

In early 2023, MEDD and Woodwell Climate undertook a climate risk assessment exercise, with a primary focus on climate change threats to forest carbon and agriculture. The assessment examined a range of climate change hazards, and identified critical gaps in national capacity for data acquisition, application and sharing. The intention is for this assessment to support adaptation planning efforts, and to enhance integrity in the supply of internationally traded carbon credits. Scaling finance mechanisms aimed at investment in NbCS will help drive critical funding to support a new climate economy.

2.0 Results summary

The NAP (2021) considers large-scale climate impacts on the DRC, but granular climate risk assessments are needed to inform localized adaptation planning. To this end, the NAP calls for the implementation of more risk assessments—including more detailed assessments and those carried out by external partner organizations—and states this need as a fundamental priority (2021, Sections 4.3, 4.4). The high-resolution (downscaled to at least 0.25°) and bias-adjusted (using historical reference data) climate risk analysis presented here can contribute to this national priority. Our analysis is primarily based on the latest projections from the Coupled Model Intercomparison Project (CMIP6)—a vast improvement from the analysis based on CMIP3-era data presented in the NAP (2021). The primary climate risks identified in the NAP (2021) include abundant rainfall, rising temperatures, and drought, which we have included in our report. Additionally, our analysis includes downstream impacts, such as heat impacts on mortality and labor productivity, and the impact of changing temperature and precipitation seasonality on principal subsistence (cassava) and exported (coffee) crops.

Here we present our findings on drought, heat stress, agricultural yields, extreme precipitation, flooding, and wildfire to help the Democratic Republic of the Congo in its plans to create a more resilient future for all residents. These risks were selected through participatory working group discussions to define priorities and issues during the first workshop (December 2022). They reflect case studies around how critical future climate factors will interact with selected key natural resources and economic infrastructure in order to guide discussion around strategic pathways to mitigate and adapt to climate change and develop a resilient economy. The analysis provided inputs into the second workshop (May 2023) where additional key issues and refinements to the models were identified. In the final workshop (October 2023), the updated analysis was reviewed and breakout groups discussed their implications for policy and practice.

As a result of climate change, drought is expected to increase across most of the country, with some areas set to experience severe drought conditions on a near year-round basis between now and mid-century. Heavy rainfall is also projected to intensify with the historical 100-year rainfall event becoming a 1-in-30 year event for the DRC by mid-century and a 1-in-15 year event by late-century. By simulating present and future rainfall and riverine flooding, we see that 300 km^2 of Kinshasa is inundated during the present-day 100-year flood, 365 km^2 is inundated by mid-century, and 403 km^2 by the late-century. Wildfire danger days will also increase for much of the DRC. The southeastern region of the country could see an almost 200% increase in days with high wildfire potential, while a few areas—mainly in the north—will see a slight decrease in wildfire danger. Models of the impact of climate change on cassava and coffee productivity suggest that suitable conditions for the cultivation of these crops will decline in general, although with regional differences in magnitude.

2.1 Drought

Most of the DRC can expect to experience severe drought stress more frequently in the future. Drought stress is based on the Palmer Drought Severity Index (PDSI), an established drought metric used for impact assessments globally[1]. Throughout 1970–2000,

[1] PDSI describes environmental water balance using monthly precipitation and evapotranspiration (NCAR 2023, Wells et al. 2004). It is a normalized index ranging from -10 (dry) to +10 (wet), with severe (or worse) drought characterized by PDSI values ≤ -4. The self-calibrated PDSI (sc-PDSI) was used in the DRC assessment, which accounts for spatial precipitation variation by calibrating to local, historical climate conditions to enable comparable results over climatically diverse regions. The sc-PDSI was computed using REMO2015, a CMIP5-era monthly, high-resolution (0.2° or ~22 km) regional climate model, RCP8.5 emissions scenario with high levels of fossil fuel use, and a calibration time period of 1971–2000.

the DRC experienced between < 1 month to almost five months' worth of severe, or worse, drought each year on average, depending on location (Figure 1, left). Over the next two decades (2021-2040), some locations within Tanganyika can expect to experience an additional annual average of up to 11 months of severe drought, resulting in severe drought conditions almost year-round (Figure 1, center). A few parts of the country, including within the provinces of Maï-Ndombe and Sud-Kivu, could see a slight decrease in time spent in severe drought, with up to two less months per year on average compared to 1970-2000 (depicted in green in figure). By mid-century (2041-2060), severe drought stress will continue to expand across much of the country, although there are still a few isolated regions—e.g. the western portions of Nord-Kivu and Sud-Kivu and the border between Haut-Uele and Ituri—that could expect a small decrease of up to two months' worth of severe drought stress per year on average (Figure 1, right).

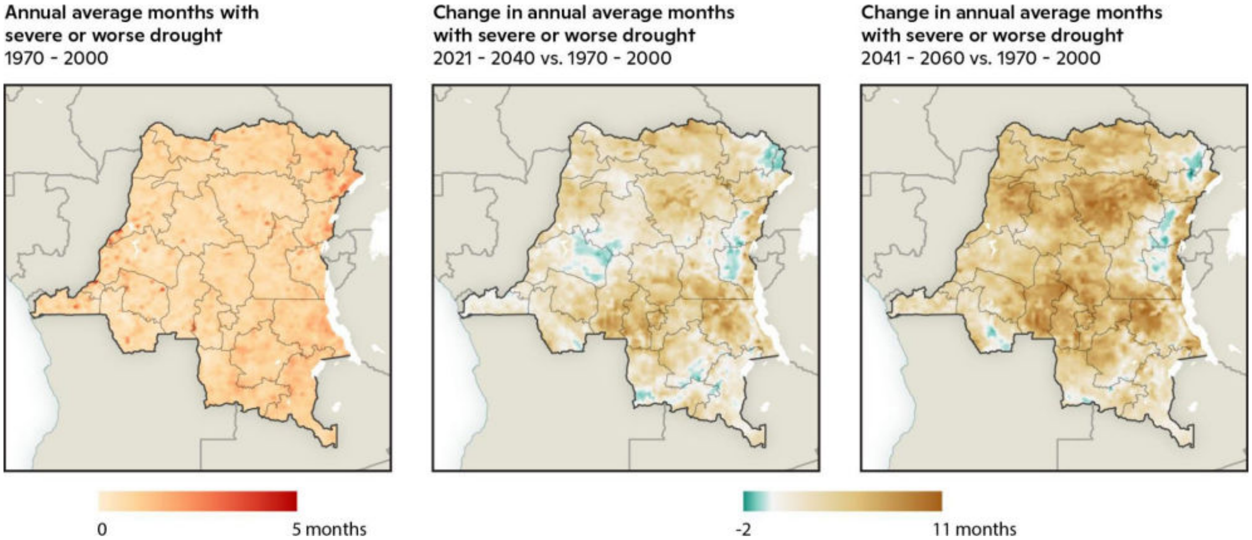

Figure 1: Change in Drought, DRC. Annual average months with severe, or worse, drought in 1970–2000 (left), and change in months in 2021–2040 (center) and 2041–2060 (right) compared to 1970–2000. Regions expected to experience additional months of drought stress are depicted in shades of brown, and regions expected to experience a decrease in months of drought stress are depicted in shades of green.

2.2 Lethal humid heat stress

The combination of high temperature and humidity can hinder the body's ability to regulate its own temperature. Exposure to these conditions for extended periods of time can place significant stress on the cardiovascular system. When both temperature and humidity are high enough for long enough periods of time (6 hours or more), this stress on the human body can lead to extreme health impacts and mortality. Following research by Powis et al. (2023) and Vecellio et al. (2022), we quantify heat stress risk using a metric that identifies days where this dangerous threshold is exceeded for more than 6 hours (a "lethal heat day"). Using bias-adjusted and downscaled CMIP6 model projections of temperature and dewpoint temperature, we have calculated the number of lethal heat days per year for the time periods 2041-2060 (mid-century) and 2081-2100 under IPCC climate scenario SSP585, a fossil fuel-intensive scenario.

The analysis shows no lethal heat days until the end of the century, when they occur annually and for multiple days per year across many areas of the country. Figure 2 shows the projected number of lethal heat days per year by 2081-2100 under IPCC scenario SSP585. Most lethal heat days are expected to occur in the Northwest and central-west provinces, some of which see more than 10 lethal heat days per year. The number of lethal heat days also increases closer to the coast, likely due to increased humidity in this area.

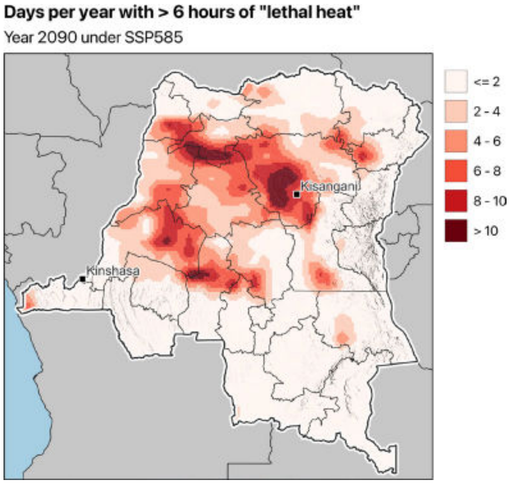

Figure 2. Projected numbers of lethal heat days per year by 2081–2100.

2.3 Lost labor productivity due to heat stress

The health effects of humid heat can also impact the productivity of exposed workers. Heat stress and exhaustion can reduce the activity levels of workers by increasing the frequency of breaks and the need for hydration. We have developed a dataset which estimates the lost percentage of working hours per worker due to heat and humidity, based on research by (Parsons et al. 2021). This analysis uses a statistical model based on empirical data which is a function of simplified Wet Bulb Globe Temperature (sWBGT)[2]. This can be easily calculated from temperature and humidity. Lost productivity is estimated for heavy laborers, i.e. those working in agricultural, mining, manufacturing or construction sectors.

Figure 3 shows this data for workers in heavy labor sectors during a standard workday (7am-7pm) for two warming levels: 1°C and 1.5°C (~2030). The northwest of the country sees the largest productivity losses, reaching in excess of 7.5% in some areas under 1.5°C of warming. This is significantly higher than in eastern and southeastern regions. Lost productivity increases around the whole country as we approach 1.5°C of warming. When accounting for population distributions[3], the country-wide average lost percentage of productivity is 2.2% and 3% under 1°C and 1.5°C of warming respectively. Providing workers with adequate hydration and shade are two measures which can reduce these impacts, however their impacts will be limited in the future. Another adaptation measure is to modify working hours to be earlier in the day or even overnight. This analysis suggests that beginning the workday 3 hours earlier could reduce country-wide lost productivity to 1.8% under 1.5°C of warming whilst working overnight could reduce this further to 1.1%.

[2] For more detail on the methodology used to generate productivity loss, see https://doi.org/10.5281/zenodo.8339161.

[3] Using the GPWv4 population count dataset, assuming that heavy labor is distributed equally to the population of the DRC.

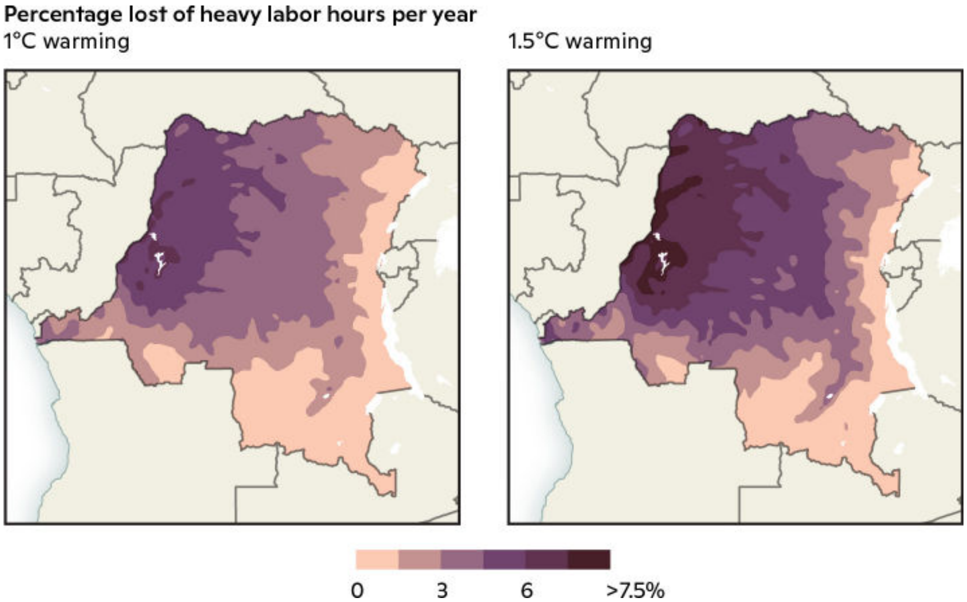

Figure 3. The lost percentage of heavy labor working hours per year due to heat and humidity under two different warming levels: 1°C (today) and 1.5°C (~2030).

2.4 Agricultural risks

While climate change is expected to significantly affect crop productivity across the world, these impacts will be highly dependent on the regional manifestation of new climatic conditions as well as the tolerance of individual crop types. To better understand these context-dependent impacts in the DRC, we developed a machine-learning model that predicts how suitable current and future climatic conditions are for the cultivation of three crops of national importance: cassava, robusta coffee, and arabica coffee. This model allowed us to assess how climate change could alter the geography of conditions for these crops to attain high yields.

2.4.1 Model development

Historical crop yield data were obtained from SPAM2010 for both robusta and arabica coffee and GAEZ+2015 for cassava. Grid cells with high crop yield values—defined as above the regional 90^{th} percentile—were selected to train a Species Distribution Model (SDM) based on a Maximum Entropy (MaxEnt) engine using the maxnet R package. As predictors, we used: (1) WorldClim's bioclimatic variables from historical conditions; (2) SoilGrids soil properties layers; and (3) terrain characteristics derived from a digital elevation model, specifically elevation, slope, and curvature. The SDM model produces maps that show the probability of a crop attaining high yields (90^{th} percentile) in the region, which we consider a measure of suitability for crop cultivation. Resulting maps are at a spatial resolution of 5 minutes (~11 km).

The training process for the SDM to predict suitability involved substantial tuning, including the optimal number of predictors to use in the final model via a stepwise feature selection process. The final version of the model was spatially cross-validated using Response Operating Characteristic (ROC) to assess its predictive skill. We obtained ROC values of 0.77 for cassava, 0.84 for arabica coffee, and 0.85 for robusta coffee, signaling high to moderately high predictive skills. Once validated, we used the model to project climatic suitabilities into the future using WorldClim's bioclimatic variables of temperature and precipitation based on CMIP6 simulations under the SSP585 scenario, a fossil fuel-intensive scenario.

2.4.2 Results—agricultural risks

Under historical conditions (1970-2000), the climatic suitability for cassava cultivation is highest in the southern and northeastern regions of the DRC and lower in the central valley (Figure 4). In near-future conditions (2021-2040), there is a minimal change in suitability for cassava cultivation, with probabilities of attaining high yields changing only between +0.1 and -0.1. By 2061-2080, the climatic suitability for cassava improves in the central valley and declines in the north and many parts of the south.

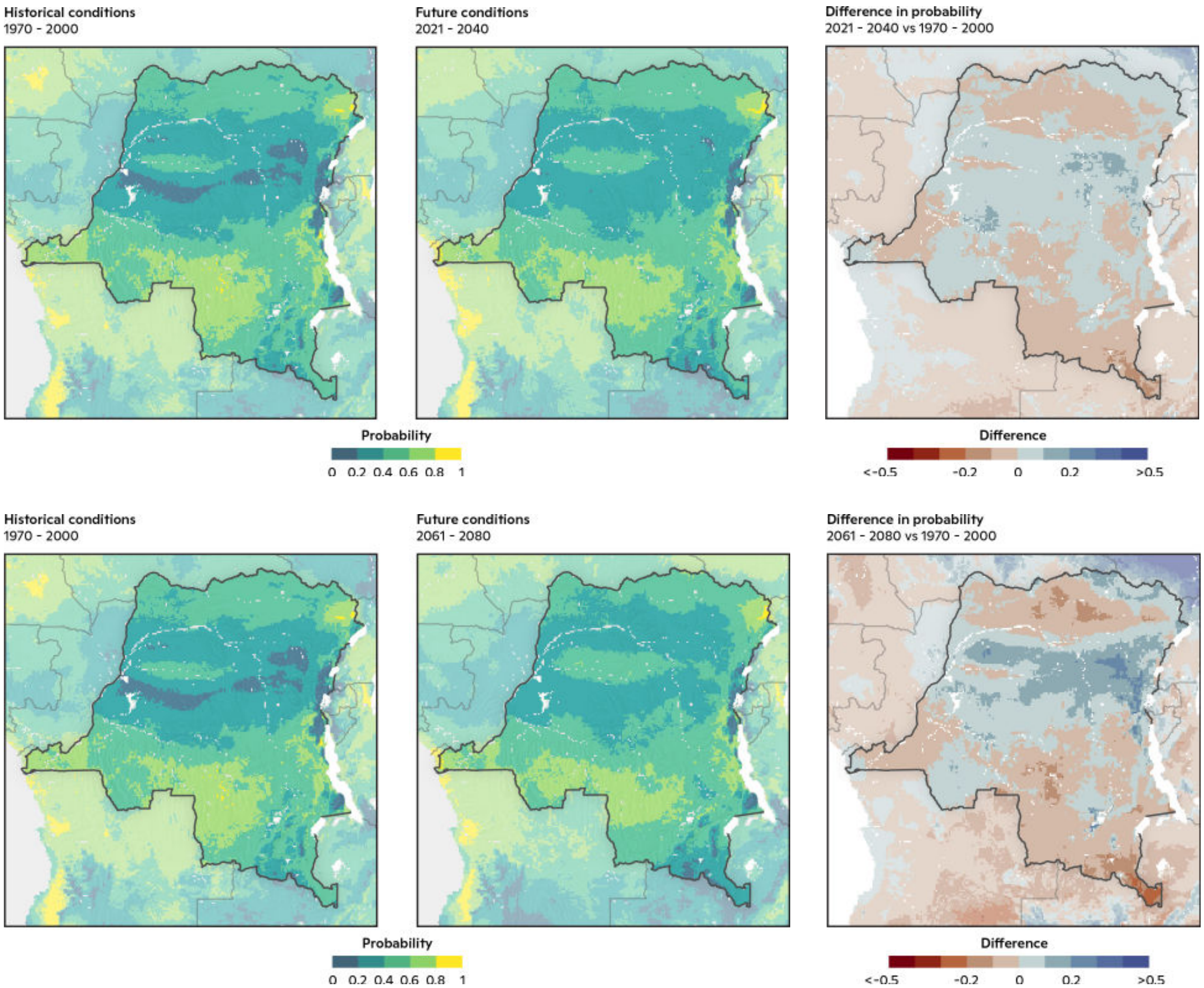

Figure 4. Historic and projected climatic suitability for cassava cultivation for two periods between 2021 and 2080.

Much of the DRC has poor climatic suitability, or low yield potential, for arabica coffee cultivation except for the eastern border of the country (Figure 5). High and moderate climatic suitability is found in this eastern region, the primary production zones of arabica coffee. However, this region is projected to experience significant changes, with its suitability expected to degrade over time. The probability of attaining high yields will decrease up to -0.2 in near-future conditions (2021-2040) and by -0.4 by 2061-2080. For the rest of the country, suitability for arabica coffee cultivation is projected to remain relatively low in the future.

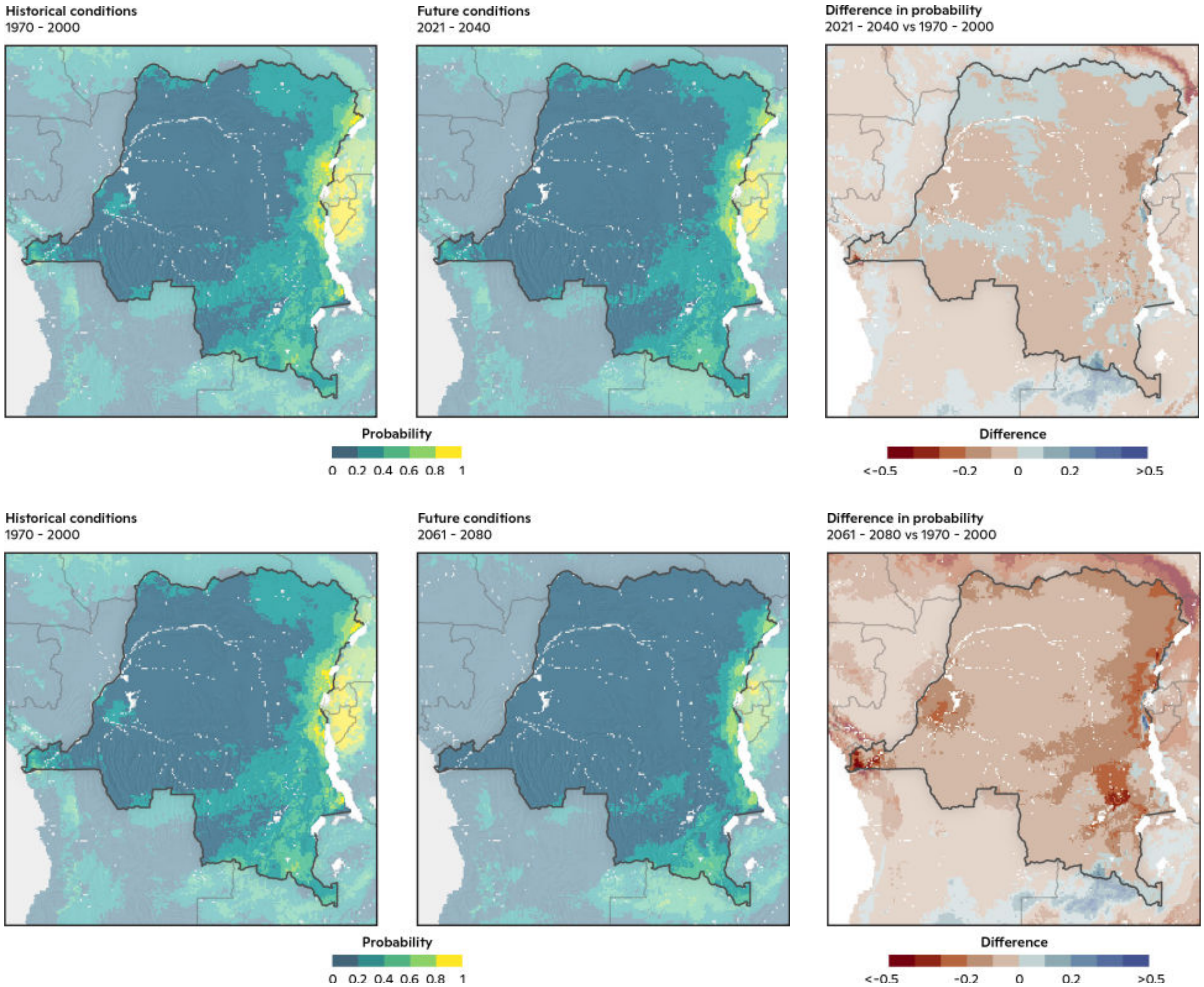

Figure 5. Historical and projected climatic suitability for arabica coffee cultivation for two periods between 2021 and 2080.

For historical (1970–2000) robusta coffee cultivation, high and moderate climatic suitability is found in the northern regions and most of the southern regions of the country, while low suitability is found in the central valley (Figure 6). In near-future conditions (2021–2040), there are minimal changes in suitability throughout the country, except for a decrease in a small area in the southeast. By 2061–2080, some areas in the east are projected to slightly increase in suitability; and thus potential yield. However, much of the north and several areas of the south of the country are expected to experience a significant decline in yield potential.

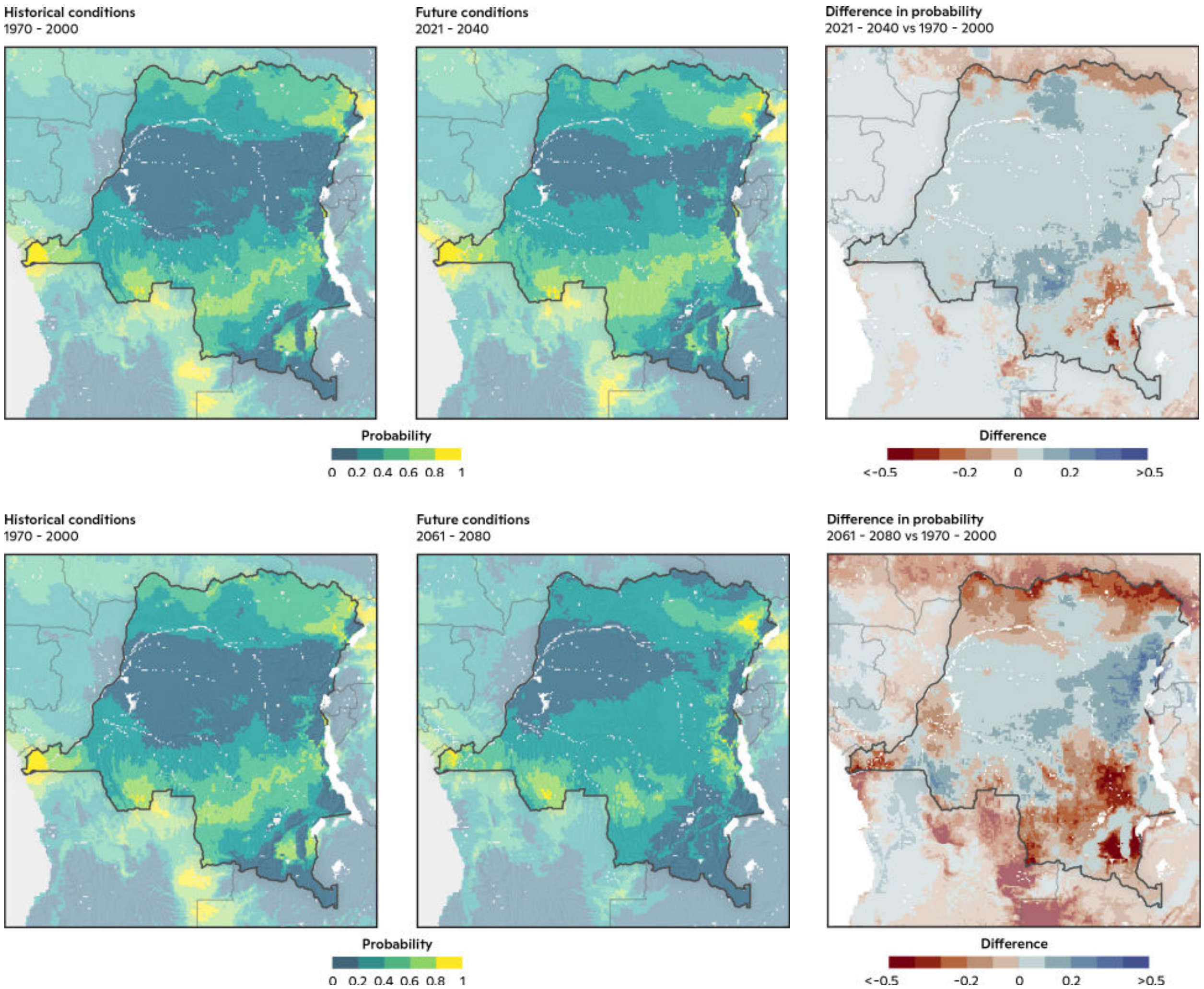

Figure 6. Historical and projected climatic suitability for robusta coffee cultivation for two periods between 2021 and 2080.

2.5 Extreme precipitation

Heavy rainfall can cause landslides and flooding leading to loss of life and property. In May 2023, torrential rains in the eastern DRC resulted in 460 deaths and over 2500 people missing in the South Kivu Province (OCHA, 2023). Across the Lake Kivu region, accumulated 5-day rainfall totals were estimated at 90 mm, with some regional stations breaking daily records with well over 100 mm on May 2 (Kimutai et al. 2023). This extreme precipitation event occurred just months after heavy rains caused landslides, destroyed roads and buildings, and took over 150 lives in December 2022 in the capital city of Kinshasa. Nearby gauges recorded 84 mm; for reference, the historical 100-year rainfall event in Kinshasa is 249 mm. In the future, these events—and those that are more extreme—will become increasingly common.

In the future, these events—and those that are more extreme—will become increasingly common. To estimate future extreme rainfall risk, we calculate the change in frequency of the historical (2000-2020) 1-in-100 year daily precipitation event for 2040-2060 and 2070-2090 under SSP585, a fossil fuel-intensive scenario, using output from a downscaled CMIP6 model ensemble. CMIP6 climate model data that has been bias-adjusted using historical observation data (ERA5) and Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) methodology (Lange 2019, Lange 2021) and then the median across models was taken. The results from this analysis are shown in Figure 7. This extreme precipitation metric is used to estimate future changes in flood risk as extreme precipitation is highly correlated with inland flood risk.

All of the DRC will see an increase in the frequency of the future 100-year rainfall event. By 2040-2060 most of the eastern portion of the county will experience a 3x increase in the occurrence of the 100-year event. By 2070-2090, the 100-year event becomes a 25-year event for almost all of the DRC with portions of the country near Kisangani experiencing a 15-year event. Rainfall records are too sparse to determine how rainfall amounts will shift country-wide, but for Kinshasa we estimated that the historical 100-year 1-day rainfall event is 249 mm. By 2040-2060 this will increase to 433 mm and by 2070-2090 will further rise to 596 mm. For comparison, the mean annual rainfall in Kinshasa is 1385 mm.

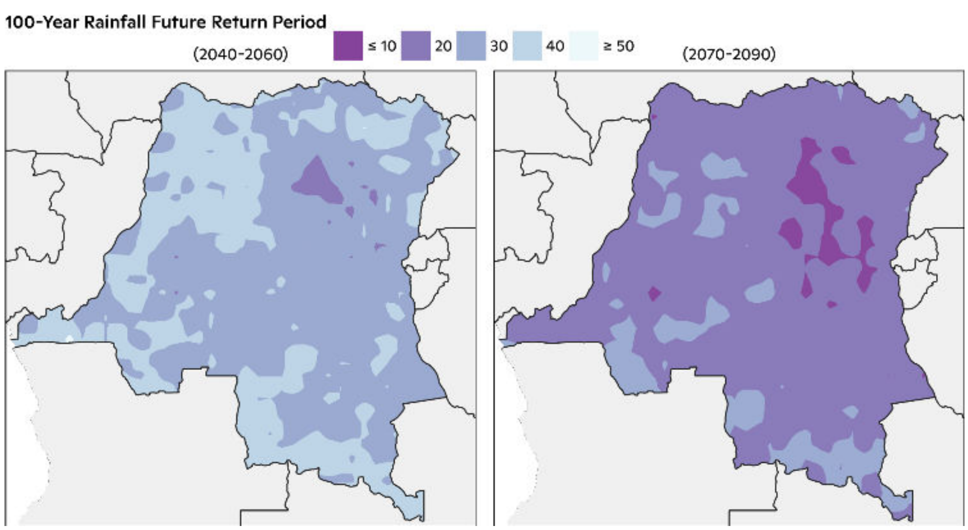

Figure 7. Future return period of the historical (2000–2020) 100-year daily rainfall event for 2040–2060 and 2070–2090 under the SSP585 scenario.

2.6 Flooding

Given its historical flooding record, and as the capital and largest city in the DRC, present and future flood risk was modeled for Kinshasa. With a population of over 17 million and increasing at a rate of almost 4.5% annually, it is the most populous city in Africa. Urban growth in flood-prone areas has exacerbated flood risk as flood management is mostly reactive rather than focused on risk reduction (He et al. 2021). High resolution, Kinshasa-wide flood studies are largely absent from the literature. Bola et al. (2022) created a Congo basin level flood model but the resolution is limited to 90 meters. He et al. (2021) used flood maps from the Fathom global flood model to assess risk to Kinshasa's transportation system. Mpanano (2019) analyzed food risk for the N'djili river basin in eastern Kinshasa.

Here we estimate current and future (2040-2060, 2070-2090) fluvial (riverine) and pluvial (rainfall) flood risk for Kinshasa under climate change. Flood risk was simulated using the LISFLOOD-FP v8.1 flood model[4] (LISFLOOD-FP developers, 2022; Sharifian et al. 2023). LISFLOOD-FP is a two-dimensional raster hydrodynamic model that solves an approximation of the shallow water equations. LISFLOOD-FP has been extensively used from the river reach scale to continental simulations and we refer the reader to Sharifian et al. (2023) for a detailed explanation of LISFLOOD-FP.

Figure 8 shows the present and future flood risk for Kinshasa. From the flood model simulations we see that the majority of flood risk is concentrated in the lowlands adjacent to the Congo River in the northern part of the city. During heavy rainfall, streams form in the urban landscape as water follows the historical flow paths towards the Congo River. This area includes the communes of Gombe, Kinshasa, Lingwala, and Barumbu which contain the older portions of the city. Under climate change, the floodplains expand considerably in this part of the city while the N'djili river floodplain in the eastern part of the city remains relatively stable through the end of the century. While most of the flood extent is located in the northern corner of the city, the red clay hills in the southern portion of Kinshasa are at risk of landslides during heavy rainfall. The flood simulations presented here do not incorporate landslide risk which should be studied further.

[4] Several datasets were used as inputs into the flood model and these include: 1) the FABDEM Digital Elevation Model Hawker et al. (2022); 2) Land cover friction values using land cover values from the S2 prototype LC 20m map of Africa 2016 and friction values from Papaioannou et al. (2018); 3) Infiltration rates estimated using hydrologic soil groups from the HYSOGs250m dataset and infiltration rates from Musgrave (1955) and presented by Innovyze for clarity; 4) The historical 100-year 1-day rainfall amount was estimated by fitting observational data from the Binza rainfall gauge, provided by Mettelsat, the DRC National Agency for Meteorology and Satellite Remote Sensing, to a generalized extreme value distribution. The future 100-year 1-day rainfall amount was estimated by calculating how the probability distribution of the 100-year event will change using the CMIP6 data presented in the Extreme Precipitation section above and then calculating where the future event fell in the historical distribution. The hyetograph (a distribution of rainfall intensity over time) for the simulation was set to a Frequency Design Storm also known as a nested hyetograph; 5) The historical 100-year 1-day streamflow value for the Congo river was estimated by fitting observational data from the Kinshasa station of the Global Runoff Data Centre. The historical 100-year 1-day streamflow value for the N'djili river was taken from Marhegeko (2013). Future streamflow values for the Congo river were calculated using the same procedure as the future rainfall but using the Future Streams dataset. Future Streams only provides weekly discharge values but through a comparison of historical data, it was found that weekly averages track daily values extremely well for the Congo river at Kinshasa. The spatial resolution of Future Streams is too coarse to simulate the N'djili river so we assume that future streamflow changes for the Congo river also apply to the N'djili river. Finally, streamflow for the Congo river was calibrated due to a lack of bathymetry data and the fact that the upstream model boundary was located further up the river than the GRDC Kinshasa Congo stream gauge. We used the Global River Radar Altimetry Time Series (GRRATS) dataset to calibrate the upstream streamflow.

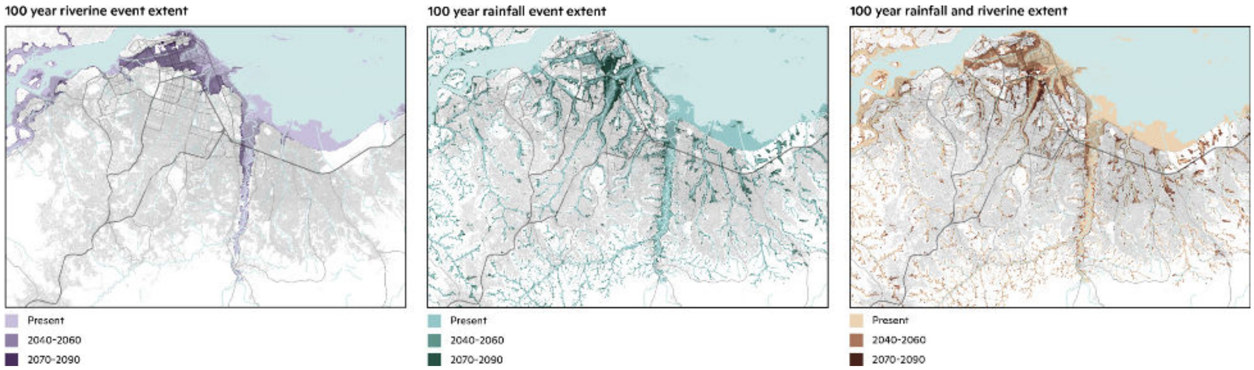

Figure 8. Present and future rainfall and riverine flood risk for Kinshasa. The right panel shows the union of the rainfall and riverine events.

Riverine flood risk also concentrated on the flat alluvial deposits near the Congo river. Presently, the river manages to encroach only to the Gombe and Barumbu communes on the eastern side of the city. By mid and late century, floodwaters from the Congo manage to sever the Gombe commune in two, isolating the northern tip of Kinshasa from the rest of the city. Combining the rainfall and riverine extents, we see that 300 km^2 of the city is inundated during the present-day 100-year flood, 365 km^2 is inundated by mid-century, and 403 km^2 by the late century.

It is important to note several caveats of this flood analysis. First is that the infiltration rates used assume the soil is saturated which may not be the case in a real-life event. Also, there was no ground truth flood extent data to validate the flood model so news reports of communes impacted by previous floods were used as a rough validation. Finally, bathymetric data for the Congo river would improve the accuracy of the model since the baseflow had to be calibrated.

2.7 Wildfire

Home to the world's second largest rainforest, the Congo Basin is referred to as the earth's "second lung," following the Amazon. Although logging and other anthropogenic activities pose the greatest threats to the Congo Rainforest, each year wildfires claim a fraction of the total forest loss, approaching a total of 400,000 ha since 2001. The provinces with the most tree cover loss from forest fires include Mongala, Maï-Ndombe, Tshopo, and Sud-Ubangi, although most observed fires in the DRC result from savannah-clearing and agriculture.

In the future, the most notable changes in levels of wildfire risk are in the equatorial rainforest region already prone to tree loss. We calculate wildfire risk based on the Fire Weather Index (FWI) System[5] across the DRC and subsequently derive fire danger levels using a validation exercise based on burned area and historical FWI with the Caliver package[6]. In the equatorial rainforest region, wildfire danger will increase from *low* to *moderate*. In the southern savannas where danger is already *very high*, it will increase to the highest level of *extreme* risk (Figure 9).

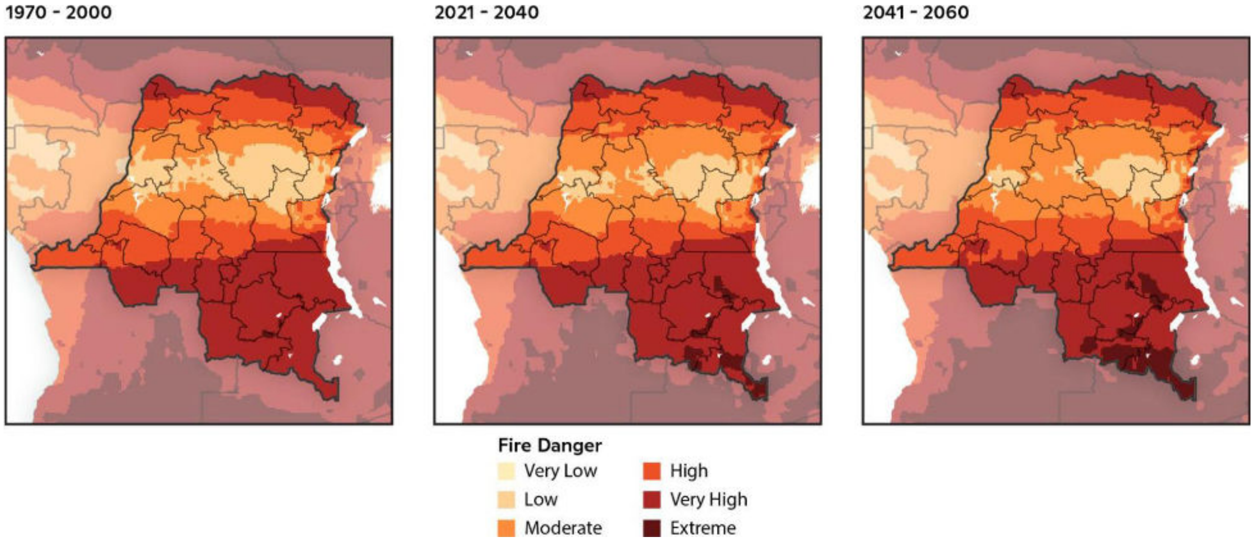

Figure 9. Wildfire Danger for 1970–2000, 2021–2040, and 2041–2060.

To further assess changes in wildfire risk, we also calculate the change in wildfire danger days. Each day above an historical extreme FWI value—the 95th percentile or 1-in-20-day FWI value from the 1970-2000 reference period in each grid cell—counts as a wildfire danger day. The future change in the amount of these days quantifies how the length of the effective fire season changes and how wildfire risk increases over time with continued climate warming. Over the next two decades (2021-2040), the southeastern region of the DRC can expect up to 22 additional wildfire danger days per year on average, signifying a yearly increase of up to 122% over the historical average of 18 days per year (Figure 10, left). Some northern and western regions of the country are expected to see a slight decrease in days with potential wildfire danger, with up to five less per year on average.

[5] FWI is a globally used, unitless quantification of ecosystem vulnerability to wildfire and wildfire potential, addressing fuel availability, drought, and fire behavior using seven indices: Buildup Index, Daily Severity Rating, Drought Code, Duff Moisture Code, Fine Fuel Moisture Code, Fire Weather Index, and Initial Spread Index (Quilcaille et al. 2023). Daily FWI values were calculated using REMO2015, a CMIP5-era monthly, high-resolution (0.2° or ~22 km) regional climate model, an RCP8.5 emission scenario with high levels of fossil fuel use. Input variables include daily air temperature, relative humidity, wind speed, precipitation, snowfall, month of the year, and latitude. FWI values were then bias-adjusted to ensure the climate simulation data matches historical observations, using Phase 3 of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) v2.5.0 methodology (Lange 2019, Lange 2021) and ERA5 reanalysis data from 1991–2020 as the calibration dataset (Vitolo et al. 2020). Historical (1970–2000) 95th percentile FWI values are used for the wildfire danger maps.

[6] The Caliver R library package is an open-source tool which implements a streamlined and efficient workflow for the calibration and verification of fire danger levels based on the original equations developed by the Canadian Forest Service. To calculate fire danger levels, we used historical FWI from ERA5 reanalysis and historical area burned (greater than 50 ha) from GFED4 cropped and masked to the DRC and regridded to a common regular 0.25° grid. Data were daily from August 1, 2000 to December 31, 2015, spanning the temporal extent of high-quality daily burned area data globally.

By mid-century (2041-2060), southeastern DRC can expect up to 35 additional wildfire danger days per year on average, a yearly increase of up to 194% over the historical average (Figure 10, right). Isolated areas in eastern DRC could see an even bigger increase in wildfire danger days. Northern regions can expect a slight decrease, with an annual average of up to four fewer wildfire danger days.

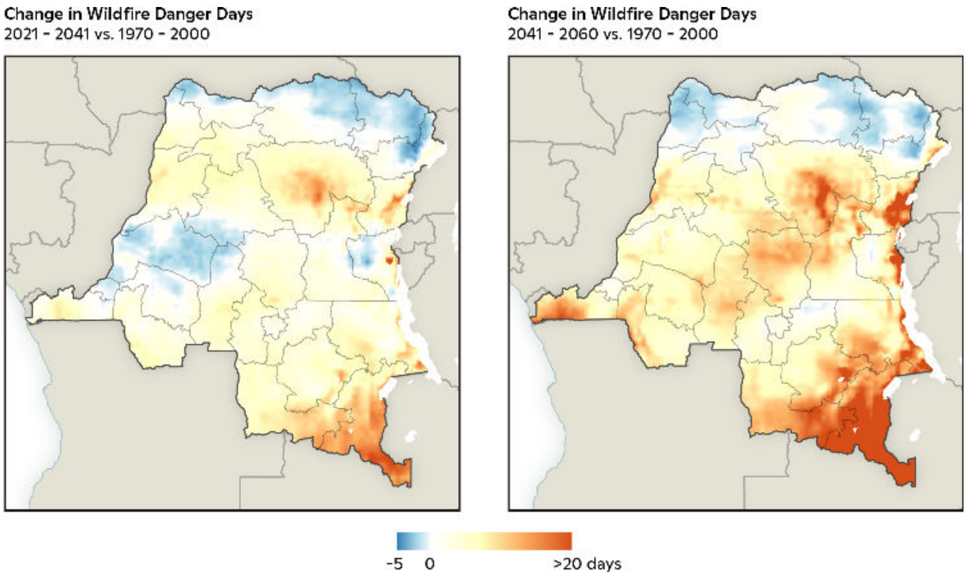

Figure 10. Change in Wildfire Danger, DRC. The additional number of days with high wildfire potential in 2021–2040 (left) and 2041–2060 (right) compared to 1970–2000. Regions expected to experience additional wildfire danger days are depicted in shades of orange, and regions expected to experience a decrease are depicted in shades of blue.

3.0 Recommendations and conclusion

The risk assessment identified future climate-driven threats to DRC's forests, agricultural crops, and cities. These threats necessitate swift adaptation measures, and also present a challenge to delivering on the country's Nationally Determined Contributions and the scaling of carbon market ambitions to finance a green economic transformation. The results are largely the product of a public sector consultation within the Ministry of Environment and Sustainable Development although other branches of government participated, including agriculture, biodiversity conservation, plans, social protection. Therefore, findings are oriented towards the developing technical policy framework and are not a comprehensive assessment of all the government agency perspectives or non-governmental stakeholders, e.g., communities, finance or private sector. However, the concerns of these groups were considered and included where they intersected with technical discussions.

After completion of the initial report, Woodwell Climate convened a final workshop in Kinshasa (October 2023) with representatives from DRC ministries, the University of Kinshasa, and the national conservation agency (Institut Congolaise pour la Conservation du Nature). After being presented with the climate risk analysis and following a discussion of the results in working groups, workshop participants identified specific challenges and solutions related to the implementation of adaptation measures. The overarching framework to implement these recommendations was identified as *a functioning carbon market regulatory framework and a Carbon Market Regulatory Authority (CMRA)*: an institution capable of managing standards, certifications, and monitoring, pursuant to Ordinance-Law n°23/007 of March 03, 2023 amending and supplementing Law n°11/009 of July 09, 2011 on the Fundamental Principles relating to the protection of the environment and establishing the DRC National Carbon Market Regulatory Authority (CMRA).

The CMRA urgently needs to develop its operational guidelines and other institutional and regulatory frameworks to enable the operationalization of the carbon market. Critical national framework opportunities include (i) the Government's current goal to assign some form of conservation status to much of its 155.5 million hectares of forest, and its 105,000 km^2 of peatlands; (ii) the willingness of local communities to engage in conservation programs and contribute to combating climate change, while at the same time improving their living standards; and (iii) the urgency of translating the country's impressive climatic potential into tangible wealth. The aim of the CMRA is to scale both the supply and demand for high integrity and quality carbon credits (accounting for ecological and social co-benefits, climate risk, permanence, and leakage) to emerging international markets, by developing the CMRA operational architecture so that they can onboard stakeholders to the DRC forest carbon markets.

Broadly, the policy recommendations focused on expanding top-level government regulation and coordination, and generating the basic data to transparently prove the GHG performance of the economic system through improved monitoring, requiring critical investment in national scientific and technical expertise. Summary narrative findings are coordinated with the NDC (2021) and the NAP (2021) and target where investment is needed to improve on the collection, analysis and sharing of data for GHG performance management. Key institutions implicated are detailed in the final workshop proceedings. The summarized needs and recommendations identified in the workshop are outlined below.

3.1 Disaster risk reduction and climate change adaptation

Not only does climate change threaten forests, but it also threatens vulnerable communities that rely on and protect them (NDC, Section 6.2.4, page 70). Consistent and accessible data from well-maintained networks is necessary to inform disaster risk reduction (DRR) and climate change adaptation (CCA) planning, and fragmented observational networks and data records have been identified as a barrier to the DRC's adaptation framework (NAP Section 3.6, page 26). Observational records, in combination with high-resolution projections, can be used to develop maps of future flooding (Section 4.6) and other measures such as early-warning systems to prevent disasters from flooding and other extreme events (NAP Section 5.2.3, page 46).

3.2 Land use and climate threats

3.2.1 Sustainable agriculture

In the DRC, agriculture is the primary source of income for over 90% of the population and is almost exclusively rainfed (NAP Section 4.2, page 30). Our analysis shows that although conditions will be more suitable for cassava production in the equatorial rainforest region, they will degrade elsewhere (Section 4.4). As growing conditions change and the DRC's growing population drives a growing food demand, the expansion of unsustainable agricultural practices such as slash-and-burn farming threatens forest conservation. By scaling up agricultural research and extension services, the DRC can support climate-resilient agriculture (e.g., smallholder farming, agroforestry, etc.) (NAP Annex 3, page 61).

3.2.2 Climate Hazards

In addition to anthropogenic threats, forests are vulnerable to natural threats. Although the NAP suggests that "large scale degradation of tropical rainforests due to climate change should not be expected," (NAP Section 5.2.1, page 45) our analysis finds that the Congo rainforest will face increased risk of slow-onset hazards such as drought (Section 4.1), and fast-onset hazards like wildfire (Section 4.7). Long-term carbon credits need to account for these growing risks.

3.2.3 Forest Concessions

Unregulated and opaque forest concessions threaten the protection of forest resources. Improved field inventory and remote sensing monitoring systems are recommended to track forest resources (NAP Section 5.2.1, page 45).

3.3 Scientific integrity and standardization around emission reductions crediting

3.3.1 Pricing and quality standards in GHG measurement, monitoring and sharing

Pricing on the voluntary carbon market favors buyers who set the price rather than sellers/producers of carbon credits and prices remain low compared to the true cost of conserving carbon in the landscape over the long term. This results in a low price per tonne of carbon in the market. A critical issue is how to achieve prices that truly incentivize the scaling of the market. This is not simply a matter of demanding higher prices, but rather a complex issue surrounding building integrity and confidence around quality (NDC 2021, Section 6.3, page 99). By implementing standards of carbon quality, sellers can be recognized and rewarded by obtaining high quality carbon credits, giving them power in the market. However, this assumes that prices also reflect a common set of criteria around quality and integrity to allow for rational price discovery. At present, the carbon credit landscape is inconsistent and integrity is not guaranteed. Accreditation/certification and verification standards for the carbon stored in forests, soils, and other landscapes must be established for various types of carbon credits. Certification standards should be universal, but country-wide standards set by an oversight agency for the DRC is a critical first step.

3.3.2 Ecosystem co-benefits

Carbon credits should account not only for the carbon present on a tract of land but also for the ecological co-benefits, including biodiversity, landscape integrity, water cycling, and temperature regulation. The DRC is recognized as one of 16 mega-biodiverse countries in the world and has included forestry among its priority adaptation programs. Yet only $100,000,000 (~2% of the DRC's total Green Climate Fund budget) is allocated to the forestry sector (NAP Annex 3, page 63). Appropriate valuation of ecosystem services would increase investment in tropical rainforests as well as better differentiate the price of carbon credits.

3.4 Capacity development

3.4.1 Technical experts

Technical expertise is the keystone of an effective and credible carbon market. To increase national ownership and lessen reliance on outside firms, building in-country technical expertise in forest inventory, forest management, and Monitoring, Reporting, and Verification (MRV) frameworks and tools is critical (NDC 2021, Section 7, page 84). This must be based upon a strong national scientific infrastructure, requiring investment in universities and research institutions (NAP Section 6.3, page 50), as well as investing in opportunities for receiving advanced education abroad.

3.4.2 Community stakeholders and forest caretakers

In addition to being incentivized to protect forested areas, communities—including Indigenous populations—need to build awareness of climate impacts (NAP Section 3.7, page 25). In particular, they should understand 1) why they are being encouraged to conserve forests (NAP Section 2.6, page 18) and 2) why revenue fluctuates in a volatile market to avoid discord and manipulation. Given the complexity of these subjects, communities need trusted local representatives or external advocates who can translate between languages and worldviews. This is particularly important with respect to the role that local communities will play in scaling NbCS approaches. The emerging green economy strategy hinges on incentives to adopt low- or zero-deforestation approaches to economic growth and poverty reduction.

3.4.3 Carbon market managers

In this new and rapidly-evolving field, carbon market managers need to be trained to understand and manage the emission management system to coordinate with a set of dynamic and heterogeneous international standards (NDC 2021, section 8.9, page 97). As the market grows and evolves, managers need a venue for experience-sharing. A credible support framework for managing carbon funds ensures trust and transparency in fund management. In terms of efficiency, processes need to be streamlined to reduce transaction costs in the lengthy and expensive project development and market access process (from program design to final sale). A public agency devoted to the processing and management of forest concessions would accelerate the operationalization of conservation concessions.

3.5 Governance and transparency

3.5.1 Cross-sectoral and multilateral coordination

The lack of coordination between ministries and sectors (private, public, and academic) impedes the swift and effective implementation of a VCM. Institutional agreements and memoranda to ensure the sharing of ideas and data across agencies and sectors (NAP Section 3.2, page 21) will reduce redundancy and encourage multidisciplinary thinking. Creating something as simple as working groups across sectors would be a significant step forward toward sharing information and experiences.

3.5.2 Stakeholder engagement and social equity

At present, there is no agreed-upon model for sharing carbon credit revenue between parties, including project promoters or investors, forest communities, and the state. All stakeholders must be involved in the establishment of a legal framework for equitable carbon credit revenue sharing.

3.5.3 Advocacy

The Congolese carbon market still needs to attract international investors. A coalition made up of other countries in the Congo Basin could advocate for Congolese carbon credits within the international market and coordinate standards with other jurisdictions.

3.6 Conclusion: Enhance the operational architecture needed to scale the national carbon market

In conclusion, if we build integrity and transparency into the national carbon market framework, scale will follow. Integrity and transparency can be built around existing technologies and by developing novel institutions to triangulate between standards and accountability, particularly between the agencies responsible for managing market coordination and those implementing technical services. Critically, the CMRA must put in place conditions that provide transparency and oversight to enable the carbon market to respond to the objectives for which it was created by resolving the critical challenges currently stifling market scaling. While there are many global initiatives to produce standards for NbCS credit generation and ratings for performance, these are presently 1) global in scope; 2) project orientated in scale; and 3) fee-for-service in nature, which have benefits but also pose limitations to market scaling. These limitations include:

1. An inability to properly characterize local-to-regional differences in biophysical quality, climate risk, and economic and social performance or in data quality and availability.
2. The failure of existing project-orientated ratings schemes to provide crediting standards with consistent criteria, leading to a lack of comparability among projects globally, confusing the market where quality and pricing are concerned.
3. The inherent conflicts of interest associated with bilateral fee-for-service relationships between projects seeking accreditation and entities providing credit ratings, which only exacerbate the potential for malign outcomes and reinforce concerns about transparency and integrity.

With these limitations in mind, an effective standard should be:

- Transparent and trusted, based on open and accessible procedures and processes,
- reflective of local biophysical, economic, and social conditions,
- practical to implement,
- easy to comply with,
- cost effective, and
- measurable with known error.

The development of a national standard and measurement architecture will help to assure the integrity of carbon markets across relevant landscapes and transcending national boundaries. The standard will facilitate a high level of transparency in the verification and communication of the performance of regional NbCS investments, and could eventually be used to establish a national warranty on credits produced within the sovereign territory of the DRC. A warranty is a well-developed instrument in contract law and assures that a seller's stated amount of carbon is removed for at least the period claimed. To provide a warranty the guarantor needs to know the risks of failure and for unintended consequences. This means that producers must be able to quantify the uncertainty around carbon removal strategies.

3.6.1 Priorities for the CMRA

1. Develop a national "umbrella framework" of measurable and enforceable criteria for carbon performance, to operationalize a regional standard for carbon market integrity and quality. Articulate guidelines, including performance benchmarks for monitoring and crediting; applicable to national inventories of carbon stock and flux in critical landscapes (forests, wetlands/peatlands, and agricultural/working lands). Define the structure and operational scope for the CMRA secretariat and a national scientific and technical advisory committee to identify the verifiable set of attributes and propose an integrated national system of accreditation of high quality and integrity NbCS carbon credits by private enterprise.

2. Identify in detail the technological needs and operational resources to enable the transparent performance assessment of regionally generated carbon credits for the global market, including organizational development needs, gaps, roles and interagency responsibilities. Utilizing best-available geospatial and field data, CMRA should establish landscape performance indices, orientated towards national supply and demand needs, which will support the creation of structured finance products for project developers, e.g., active and passive funds and bonds, and facilitate supply-side market coordination through emerging exchanges. The indices will incorporate the objectively verifiable biophysical quality as well as anthropogenic and climate risk characteristics of the landscape and will be generated independent of the crediting process.

3. Enhance the digital framework for data access and transparency of NbCS carbon credits, building around existing emerging national infrastructure. The framework will describe a web-based architecture to access precise and timely data, which are essential to the robust functioning of capital markets. An advanced data infrastructure and reference portal will promote the transparency of carbon credit data and transactions. A process should be defined to identify the technical and managerial competence to support delivery of a robust digital method (coordinated with existing global and regional initiatives) such that on-the-ground impacts of issued NbCS carbon

credits and supply chain commitments are independently verifiable, building on the issuing authority standards at project, jurisdictional or national levels.

A critical issue will be to further define equity concerns and mitigation measures to safeguard local communities' and marginalized groups' access to, and benefits from, the emerging carbon market, articulating specific interventions and public investment needed to ensure that mitigation measures can be implemented at scale as per many of the recommendations in this report.

Appendix

Final workshop participant list Kinshasa, October 25, 2023

The authors wish to acknowledge the inputs from a wide gathering of national government and non-government stakeholders in the formulation and discussion of the recommendations and conclusion through the workshop process.

Name	Institution	Position or function
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Matondo Mutsionga Roger	IDSEEBE	President
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WOODWELL CLIMATE RESEARCH CENTER conducts scientific research to find solutions at the intersection of climate, people and nature. We work in partnership with leaders and communities to make a fair and meaningful impact on the climate crisis. Our scientists helped launch the United Nations Framework Convention on Climate Change in 1992 and, in 2007, Woodwell Climate scientists shared the Nobel Prize awarded to the Intergovernmental Panel on Climate Change. For over 35 years, Woodwell Climate has combined practical experience and political impact to identify and support society-wide solutions that can be implemented immediately. This includes working with communities on the front line of the climate crisis.

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