Environmental Issues in Central Africa

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Abstract

The Central African forests, the planet's second largest rainforest block, are key to global environmental health. They influence climate change through their crucial role in carbon sinking and storage, affect weather patterns across Africa, and safeguard unique species and biodiverse communities. Their fate is important to everyone, not just today's inhabitants. The forests cover seven countries, and the differing socioeconomic histories and trajectories of these nations determine divergent fates for people, trees, and wildlife across the region. We review current knowledge of how the Central African forests have been shaped by climate and human activity within the region and assess how they may evolve under future climate change, population growth, and the Anthropocene race for wealth and energy. We highlight three different environmental trajectories for the countries of the region, identify key current regional issues that have an international dimension, and highlight five new points of future concern.

Contents

1. INTRODUCTION

1.1. An Overview of Central Africa

Central Africa, at the heart of the continent, connects the culturally and environmentally distinct regions of North, South, East, and West Africa. Bisected by the Equator, the region encompasses the countries of Cameroon, Gabon, Equatorial Guinea, the Democratic Republic of the Congo (DRC), the Republic of Congo (Congo), the Central African Republic (CAR), and the tiny Angolan exclave of Cabinda, which is currently petitioning for independence (**Figure 1**). The region is home to approximately 113 million people, nearly 80 million of them in the DRC and more than 23 million in Cameroon (**Table 1**). Dense rainforest predominates, and rural populations, although sedentarizing rapidly, still live a partly hunter-gatherer lifestyle in many areas, using small areas of shift-and-burn agriculture for subsistence consumption. Thus hunting wildlife and gathering nontimber forest products are important pressures on the forest habitat.

The region was politically born just five decades ago. Four of the six countries gained independence from France in 1960, the DRC becoming independent from Belgium in the same year and Equatorial Guinea gaining independence from Spain in 1968. Cabinda's sovereignty from Angola is still disputed. Economic union between the western nations followed in 1972 with the creation of the Bank of the States of Central Africa; a common currency, the Franc de la

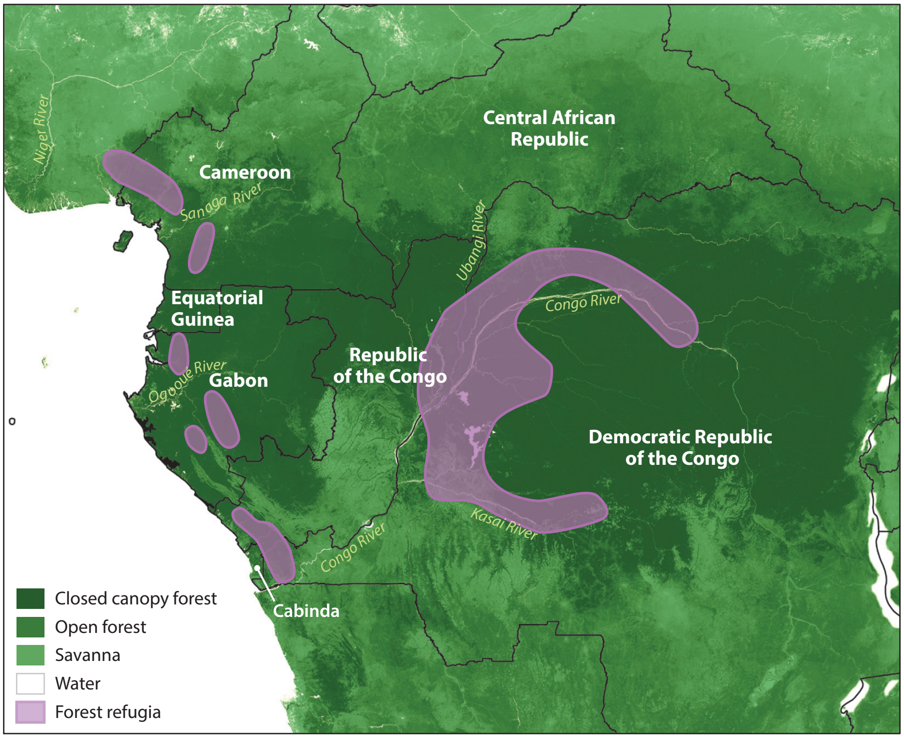


Figure 1

Map of Central Africa showing major rivers, country boundaries, Pleistocene refugial forests, and current dense forest cover. Pleistocene refugial forests drawn from descriptions in Reference 5 and discussion with the author. Forest cover from Google Earth: TerraMetrics TruEarth 15-m imagery (2015) (accessed via Global Forest Watch: **http://www.globalforestwatch.org**).

Table 1 2015 statistics for Congo Basin countries[a]

Country	Total popula-tion	Rural population density (persons/km^2)	Percentage of population in urban settlements of >300,000	Per capita GDP	Percentage of timber contribu-tions to GDP in 2011	Percentage of mineral revenue contribu-tions to total exports in 2015	Percentage of population with mains electricity in 2015	Land area (km^2)	Forest area in 2014[b]	Percentage of forest cover in 2015	Percentage of forest loss between 2000 and 2014[c]	Percentage of forest loss between 2014 and 2015[c]
Cameroon	23,344,180	22.5	54.4	1,385	2.8	56.7	53.7	472,710	259,991	55	2.088	0.0051
Democratic Republic of the Congo	77,266,810	19.6	42.5	515	0.6	81.7	16.4	2,267,050	1,133,525	50	4.004	0.0063
Equatorial Guinea	845,060	18.1	39.9	22,055	0.3	94	66	28,050	27,489	98	2.531	0.0050
Congo	4,620,330	4.7	65.4	3,041	0.9	91.6	41.6	341,500	242,465	71	1.559	0.0022
Central African Republic	4,900,270	4.7	40.0	385	3.5	43.9	10.8	622,979	311,490	50	1.162	0.0011
Gabon	1,725,290	0.9	87.2	9,918	1.8	72.2	89.3	257,670	237,056	92	1.123	0.0017
Cabinda	~500,000	NR	NR	NR	NR	NR	NR	7,340	NR	NR	NR	NR

Abbreviation: NR, not reported.

[a]Country statistics in the first three columns (beginning with "Total population") are provided by the UN Population Division (**http://esa.un.org/unpd/wup/DataQuery**), in the next three columns (beginning with "Per capita GDP") by the UN Conference on Trade and Development (**http://unctadstat.unctad.org**), in the "Percentage of population with mains electricity in 2015" and "Land area (km^2)" columns by the World Bank (**http://www.worldbank.org**), and in the final four columns (beginning with "Forest area in 2014") by Global Forest Watch (see **http://www.globalforestwatch.org**, and sources therein).

[b]The forest area is approximate to the total square kilometers each having greater than 50% tree canopy cover at the end of 2014.

[c]The forest loss percentage is measured as loss of land area retaining greater than 50% tree canopy cover.

Cooperation Financière en Afrique Centrale (the FCFA); and the emergence of a coherent regional identity. The DRC remains financially independent, using the Congolese franc, although inflation has rendered this currency highly unstable, and many daily transactions use the US dollar. The region is still chiefly francophone, although Equatorial Guinea remains hispanophone, and Lingala (in Congo and in western DRC) and Swahili (in eastern DRC) are also widely spoken.

The region harbors rich mineral wealth, with large oil reserves in the west and diverse mineral deposits in all countries underpinning economies based on the extraction of minerals supplemented by timber revenues (**Table 1**). The mineral riches of eastern DRC were known before 1960, but new wealth from oil discoveries revolutionized the economies of Gabon and Congo during the 1960s. Cameroon discovered oil reserves in the late 1970s and Equatorial Guinea in the late 1990s, the latter taking its per capita GDP from less than $600 in 1996 to more than $22,000 in 2015 (1). Historically, trade partnerships have been predominantly with Europe, although the past decade has seen significant investment by China across the region and increasing trade partnerships with Asia and America (1).

However, despite clear economic viability and potential for growth, over the past half-century violent internal conflicts have arisen in all these countries except Gabon and to a certain extent Cameroon, weakening civil society, depleting government resources, and limiting the development of social capital and economic diversification. The result has been a half-century of dependence on the extraction of raw natural resources using relatively unskilled and low-paid labor, with damaging consequences for the environment and society.

The region is poorly served by international transport links, is difficult and expensive to reach, and is thus poorly known beyond the ex-colonial powers of France, Spain, and Belgium. However, the multiple levels on which Central Africa is important to the global environment are becoming increasingly clear (as this review demonstrates), as is raising the profile of the region as an international environmental management challenge.

1.2. The Guineo-Congolian Forest Biome

The Central African forests are often oversimplistically referred to as the Congo Basin, a term that for many is the epitome of dense rainforest jungle. In fact the vast Congo River drains only the eastern part of Central Africa. These Congolian rainforests (2) cover Africa's heartland from the continent's eastern Albertine Rift Valley to its western coast, through the DRC, southern CAR, Congo, and Cabinda. West of the Congo River drainage, the contiguous Lower Guinean forests (2) cover western Central Africa, stretching east and south from the Cross River through southern Cameroon, Gabon, and Equatorial Guinea (**Figure 1**).

This contiguous block of Guineo-Congolian rainforests is recognized as biologically distinct from the West African rainforests, which stretch along the western coast of the continent, from southern Senegal to the Dahomey Gap (3). It differs also from the unique swamp forests of the south Nigerian coasts and the Niger River Delta, which span the coast from the Dahomey Gap to the Cross River (4).

The forests covering Central Africa today expanded from Pleistocene mountain and swamp-riverine macrorefugia (5) and multiple small microrefugial patches (6), which maintained their forest cover throughout the cold, dry, and forest-hostile climate of the Last Glacial Maximum [18,000–12,000 years ago (7)]. Over the past 12 millennia, the climate has become wetter and warmer and, particularly during windows of opportunity when human-induced fires were rare (8, 9), forest cover has been able to expand from these Pleistocene refugia, a process continuing today at the forests' borders (10). The forests of the refugial regions, on the massive swamps of central DRC and the mountain ranges of the western equatorial forests, are the oldest forests of the region, some more than 18,000 years old. The youngest forests, just a few decades old, now border the transition to savanna hundreds of kilometers to the north and south of the refugia, or fill colonized savanna patches, recently engulfed as the forest edge advances (8). The biogeography of the Pleistocene refugia still broadly underpins many contemporary species distributions, particularly for slow-dispersing, forest-obligate taxa, such as gorillas (11) or Begonias (12). These forests are areas of high evolutionary plant and animal diversity, even though today their diversity has been eroded by modern logging and other human pressures (13). Important clues to the future resilience of the Central African forests may be held in understanding the structural attributes and ecological functioning of these oldest forests, which persisted in the face of severe climate changes in the past (13, 14).

1.3. Central Africa in the Anthropocene

Although environmental conditions fluctuate naturally without the influence of man, in the twenty-first century globally significant environmental issues seem inextricably linked to human activities. The overwhelming influence of *Homo sapiens* on the planet's environment and function is now widely accepted and defined as our entry into a new epoch: the Anthropocene (15, 16). As human activity extends across the Earth's surface, and into all biomes, we are living within an imbroglio of environmental processes established over evolutionary time but now shaped by anthropogenic influences and new, directly anthropogenically-induced processes. One key aspect of the Anthropocene is the diminishing relevance of physical distance in biological systems. Changes to the atmosphere, rapid and regular long-distance dispersal of biological organisms, and global economics mean that even the most remote places on Earth feel the influence of humanity. The forests of Central Africa, although seemingly a wilderness with one of the lowest densities of built infrastructure (17), are already highly impacted by human activities in other parts of the world (18, 19)—through global atmospheric changes, economies that invest in extracting the region's natural resources, and introduced invasive species. In turn, Central Africa's forests exert substantial influence on the overall health of the rest of the Earth, due to their vast and increasing carbon stocks (20), their key role in global climatic patterns (21), and their considerable importance for the world's terrestrial biodiversity (22). People living thousands of kilometers outside Africa can not only affect the fate of these forests, but will also feel the consequences of that fate, whatever that will be.

The major environmental issues facing Central Africa's environment are those that affect the persistence of the rainforest biome. Responses to deforestation and climate change dominate environmental agendas in the region (21, 23), and the consequences of defaunating the tropical forests (loss of the wildlife within a standing forest) have become a major concern in international fora (22, 24).

Excepting Cabinda, which covers just 730,000 hectares, the Guineo-Congolian rainforest biome is governed by six nations, and the modern environmental issues affecting it are of mutual concern. These nations share many environmental policies through the COMIFAC convention (25; see also **http://www.comifac.org**), although differences in individual socioeconomic trajectories do, and will continue to, affect the relative success of common environmental management strategies.

The region is now at an economic crossroads: Oil is no longer a panacea for poor skills development or strategic economic planning. New political manifestos at regional and national levels clearly target economic diversification and although improved sustainability in natural resource exploitation is often cited (25), diverse land uses that replace oil exploitation are likely to take up more space and be more challenging to manage. Increasing human populations in the region, demand for economic growth, global climate change, and a natural environment made fragile by overexploitation and weak governance could soon bring the region to a tipping point of rapid and unpredictable environmental change. Society, both within the region and internationally, is realizing the implications of that.

We review not only the foremost environmental issues—deforestation, climate change, and defaunation—but also cover some less prominently discussed threats to the Central African environment, in order to provide a finely tuned consideration of the region's possible environmental futures. We discuss how heterogeneity between the countries divides them onto three broad environmental trajectories. We highlight six current environmental issues for Central Africa that have a clear global dimension and go on to highlight five key environmental issues that should hold international attention for the coming decade.

2. CLIMATE-DRIVEN ENVIRONMENTAL CHANGE

2.1. Models of Climate Change

Despite intensified climate research since the formation of the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC), there is still high uncertainty about the climatic future for Central Africa, largely due to a dearth of robust empirical data from the region and the complexity of the weather systems on the Equator and western coast (26–28). There is, however, mean across-model agreement that the region will probably experience temperature rises of close to +1°C per +1°C of mean global warming, thus an overall warming potentially exceeding 3°C by the end of the century, even under the most mitigated scenario [Representative Concentration Pathway (RCP) 2.6] or the <2°C maximum mean global temperature rise target, set by the Paris Accord in 2015 (29). Predictions differ far more in the spatial pattern of wetter and drier scenarios, linked to their interpretation of the dominance of Atlantic or Indian Ocean sea surface temperature effects. James et al. (26) review models of particular relevance for the region and show majority agreement, for all RCPs, on predictions of a wetter climate in the east (eastern DRC) and drier conditions in the western equatorial forests, characterized by extended periods of drought, possibly even severe enough to induce forest retreat (30). Highest uncertainty lies at the center of the continent, for large areas south and east of the dense swamp forests of the Congo River Pleistocene refuge (**Figure 1**), where most models predict increased seasonality, but the boundaries of hypothetically drier or wetter regions vary greatly. Supra-annual patterns and the future frequency of extreme weather events (particularly high rainfall, drought, or exceptional temperatures) are very unclear. Although the frequency of rare weather events has been postulated to be a determining factor in ecosystem resilience to climate change, we have inadequate ability to model them for Central Africa, as empirical data over the required timescales are lacking (31).

2.2. Measured Changes and Trends in Rainfall and Temperature

Models are hypotheses and in regions of high uncertainty, such as Central Africa, empirical measures of actual change are essential for model improvement. Many climate models for the region were derived from small empirical datasets together with remote sensing outputs. They require extensive ground-truthing over the coming years to validate them as climate change proceeds. As historical data on local weather patterns are so few for Central Africa, the degree to which any modern change is a departure from expected fluctuations is uncertain (32). Rainfall has been poorly measured, with rain gauge coverage of the region declining over the past 20 years, giving rise to potentially erroneous estimates, in place of real data (31). A recent comparative analysis of eight rainfall estimates (interpolated data for areas between ground rain gauges or rain inferences from satellite measures of cloud cover) showed considerable differences between them (31). Differences between rainfall estimates and empirical measures for the western region are more marked for the period December to May than from June to November, corresponding to crucial variation in the movements of the Intertropical Convergence Zone (ITCZ). Importantly, seasonality is shifting, with more marked changes in seasonal effects along the western coasts and northern Sahelian border and less marked seasonality within the Congo Basin itself (33, 34). In line with expectations from highly variable local temperature and rainfall data, measured evapotranspiration rates are also heterogeneous across the region (35). Soil moisture is a key factor determining forest cover, and although measures of rainfall and evapotranspiration contribute to soil moisture estimates, actual soil moisture has rarely been reliably measured empirically, which remains a key problem in assigning confidence to models of potential changes in forest extent (30). Robust data on flow changes in the major rivers have been collected regularly and contribute some insight into overall water balance patterns. Flows in the Congo and Ogooué rivers have maintained their intra-annual seasonality patterns, and over the past century the seasonal flow of the Congo River has not significantly changed; this may indicate that the predicted heterogeneous wetter/drier changes across the Congo Basin may be balancing out at a Basin-wide level, or that the significant peat formations of the central Congo Basin provide a buffering effect between the modeled overall rainfall increases (32) and consequent river flow rates (34). In contrast, the flow of the Ogooué, although maintaining its seasonality pattern, has persistently declined over the past 60 years (34). Overall decline in Ogooué flow, together with increased variability, is most marked the March–May wet season, consistent with the strong influence of the ITCZ in the western region. The relative importance of flow in the two wet seasons has changed: Ogooué flow rates in the 1950s indicated two equal wet seasons; by 2015 the effect of the March–May wet season had reduced significantly in relation to the October–December period, an environmental change that could well be effecting significant vegetation responses. The paucity of robust empirical measures of soil moisture drastically reduces the predictive power of models and our depth of understanding. Locally, high runoff events have been associated with increasing anomalously large rainstorms (36); however, relative effects of differences in daily rainfall patterns, rather than seasonal or annual amounts, on soil moisture or cumulative water deficits remain intractable, as the modifying effects of forest structure, soils, or forest productivity are largely unknown.

Brought together, the empirical picture emerging is one of increased seasonality and increased water stress across the northern and western Lower Guinean forests, with potential for changes in forest function and even forest extent. For the center, south, and eastern forests of the Congo Basin the picture is less clear. Local changes to precipitation patterns are certainly happening; however, although obvious directional changes in water stress are unclear, the considerable deficiency in empirical data may mean that change is undetectable, rather than proving stability in the area.

2.3. Forest Resilience to Climate Change

In addition to uncertainty over the extent of real change in environmental parameters, discussed above, there is also considerable debate on the mechanisms by which the Central African forests could respond (26, 32). African rainforests have been postulated to have potentially higher resilience to water stress and drought than neotropical rainforests, due to their history of post-Pleistocene periods of drought-induced contraction (14, 37) and their relatively high proportion of large, old, high-wood-density trees (38). Their comparative resilience to the droughts of 2005 and 2010 lends support to this hypothesis (32); however, there will likely be a range of varying vulnerability between individual species or communities. Gond et al. (39) show a robust relationship between forest basal area and evergreenness in Central Africa, indicating that older, less disturbed forests, which have the highest biomasses and the largest trees, also tend to be more evergreen. Evergreenness may indicate more vulnerability to drought, as evapotranspiration is continuous through the year, and Zhou et al. (40) demonstrate a significant loss of greenness between 2002 and 2012 for the central and eastern Congo Basin during the dry season. This loss of greenness in the Congolian forest has not been related to significant forest-wide dieback but rather to small, discrete changes within the structure and composition of the canopy, pointing to differences in the drought resilience of individual species or specific locations, rather than community-wide tipping points.

Although as a community these forests may prove resilient to drought, the largest, evergreen trees may prove the least resilient individuals. As the largest trees are disproportionally important in biomass, carbon storage (41, 42), and contribution to evapotranspiration (43), arriving at a level of physiological stress that impacts these trees may be a structural and ecological tipping point for forests, even if the majority of tree cover is retained (44). In West Africa, forest compositional shifts toward more deciduous species have been documented in response to only 20 years of persistent drought conditions (45). Although considerable further work is needed for the whole region, changes in forest composition toward more deciduous, drought-tolerant species with smaller sizes and lower wood densities are a possible response over time under a warmer climate and persistent water stress, and may already be underway in the northern and western areas (39, 45). How these compositional shifts will occur—rapidly through differentially high mortality of evergreens and replacement by more successful deciduous species and/or over a longer term through widely disrupted patterns of tree reproduction—is undetermined.

2.4. Changes in Tree Behavior

Environmental cues determine phenology patterns in temperate plants, but the proximate triggers for vegetative productivity or reproduction are poorly understood for tropical species. In some African rainforest trees a cool temperature episode may trigger flowering (46, 47), but despite the region-wide directional change in temperatures since 1980, there is very little empirical evidence of correlated directional change in flowering patterns. A pan-African comparison of phenology data from studies of >10 years at forested sites showed both site-specific increases and decreases in community-wide flowering between 1990 and 2010 and did not detect obvious trends at multiple sites based on geographic location, forest type, or recent weather patterns (48). A complex suite of factors is likely to be controlling species-level phenological responses in African forests, and disentangling the relative importance of each is an important component of predicting forest responses to climate change. At Taï National Park in Ivory Coast, which has undergone more intense water stress than Central Africa (32), rainfall was negatively associated with a 12-year increase in community-wide ripe fruit production, which was best explained by the upward trend in solar radiation at the site (49). Interestingly, however, the upward trend in ripe fruit availability at Taï also covaried with a loss of arboreal frugivores, which may have lowered the prior predation of flowers and unripe fruit, leading to more ripe fruit observation. Research into the relationship between climate and forest regeneration must include the modifying role of plant-wildlife interactions, which happen at much finer temporal scales than the lives of tropical trees, but are usually an integral part of tree reproductive cycles in tropical forests, via pollination, seed predation, or seed dispersal (50).

2.5. Potential Climatic Drivers of Shifts in Ecosystem Extent

Water stress is highly likely to have been a determining factor in the current extent of the African forests (5, 14). Water deficits accumulating over several years are increasingly identified as a key factor in the fragility of forests and ultimate loss of forest cover (51); for example, the distribution of Amazon forest dieback in 2010 was significantly affected by water deficits accumulated in the 2005 drought and unresolved over the five subsequent years (52). Water deficit patterns measured in the western forests and those modeled—but less convincingly confirmed—for the Congo Basin suggest that at a regional level soil water is likely to be reduced over the coming years by overall lower rainfall, higher poststorm runoff (53), and higher evapotranspiration driven by warmer temperatures. Such changes would reduce the ability of the land to support forest cover at the current extremes of the forest extent, resulting in directly climate-driven forest contraction (30). However, water balances that determine the rainforest's ability to survive (51) are also critical in determining the suitability of land for alternative agricultural uses. The geographic pattern of water stress across Central Africa's forests will be one of the key factors in determining the spatiotemporal probabilities of rapid land use change, and it is a priority to better understand the role of intact forests and alternative land uses in local precipitation and water retention patterns (35).

There is considerable potential for climate change to drive significant forest loss via land conversion to agriculture, even if climatic conditions do not themselves lead the trees to decline (54). Empirical studies of the factors controlling evapotranspiration and tree responses to water stress are not yet adequate to underpin confident predictions of directly climate-driven tree loss, but modeled predictions of land suitability for crops may be a more determinant factor for governments in the allocation of land use.

2.6. Feedback from the Congolian Forests to Global Weather Patterns

Central African rainforests are significant global carbon stores providing the highest above-ground carbon storage on the continent, estimated to reach well over 425 Mg/ha (38). Until recently, old-growth forests were hypothesized to be in a climax state, with carbon balances in equilibrium, but new research has revealed that these forests also continue to be significant carbon sinks (55). The large and accruing carbon store renders the region crucially important for global climate, an attribute that nonlinear relationships between gas balances and forest productivity will disproportionally increase under future warmer temperatures (56). Aside from their global importance over the long term, the state of forests affects regional climate and local weather within far shorter time frames. Forest productivity, composition, and structure affect their contribution to atmospheric gas balances (57), evapotranspiration rates and surface albedo (58), and air passage rates and aerosol generation (59); these in turn affect precipitation (43), temperature cycles (56), and regional winds (59). There are clearly complex interactions between these factors that are still poorly understood but likely to generate multiple feedback loops that will ultimately influence weather beyond Central Africa. At present, the lack of empirical ground data on local weather precludes refinement of existing global models with the inclusion of effects from the Congolian forests, which raises uncertainty for climate predictions across the whole Earth system (31, 32, 59).

2.7. Predicted Sea Level Rises

Beyond Central Africa, global temperature rises are provoking sea level changes. Mid-Atlantic sea level rise predictions range from 40 to 50 cm by 2100 under RCP 2.6, to more than 80 cm under the RCP 8.5 highest emissions scenario (60). Although the magnitude of local sea level rise is predicted with low confidence for the region—due to the high level of interactions with rapidly changing human activity on the coasts, as well as large uncertainty as to the role of extreme weather events (61)—even the ~50 cm RCP 2.6 trajectory will significantly affect Central Africa's Atlantic coast. The major economic activities of the region are primarily in coastal cities: Malabo and Bata of Equatorial Guinea, Libreville and Port Gentil of Gabon, Pointe Noire of Congo, Cabinda of Angola, and Douala and Kribi of Cameroon. These ports dominate international trade and affect how the entire western half of the region connects to the rest of the world, with very few trade goods moving overland or by air. Portside infrastructure, refineries, airports, and large proportions of the residential areas of these cities lie <10 m above sea level (62). In addition to the preponderance of coastal infrastructure, for Gabon and Cameroon—the countries with most coastline—coastal lands also represent significant resources. Under an RCP 2.6 scenario, related socioeconomic projections to 2100, and feasible attempts at adaptation to saline intrusion or flooding (spending of US$88—100 million per annum), Cameroon and Gabon could still lose a monetary value of several billion US dollars in coastal forests and wetlands before the turn of the century (62), affecting their entire economic outlook and strategy.

3. ECONOMIC DRIVERS OF ENVIRONMENTAL CHANGE

As the importance of forest health for overall climate change is recognized (63), all drivers of change are under scrutiny. Our altering climate, although inescapable and potentially damaging to the rainforest biome, is arguably not the most intense pressure the Central African forests face in the short term and may not bring about the most immediate changes.

3.1. A History of Trade in Natural Resources

Central Africa has been inhabited by hunter-gatherer peoples throughout the past 50–90,000 years, but these people have not been the architects of change in the forest (64). Beginning with Bantu migrations from the northwest approximately five millennia ago, the Central African environment has been more changed by the influence of immigrant people than by its most ancient indigenous peoples (**Figure 2**) (65). Bantu farmers from West Africa brought crops critical for human population growth (66–68). There was ensuing population growth, immigration, and sedentarization provoking local environmental change, altered forest extent and wildlife populations, a signature that can still be seen in the forest today (37, 69, 70). Iron Age trade established transport routes across the region that persisted to the twentieth century (71), facilitating intense exploitation of

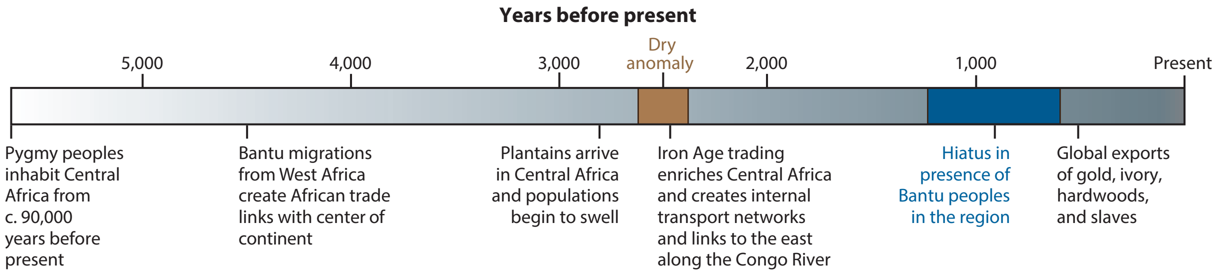


Figure 2

Timeline of last 5,000 years of human impacts on the region. Source information from References 64–72.

valuable forest products, such as ivory, gold, mahogany, ebonies, and enslaved people, to satisfy a functionally limitless external demand, beginning the economic influence on Central Africa not just of other African countries, but of other continents (72).

In the most recent wave of external economic influence, and continuing the patterns of the past, foreign investments from other continents and demand for oil and minerals (73), timber (74), agricultural land (75), and wildlife products (76) are driving environmental change in Central Africa more rapidly than local climate is altering the lives of its trees (19).

3.2. The Influence of Modern Global Trade

The ease of modern globalized trade enables demand anywhere on the globe to exact pressure on natural resources anywhere else. National economies in Central Africa are heavily biased to extractive industries, with oil and minerals responsible for the majority of the GDP in four out of the six nations (**Table 1**) and timber and mining concessions now covering a large part of the total dense forested area (**Figure 3**). Timber revenues are most important in Cameroon and CAR, whose economies are less absolutely dominated by mineral revenues; however, despite the vast extent of timber concessions, the contribution of timber to GDP in any country is <4%. All the contemporary economies are based on exports for foreign markets and foreign direct investments (**Figure 4**), making the region particularly vulnerable to socioeconomic circumstances far beyond its own borders or influence.

3.3. Interaction Between Climate Change and Economics

It is inevitable that climate change and global economics will intersect and alter each other, probably in ways we have not quite foreseen. The relative value of the region's standing forests versus its extracted timber and mineral resources will be determined by the value we ultimately put on carbon stocks and sinks, biodiversity, and ecosystem services, as well as the more conventional value of raw natural resources. The UN-facilitated REDD+ framework, initially launched by Gabon and New Guinea in 2005, and adopted internationally at the Paris COP21 in 2015, aims to provide an international framework for payments for carbon stocks and forest preservation (see sidebar, What Are the REDD+ Issues?). However, there is doubt that REDD+ alone can reach a value competitive with alternative land uses in the coming century.

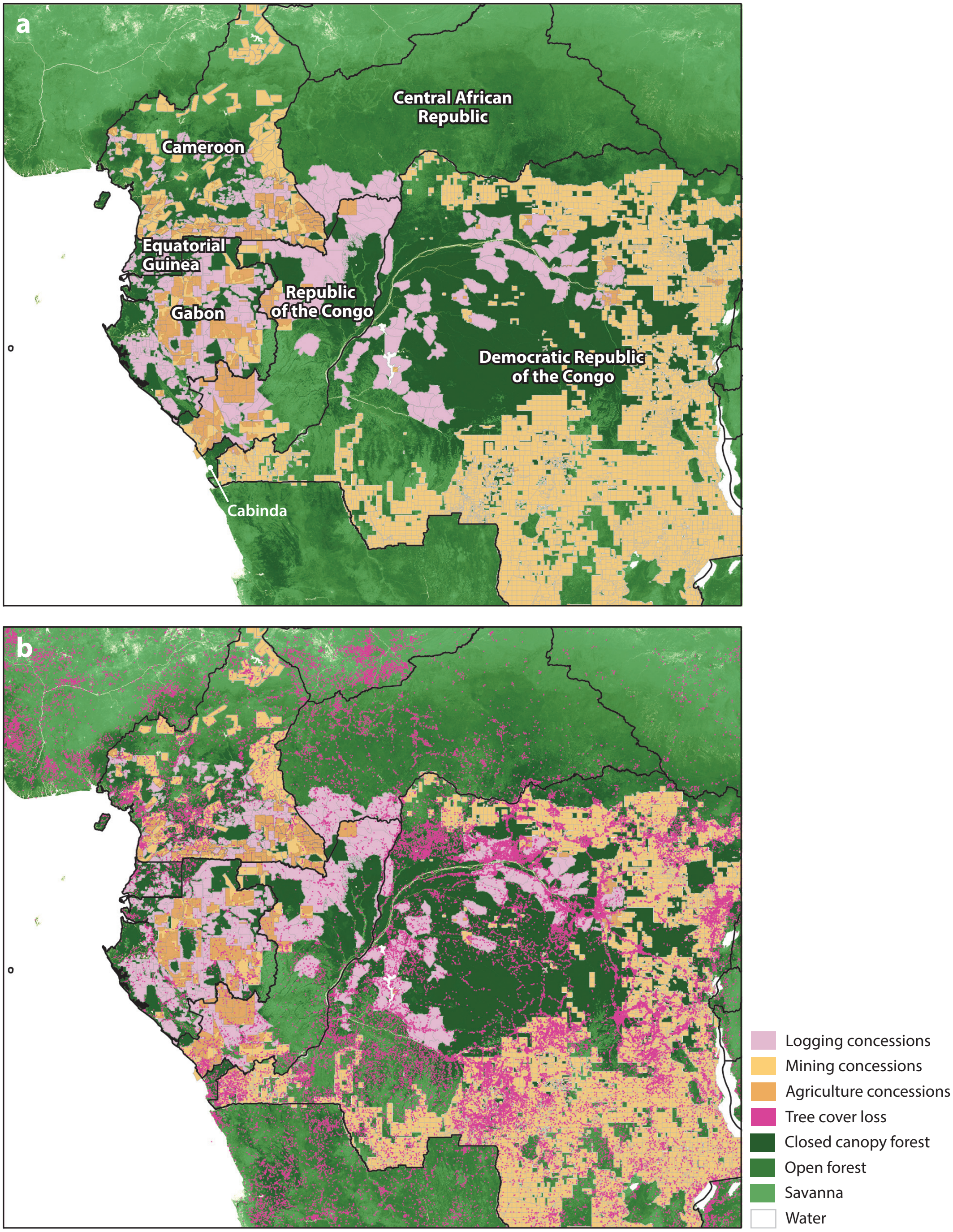
4. MECHANISMS OF CHANGE: DEFORESTATION AND DEGRADATION

Supplemental Material

Clearance is evidently the most dramatic thing that can happen to a forest. Thus, the drivers of deforestation, the permanence of subsequent land use changes, and possible pathways for mitigation are receiving an increasing share of research attention in Central Africa (see **Supplemental Figure 1** by following the **Supplemental Material link** in the online version of this article or

Figure 3

Map of current extent of (*a*) extractive concessions and (*b*) tree cover loss between 2000 and 2015. Land use data are from Global Forest Watch, and Tree Cover Loss (>50%). Source: Hansen/UMD/Google/USGS/NASA (83). Data available online at at **http://earthenginepartners.appspot.com/science-2013-global-forest**. Data on forest cover are from Google Earth: TerraMetrics TruEarth 15-m imagery (2015). All source data accessed through Global Forest Watch on January 2, 2016 (**http://www.globalforestwatch.org**).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Central African Republic
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Equatorial Guinea
Republic of the Congo
Gabon
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Logging concessions
Mining concessions
Agriculture concessions
Tree cover loss
Closed canopy forest
Open forest
Savanna
Water

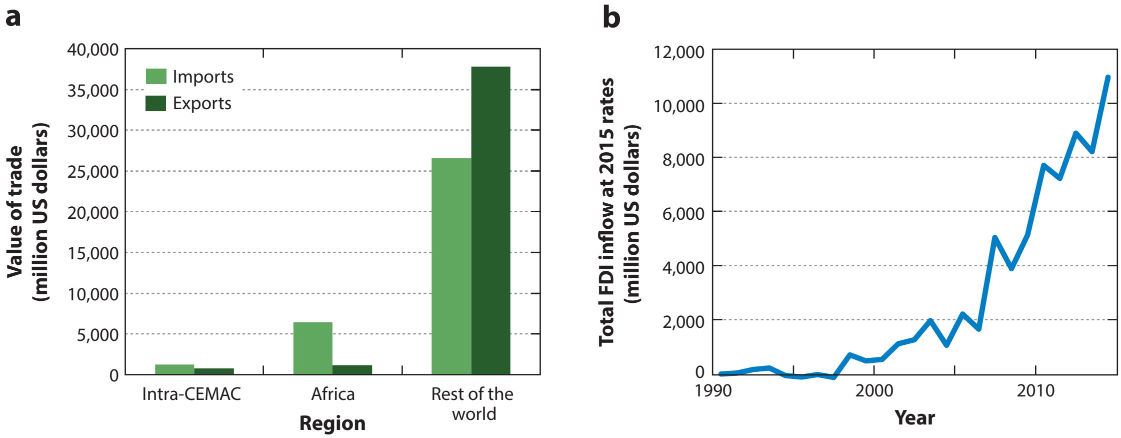

Figure 4

Foreign direct investment (FDI) and trade figures. (*a*) Gross import and export value from the Central African Monetary Community (CEMAC) area for 2015. (*b*) FDI inward flows, from 1990 to 2015, showing the large and increasing (FDI) influence of external trade and investment on the region. Data are from the 2015 United Nations Conference on Trade and Development (**http://unctadstat.unctad.org/EN/**), accessed on January 6, 2016.

at **http://www.annualreviews.org/**). The land conversion for industrial agriculture that caused dramatic deforestation in the Amazon (beginning in the 1980s) and Southeast Asian forests (beginning in the 1990s) was completely absent in Central Africa until approximately 2009 and is still of minor impact (75): Between 2000 and 2012, the annual forest loss was only 0.14% (77). Central government wealth from oil or mineral extraction, widespread rural civil unrest, and low road densities in the forested areas made conversion to state agriculture unappealing (78), and forests have been preferentially exploited for their timber with relatively low canopy loss (79). The main drivers of deforestation in the countries of Central Africa over the past 30 years have been (in order of importance) (*a*) clearance for smallholder agriculture (80), (*b*) firewood and charcoal extraction

WHAT ARE THE REDD+ ISSUES?

The UN Framework Convention on Climate Change (UNFCCC) REDD+ framework will guide most forest carbon preservation strategies for the future. REDD+ has five objectives: (*a*) reducing emissions from deforestation, (*b*) reducing emissions from forest degradation, (*c*) conservation of forest carbon stocks, (*d*) sustainable management of forests, and (*e*) enhancement of forest carbon stocks. The framework was adopted at the 2015 Paris COP21, after 10 years of debate and methodological development. However, with the exception of significant bilateral commitments from Norway, the funding to make REDD+ a reality has not materialized. For countries controlling very large carbon stocks, restructuring forestry policies could result in avoided emissions of many millions of tons annually; however, the World Bank's Forest Carbon Partnership Facility has just $500 million to make payments under REDD+ (**http://www.forestcarbonpartnership.org**). Various economic analyses have demonstrated that reducing tropical deforestation is a cost-effective way to fight climate change (164, 165) but the estimated competitive price against other land uses is much higher than the $5/ton of avoided carbon emissions currently set. High-forest-carbon countries are wary of introducing reforms that the REDD+ donors may not provide the resources for. Further innovation and sound land use planning integrating sustainable forestry and agriculture will be needed if tropical rainforest countries are to avoid massive deforestation.

(79), (*c*) timber logging (especially illegal logging) (74), and (*d*) mining (73). Multiple contributory secondary factors, such as national economic context, population demography, infrastructure status, climate, agricultural productivity, and access to markets, can interact to locally intensify the problem, often in a predictable and successional way, as discussed below (21, 81, 82).

4.1. The Importance of Urbanization

Post independence, the emergence of new economies in the region divided the Central African forest countries onto two separate socioeconomic tracks. The first was an "urban" track (Gabon, Congo, and Cameroon), driven by foreign investment and trade, which moved these nations rapidly toward urbanization, and passing (as a group) the >50% urban dwellers mark in 1985 (**Figure 5**). The other countries (DRC, CAR, and Equatorial Guinea) followed a "rural" track with central governments beset with civil strife and unable to attract investments or centralize employment, and local economies driven mostly by rural smallholder populations and the productivity of forests and farmland. These countries urbanized far more slowly than their neighbors, and are currently projected to urbanize at the same rate as the rest of Africa until at least 2050, becoming 50% urban dwellers only around 2038, more than half a century (locally, a lifetime) later than the countries on the urban track. This divergence of socioeconomic trajectories is a key factor in the current state of the Central African environment. Rudel (78) shows a convincing link between the proportion of oil or mineral revenues as a national level determinant of the overall deforestation rates for the countries of the region in the year 2000, arguing that the mineral-rich central governments that facilitated urban employment and initiated a rural exodus have played an unintentionally key role in protecting the forests. As the wealth of mineral-rich nations increased, currency increased in strength, labor became expensive, and food imports became more appealing than national agriculture, intensifying urbanization and reducing pressure for rural land use change. Although Rudel does not comment on the expected evolution of the relationship he finds in 2000, given this scenario one might expect that improving central government wealth might reduce deforestation, or that declining oil/mineral revenues would ultimately reverse the trend and result in increases in deforestation. However, comparison between 2000 and 2014 across the six countries finds a changed relationship between oil/mineral revenues and deforestation. Cameroon, with a far greater proportion of total revenues from oil in 2014 than 2000 (1), now has nonetheless a higher deforestation rate, whereas the DRC, which has maintained the high contribution of mineral revenues to its total exports (>85%), has also developed the highest annual and cumulative rate of deforestation (83). Current figures on exports and deforestation between 2000 and 2015 show that all the countries are experiencing tree cover loss and that the DRC, due to its size and great extent of forest, is losing forest both relatively and absolutely faster than the other countries of the region (83) (**Table 1**; see also **Figure 3*b***). The departure from the relatively simple relationship between mineral extraction revenues and deforestation in the year 2000 (78) is an indication that as the region's population grows and population demographics change, deforestation rates are responding to a more complex and dynamic equation between driving forces (81, 84).

4.2. Impacts of Rural Populations

A closer look at the interplay between socioeconomic pathways and actual deforestation trends in 2014 (83) reveals two deforestation trajectories within the Central African region, but these are no longer correlated to the proportion of mineral wealth, nor even per capita GDP. The first group has very low rural population density and low to very low deforestation rates. This broadly describes the nations of Congo, Gabon, and CAR. The second group is characterized by

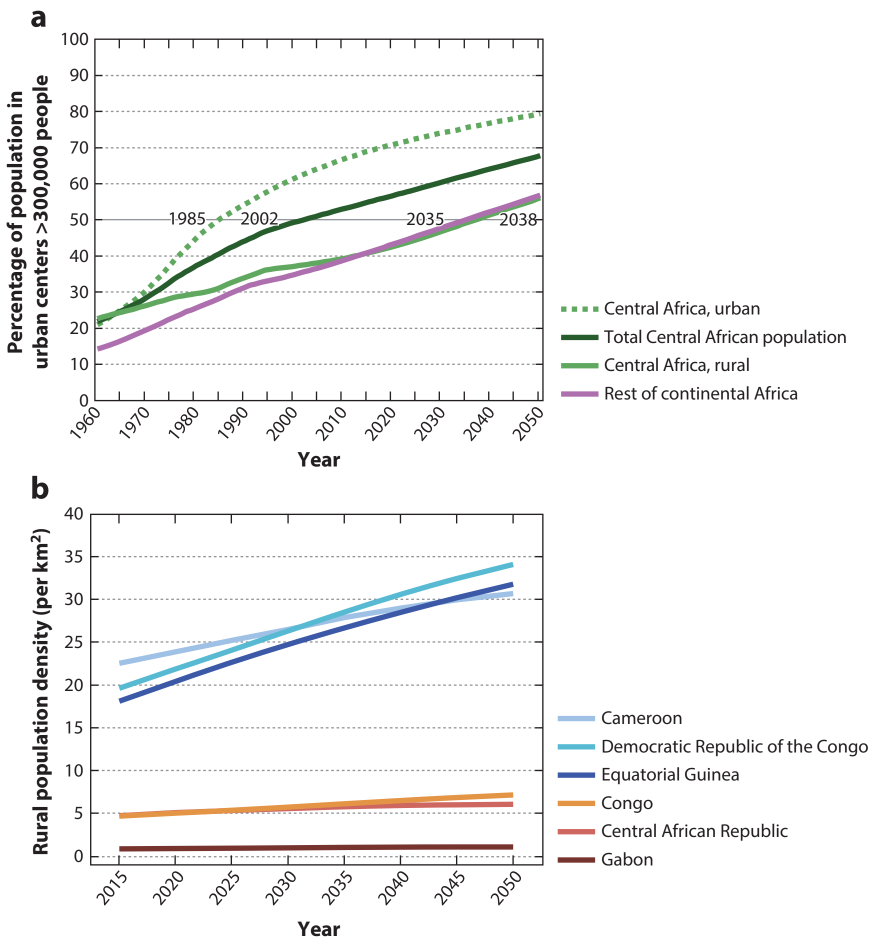

Figure 5

Urban and rural population growth trajectories. (*a*) Rates of past urbanization and future urbanization projections under a no-immigration scenario. Urban dwelling is considered as cities >300,000 people. Urban track countries are Gabon, Congo, and Cameroon; rural track countries are Equatorial Guinea, Democratic Republic of the Congo, and Central African Republic (see **Table 1**). Years next to lines indicate the exact year in which the population did or is predicted to become more urban than rural (passes 50% urban). (*b*) Density and projected growth of the rural populations until 2050. The countries group differently under these two metrics for considering population distribution. Data are from the UN Population Division for 2015 (**http://esa.un.org/unpd/wup/DataQuery**), accessed on January 6, 2016.

high density and growing rural populations and has much higher deforestation rates both actually (2014–2015) and cumulatively between 2000 and 2014 (**Table 1**). This describes the nations of Equatorial Guinea, the DRC, and Cameroon (**Figure 5**). Of the groups of countries that we defined earlier by their urbanization trajectories, two countries have changed groups, demonstrating that evaluating rural population density as well as the national degree of urbanization is important in understanding patterns of deforestation. Cameroon has a high overall rate of urbanization (54% in 2015) and clusters with Congo and Gabon in its historic and projected national rate of urbanization; it also has a growing economy and oil wealth. However, unlike Congo and Gabon, a large overall population in Cameroon means that it also has a high-density rural population, and this drives deforestation through smallholder agriculture, production of resources for urban centers, and infrastructure expansion, despite the contribution of oil to GDP and the high degree of urbanization. In contrast, CAR, which is deemed rural when considering the national proportion of urbanization, has such a low overall population that it clusters with the truly urban nations of Gabon and Congo in low rural population density and has a correspondingly low deforestation rate (**Table 1**). Looking to the future, these differences seem likely to deepen: The low rural density in Gabon, Congo, and CAR is predicted to remain approximately the same, whereas the high rural densities in the DRC, Cameroon, and Equatorial Guinea are predicted to rise steeply, intensifying rural smallholder impacts on the forest in addition to impacts from urban centers (84). Recall, however, that these analyses are based on national figures without immigration, and the current civil strife in CAR may dramatically and unpredictably increase its rural population.

4.3. Spatial Signatures in Degradation

For a given human population, urban and rural communities will impact a local landscape in mechanistically similar, although spatially different, ways. Two recent African studies, Ahrends et al.'s (85) (very large city) and Mayaux et al.'s (79) (towns >50,000 people), focus on the mechanisms by which urban populations provoke deforestation and land conversion. They find that resources, beginning with highest value land uses and extracted commodities (timber, precious minerals), are exploited in a geographic pattern akin to the ripples spreading from a stone thrown into a pool at the city center. As resources are stripped below a profitable margin, exploitation of lower value commodities (charcoal, smallholder agriculture) begins and new land at the front edge of the spreading wave is taken for the higher value uses (85). This effect produces haloes of deforestation around cities and transport routes, which increase over time in the intensity of degradation. The speed of travel of the degradation front is determined by the size of the urban center (demand) and the quality of the transport routes (opportunity cost of exploitation) (17). Such a depletion halo is also the pattern around small village settlements. Where roads and vehicles are uncommon, however, the maximum distances humans will walk carrying loads determine the speed of travel of the wave of degradation. This limits intense village deforestation to impacts within ~5 to 10 km of a village (86). In areas of high rural density, village haloes link up, causing the smallholder-driven deforestation signature widespread across the densely populated areas of the DRC, Equatorial Guinea, and southern Cameroon (**Figure 3*b***). Mayaux et al. (79) show that a rural density of approximately 8 people/km^2 is a tipping point at which canopy loss accelerates and deforestation haloes become permanent land conversion for agriculture. **Table 1** shows that this rural density is already vastly exceeded in the DRC, Cameroon, and Equatorial Guinea and is consistent with their relatively high rates of forest loss and permanent conversion, but is not even approached in Gabon, Congo, or CAR.

4.4. The Critical Role of Transport Infrastructure

The poverty of the transport network in the Congo Basin is a major limitation to economic development and is recognized as a priority for the region to address. Several multicountry projects are underway and others planned for the region, coordinated in a regional plan for development corridors aimed to enhance market access and reduce transport times and costs, which creates conditions for large-scale agricultural ventures (81). These corridors are a key determinant of the future (87) as the region shifts toward the large-scale agriculture that was the proximate driver of deforestation in Asia and Latin America (75), but also tries, with the international community behind it, to avoid environmental disasters (81). This is no small task. Road building into previously intact forests has raised great concern within the conservation community as multiple examples from the tropics, including most pertinently the recent Bangui–Douala road (88), confirm that increased access will accelerate the degradation of forest ecosystems and increase the permanence of land use changes toward simpler, less biodiverse habitats (89). Alongside, or even without, agricultural land conversion, roads cause degradation and deforestation around them, linked closely to their quality (80). As transport efficiency determines the spatiotemporal pattern of urban demand on the landscape, roads and road improvements can seriously increase the speed and intensity of environmental degradation spreading from an urban center (71, 78). The CongoBIOM model [developed by the World Bank as a derivative of the GLOBIOM model (81)] projects deforestation in the Congo Basin over the next 15 years to be more closely linked to transport infrastructure development than to any other driver.

5. THE CHALLENGES OF GROWING CITIES

5.1. Energy Generation

As cities grow and proportionally more people live in them, patterns of energy demand will change. Although the region is a net producer of hydrocarbons, meagre refinery and distribution capacities leave local energy needs unaccounted for. Domestic energy is currently based mainly on hydroelectricity generation (for urban centers) and fuelwood from forests for rural or even peri-urban populations (90). Both these sources have potentially far-reaching consequences for the environment, thus the decisions relative to energy production in the region harbor both great risk and great potential for good environmental management. Household access to electricity is a primary need and household consumption is currently the largest proportion of total energy consumption in all the countries (90), but limited national grids only permit access to household electricity for urban dwellers, thus potentially contributing to accelerated urbanization (91). As temperatures rise, more air conditioning and refrigeration will be necessary to maintain current lifestyles, and domestic demand may rise steeply. Where will the extra energy come from? More hydroelectric generation is planned in all countries but most importantly and controversially the world's largest hydroelectric scheme is proposed for the lower Congo River at the Inga Falls. This scheme will produce more electricity than any other center on Earth (40,000 MW), potentially supplying all of sub-Saharan Africa and even Europe and providing important revenues for the DRC. However, the proposal will disrupt flow and discharge of the Congo River, intends to drown more than 22,000 km^2 of forest (with associated carbon emissions), and does not provide for more rural domestic distribution in the DRC, as the power is destined for cities and export (92). As the project has a very real potential to indebt the nation for years to come (93) and may cause as many problems as it solves, the future of this dam is uncertain. However, the mere fact that it has been considered is indicative of the desperation for energy and revenue generation solutions within the Congo Basin. There is a clear risk that the DRC, following the so-called tiger economies of the east, may consider high environmental damage levels acceptable in the search for energy to power economic growth. As the world commits to reduce carbon emissions, a key component of success will be finding suitable, rapid, and realistic solutions to the African energy crisis.

5.2. Pollution

Major pollution problems tend to affect countries that have industrialized and urbanized rapidly with weak regulation, which is a clear forewarning for the emerging economies of Central Africa.

In 2015, three sites involved in energy production—Kribi in Cameroon, Mounana in Gabon, and Pointe Noire in Congo—as well as multiple artisanal mine sites on the eastern border of the DRC were newly registered in the UN-supported Toxic Sites Identification Program (94). In the short term, cleaning these sites and preventing pollution of larger areas is a challenge. The major toxic threats worldwide include radionucleotides, lead, mercury, cadmium, chromium, and pesticides (94). For Central Africa, this draws attention to (*a*) the future management of lead-laden city infrastructure and lead mining in southern Cameroon, Gabon, and eastern DRC (73), (*b*) clean-up costs for radionucleotide sites, (*c*) the regulation of artisanal mining practices, and (*d*) the management of effluent pesticides. Evidence of severe pollutant outcomes from misuse of mercury in artisanal gold mining precipitated the 2013 UN Environment Programme (UNEP) Minimata Convention on Mercury, signed by four Central African countries (95). Artisanal gold mining has been widespread across the region and may already have caused extensive damage to public and environmental health. Without careful attention, pesticide pollution could also become a serious issue, as peri-urban agriculture intensifies and large-scale production projects are installed on marginal lands (54). How the Central African countries will regulate pollution as they rush also to industrialize and urbanize may turn out to be a major determinant of environmental health for the region, as it has for Asian economies.

6. MECHANISMS OF CHANGE: DEFAUNATION

The environmental degradation associated with cities is highly visible in forested areas where the loss of tree cover gives a stark and immediate indication of the anthropogenic transformation of the natural habitat. However, the ecological function of a structurally intact forest is highly degraded if it has lost its wildlife (96). This extraction pressure cannot be so easily mapped by remote sensing, yet is as prevalent and potentially as catastrophic for the region as the removal of tree canopy cover. Defaunated forests will begin to alter over time in unpredictable ways that are likely to have knock-on effects on their resilience (97). However, as for the issues of deforestation and land conversion, not enough attention has been paid to the heterogeneity across the region in the ways human impacts are delivered. Subsistence-driven, village-based hunting, practiced typically by resident rural populations with low levels of technology, has a very different ecological signature in space and time to the (relatively modern) commercial hunting for high-value products, such as ivory, typically practiced by itinerant hunters with high levels of technology. The two scenarios can be teased apart for most localities and usually implicate different actors and drivers (98). Appraising the different spatial distributions and differential ecological impacts of the two types of hunting is key to an evaluation of the overall environmental damage that Central Africa is suffering through hunting.

6.1. Village-Based Subsistence Hunting

Subsistence hunting and gathering is important to forest communities with their overall health and diet quality closely related to the state of the forest (99, 100). Protein from wildlife and fish are important components of rural food security, and thus subsistence hunting is a constant pressure on forests and intensifies with high rural population densities (86). Over the past half-century, newly urban populations have lost direct access to the forest and have only limited and costly access to imported commodities in the urban centers. Their demand for forest products is aggregated by city dwelling, ensuring constant demand and inflating prices for bushmeat, which becomes a luxury of the rich in many urban areas (101). Thus, commercial markets open, providing a new revenue stream for the very poor that exploits open-access forest for negligible opportunity cost.

Although revenues are small, the commercial exploitation of forest products is often the only source of revenues for rural communities (102, 103). The returns enable rural poor to access modern services and commodities of primary necessity, such as medicines, energy, and education, making the regulation of hunting a complicated trade-off between biodiversity and economic development (104). Village hunters preferentially target medium-bodied mammal species, such as red duikers or pigs (105). Under sustained hunting pressure, a moving cline in wildlife body size occurs around the village as larger-bodied species are overexploited and over time are found further from the hunting center (106). Village subsistence hunting is limited by the mobility of hunters, and even over long periods of hunting, intense depletion tends to be restricted to a radius of <10 km from a village, although some hunting will affect forests even further away (107). As trade opportunities open up, however, hunters trade the largest and rarest species of their catch (106, 108), thus for villages with access to both markets and intact forests, hunters have an incentive to travel further, hunt larger animals and trade more of their catch, pushing the depletion envelope out from the village further and faster (108). Village hunters in all countries now trade a large proportion of their offtake directly for revenues [40–60% of biomass (97)], and villages with better market access trade more (109, 110), thus as transport infrastructure increases and urban demand increases, subsistence livelihoods will probably contain an increasing proportion of revenues from trading bushmeat and other forest products. As subsistence livelihoods tend toward commercial activity, not only do the impacts on wildlife become more severe and less sustainable, but rural food security can also decline, with families consuming less and lower quality meat in order to improve their revenues (111). In contrast to the 8 person/km^2 carrying capacity for the tree cover of forests (79), wildlife biomass in tropical forests is estimated to support only 1 person/km^2 (112), a figure that is already exceeded by all countries' total population density and by all except Gabon in terms of rural populations (**Table 1**). The demands on wildlife are too high, and in most areas hunting has become locally unsustainable, provoking declines in overall wildlife densities (113). Ziegler et al. (86) modeled the extent of subsistence hunting pressure across the Congo Basin in 2015, and Ingram et al. (114) have simultaneously developed indicators for the state of wildlife communities under long-term pressure from subsistence hunting. They find most intense pressure in the areas of high rural population density and road infrastructure. Over the past 45 years, approximately since the widespread use of guns and sedentarization of villages (115), there has been a significant decline across the region in the mean body size of captured mammals (114). Already the majority of the land area of Central Africa is under some pressure from village hunting. Within the forests, village hunting affects at least 177 wildlife species (116) and has a disproportionate direct effect on mammals (97) and larger carnivores competing for prey (117, 118). Given the likely geographic extent of village hunting pressure (**Figure 6**) and the rural population trends analyzed above (**Figure 5**), by 2050 the region will have little land, if any, left untouched by hunting, and the areas that supported traditional rural communities will no longer be able to provide for them (119).

6.2. Commercial Hunting

Ziegler et al.'s (86) assessment of the spatial patterns of village hunting indicates presumed areas of low impact in the center of the DRC, northern Congo, and northeastern Gabon, equivalent to the areas of lowest human and infrastructural density. Until extremely recently, the low human infrastructure density in these wildernesses had preserved populations of large mammals such as apes, elephants, or leopards in comparison to the eroded communities of the populated areas hunted for food (120–123). However, survey assessments of the human signs of hunting in 2012 (122) and 2013 (reported in 123) modify this picture, with medium to high encounter rates of

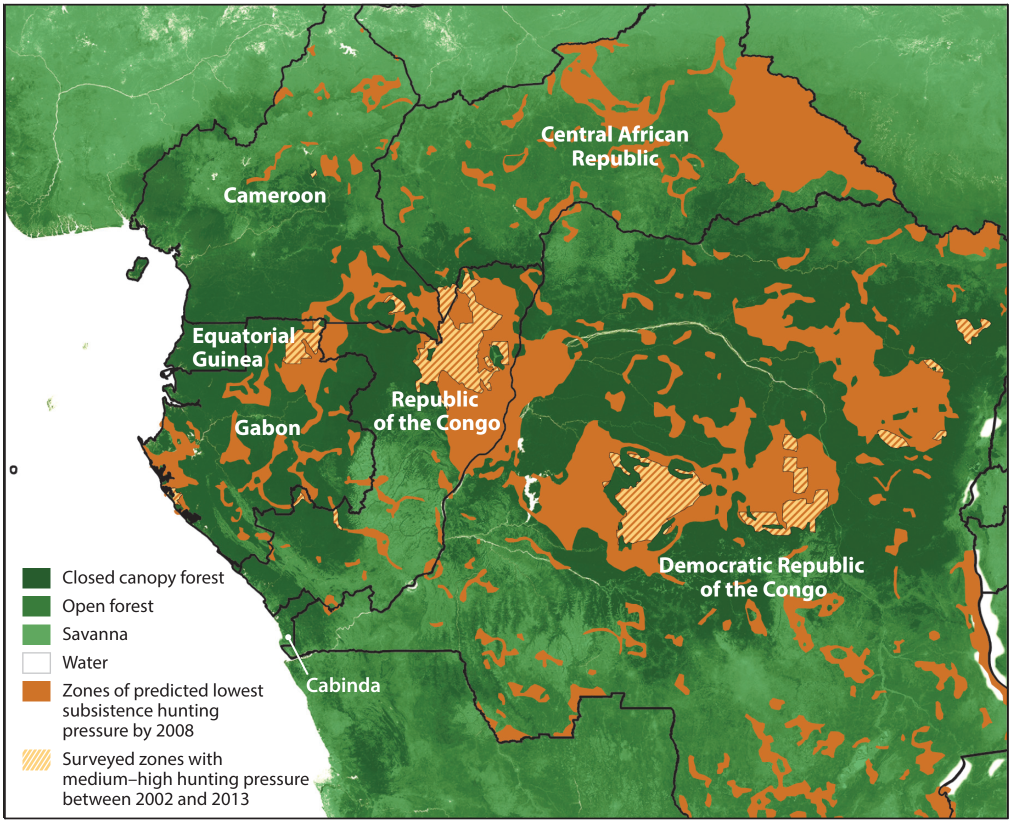

Figure 6

Extent of hunting pressure. Brown areas show predicted low to zero pressure from village hunters (2008). Crosshatching shows areas surveyed within this zone (2002–2013) revealing medium to high human hunter sign. Figure drawn from the model in Reference 86 and survey data from the Gabon National Parks Agency (2014) (unpublished data, as cited in Reference 124). Data from the International Union for Conservation of Nature and the Wildlife Conservation Society are provided as published in Reference 122. Forest cover from Google Earth: TerraMetrics TruEarth 15-m imagery (2015) (accessed via Global Forest Watch: **http://www.globalforestwatch.org**).

human sign (0.7–8.8 signs per km walked) in large areas of the predicted low-impact zone, especially in the DRC (**Figure 6**). From the mid-2000s, exploding prices for ivory and other wildlife products have attracted well-funded criminal organizations to Africa (125). Access to hi-tech navigational equipment, high-power rifles, and mobile communications enables them "free" and therefore highly profitable access to wildlife resources that command exceptional prices on international markets. Controlling external demand and export is now the most serious consideration for the survival of these species (67, 107). The 2014 London Declaration and 2015 Kasane Statement on combatting illegal wildlife trade, signed respectively by 46 and 32 nations, demonstrate widespread recognition of the severity of threat and the need for a coordinated, immediate international effort to save Africa's iconic wildlife.

Commercial hunting to date has targeted large species, although smaller species such as pangolins are now also taken for specialty restaurants and traditional Asian medicinal use (126). Modern poaching has the capacity to remove these species very swiftly and has taken at least 62% of Central Africa's elephants between 2002 and 2011 (122). Elephants can represent more than 50% of mammalian biomass in an intact Central African wildlife community (127). These megafauna have persisted until this century as functional parts of their ecosystem, but this balance is now in jeopardy and when such large species can be removed so rapidly, the whole ecosystem is left extremely vulnerable. Hunters that are driven by commercial demand tend, in the face of declining returns, to move on to other species to maintain the overall value of their supply. Once a very valuable product, such as ivory, has created a network of local traders the opportunity costs of trading other species are reduced, and so other species (or products) of less absolute value still become commercially appealing (105). The appearance of an illegal ivory trade has been the first step in the erosion of Central Africa's wilderness forests, but it is being followed by hunting and trade of other species and the establishment of semipermanent access routes and trade chains to extract resources from even the most remote zones (76). As subsistence hunting expands and becomes also partly commercially driven, there is diminishing hope that any wildlife community will be untouched within the next decade.

6.3. Ecological Change in Hunted Ecosystems

Hunting a species to local extinction, particularly a large herbivore or predatory species, causes a suite of changes as interactions in the ecosystem are modified, often in ways that are hard to predict (128). Human predators target more large and apex species in their prey than any other predator and remove the largest, healthiest individuals from a prey population, rather than the old, young, or weak (129). This translates into rapid impacts on prey populations as breeding adults are lost, decreasing population resilience to further hunting pressure. Over the past decade, the world's largest species across all trophic groups, terrestrial carnivores (130), herbivores (131), frugivores (100, 104), seabirds (132), and sea fish (133) have suffered severe population declines, altering the ecosystems they live in and leading to a stark appreciation of the consequences of defaunation (24) and the direct role of human activity in driving it (134).

Hunting in Central Africa takes high numbers of frugivores (97). Seed dispersal services are important wildlife–plant interactions in these forests, which have exceptionally high proportions of frugivorous species and trees producing zoochorous fruits. Frugivore loss has obvious consequences for trees that use them for seed dispersal. After the extinction of megafauna in Amazonia, the geographical range of animal-dispersed tree species became greatly reduced, fundamentally changing the forest's composition—and thus carbon storage capacity—as large seeded species were disproportionally reliant on large mammals (135). This relationship is still evident today in tropical forests. Changes in seed dispersal success (136), seedling recruitment (137), and sapling recruitment (138) have already been linked to frugivore declines in Central Africa (139, 140) and in turn to decreases in carbon storage (141). However, diminished seed dispersal, particularly for long-lived trees with a large number of dispersers, could be less relevant than the increased sapling choking and understory thickening, which also occurs when browsers such as elephants or gorillas are lost. On the other hand, severe sapling browsing by elephants may inhibit recruitment, even when seed dispersal is high (139, 142). Grasping the significance of rapid changes in animal populations has placed defaunation prominently on the list of critical anthropogenic factors in environmental issues for the region, but although we understand that trophic change is in motion, for many plant and animal species in Central Africa direct mortality from land conversion or hunting will alter populations, possibly eradicating them, far faster than declines from reduced ecological success. Deleterious effects of trophic disruption may only be visible for species whose generation times are short, such that population turnover is faster than the velocity of current deforestation and hunting impacts. For these smaller wildlife species, very little ecological knowledge exists from which to establish baselines. We may never see the inevitable changes in the populations or ecology of these small species, because we do not know where they are, how many there are, or what we should be looking for.

6.4. Wildlife Disease

Disease is a potent force, potentially defaunating large areas (143) and shaping wildlife communities through evolutionary time and space. The environmental pressures we have discussed above—deforestation, climate change, and hunting—have all been implicated in rises in zoonotic diseases and changes in their patterns of emergence (144–146). Pathogens of global significance, such as the Simian/Human Immunodeficiency Viruses (SIV/HIV viral group) (147), *Plasmodium* species (148, 149), or hemorrhagic fever retroviruses (150), erupted out of Central Africa in the past and now affect millions of humans and many wildlife species, but how they emerged and how future pathogens may follow them are unclear. Death tolls from Ebola in apes have been high; Ebola fever was the primary cause of ape decline between 1983 and 2000 in a large area that included Gabon and part of Congo, covering approximately 10–15% of the range of western lowland gorillas and chimpanzees (123) and most severely affecting the highest density populations (151), otherwise unthreatened in remote forest landscapes. Controversial vaccination programs may now be required to prevent local ape extinction as protected-areas borders are invisible to disease spread (152, 153), although international biosafety agreements would need to be carefully followed. Canopy disturbance has been proposed to explain the eruption of Ebola (154), and there is consensus that consumption of bushmeat has been the cause of its jump into human populations (155). Although zoonotic diseases are so evidently important biotic forces, our awareness of them in Central Africa and our attention to their potential impacts have been far from sufficient.

7. ENVIRONMENTAL STEWARDSHIP

Environmental awareness and protection policies began in independent Africa with the 1968 Algiers Convention, which recognized the continent's exceptional wildlife populations and undamaged natural habitats, lost from other continents and necessary to protect. Forty-eight African nations, including the six Central African countries, are signatories to the UN Convention on Biodiversity and throughout the past century Africa has been synonymous with large, wild animals in vast landscapes.

7.1. Protected Areas

Conservation policies in Africa have reposed mainly on laws protecting land areas or particular species and relying on government resources, with NGO aid, to enforce protection. Although protected areas have been only moderately successful in protecting functioning ecosystems (156) and have been particularly unsuccessful in ensuring a future for very large or very valuable species (157), their success in Central Africa has been relatively high compared to other tropical forests, and the Central African nations have sequestered a higher than average proportion of their land for conservation (156). Legally protected areas have, to a large extent, resisted the attribution of extractive industry permits, land conversion, and village-based hunting intrusion that have been the main agents of forest degradation across the region. However, recent evaluations of the success of Protected Areas shows that they are neither withstanding the current new onslaught from commercial poachers (123, 157) nor can they protect wildlife from ravaging disease (123, 143). As we move into the future protected areas should remain a key part of forest and wildlife conservation in Central Africa, but new paradigms are required to ensure they are more impermeable to disease and to the incursions of organized poaching.

7.2. Private Sector Initiatives and State Regulation

All six of the large forested countries in Central Africa attribute timber and mineral concessions to private sector companies across the majority of their forested area (**Figure 3**). Dependent on both government regulation and company strategies, such concessions can either extend the forest extent under sustainable management, or they can facilitate unregulated access to previously remote areas and locally increase degradation (82). Considerable effort has been made to create guidelines for sustainable tropical timber exploitation, but for species with such long generation times as tropical trees, and such complex ecosystems as rainforests, defining sustainability is elusive. Recent research to evaluate the impacts of current sustainable timber harvest guidelines have shown mixed success for policies, but have shown clearly that the Central African states do not yet have the capacity on the ground to enforce sustainability policies if the private sector is not voluntarily willing to comply (158, 159).

7.3. Civil Society

There is no history of private ownership of forested land in any of the countries whose governments own and administer more than 90% of forests (160). As traditional cultural ties to land also become weakened by modern mobility, forest dwellers are tending to choose practices that maximize short-term gains, rather than long-term security (110). In the rapidly urbanizing countries people do not see their future in rural areas, and rural community forest management initiatives have not been underpinned with sufficient security of land tenure to promote consequential private investments. Instead, as hunting and gathering livelihoods become precarious, rural populations respond with a rural exodus (Gabon, Congo) or faster forest degradation to smallholder agriculture (CAR, the DRC, Cameroon, Equatorial Guinea). Empowering local community governance has had some success in West Africa, particularly in Ghana (161), but very limited success in the Central African region (162, 163). Civil society environmental initiatives in the recent past have tended, rather unsuccessfully, to target rural livelihoods and promote small improvements in household economies (163). The massive urbanization of the region means that rural-only approaches now neglect the majority of people in the urban countries and will become less politically relevant in all countries over the next 20 years. For robust environmental security, civil society awareness of environmental issues must strengthen, and environmental performance must become important to both rural and urban dwellers and voters.

8. FUTURE TRAJECTORIES

8.1. Regional Biodiversity Loss

Hunting of large commercial species is capable of sweeping ecological change within 10 years, potentially extirpating target populations, unless international policing and price drops make the practice untenable. This will set trophic changes into motion even within protected forests, although the long-term consequences of these may be hard to identify or quantify. At current hunter densities, wildlife communities may be resilient to subsistence hunting for several decades, although over time species and ecological functions will be eroded. As growing rural populations and extended road networks enable swifter and more permanent degradation of forests, the loss of wildlife will be correspondingly faster, even under village hunting scenarios. This will drive demographic change in human populations, as traditional rural livelihoods become untenable.

8.2. Regional Forest Loss

The most perceptible environmental change within the next 10 years will probably be in the diminished extent of dense forests, as pressure from smallholder agriculture and urban halo depletion continues, driven simply by population growth and infrastructure extensions. These effects are likely to be most rapid and of largest extent in the eastern and southern DRC, and southern Cameroon, where rural population densities are highest and foreign demand for agricultural lands is also high.

Climate may well be the least visible driver of change in forest cover. Warmer temperatures and changed precipitation may provoke forest loss in areas suffering water stress but conversion of land to agriculture could by then have overtaken the forest. This will depend on the reality of infrastructural improvements, projected agricultural land suitability, and the appeal of Central African investments on the world economic stage. National economies and foreign direct investment flows will in turn depend on the socioeconomic consequences of rapid urbanization, sea level rises, health costs of industrial pollution, and the availability of sufficient energy.

8.3. Gabon and Congo

Gabon and Congo, the two clear urban track countries with high GDP and low rural populations, could retain their key forest wildlife and biodiversity in their large protected areas and managed forests, if they invest in innovative disease protection policies and international collaboration for law enforcement. Early investments and economic diversification could prevent energy needs demanding environmentally-costly solutions, given the low populations. The importance of coastal infrastructure means they also face steep challenges in protection against sea level rises, which may be the most outstanding environmental challenge yet.

8.4. Equatorial Guinea and Cameroon

Although Equatorial Guinea and Cameroon have consequential wealth, they also have large rural populations, high deforestation, and an already advanced loss of wildlife over a large proportion of their forests. It will be a considerable challenge, perhaps impossible, to reverse the current state of forest degradation. Protected areas are impacted; even internationally supported biodiversity hotspots have suffered degradation, and wildlife has a far less certain future than in Gabon or Congo. For Equatorial Guinea and Cameroon, environmental challenges rest in harnessing recent oil wealth to reduce hunting and forest degradation rates by improving rural livelihoods and, like Gabon and Congo, in responding to the pressures of sea level rise on their economic hubs.

8.5. Central African Republic and the Democratic Republic of the Congo

CAR and the DRC are very poor nations, beset with internal civil strife, receiving immigrants from the war-torn countries of the eastern Sahel and likely to receive more. Deforestation is high in the DRC where rural populations are high, and although currently low in CAR, it could become rapidly higher if refugees from the Sahelian conflicts move into the forests. These countries have poor governance, least weight in regional negotiations for foreign investments and are most vulnerable to environmental degradation driven by external commercial interests. For CAR and the DRC the challenges are in governance of rural communities and control on the demands of external investors, to ensure sustainable rural solutions and resistance to environmentally damaging industrial developments.

SUMMARY POINTS

1. The foremost issues for the Central African environment are deforestation, climate change, and defaunation, but managing pollution, energy generation, urbanization, and zoonotic disease spread are becoming increasingly important considerations in environmental governance.
2. A dire lack of empirical data collection on weather and water stresses across Central Africa is severely affecting our ability to model and understand how climate change is occurring and thus to predict and plan for the environmental changes that may ensue.
3. Overhunting for the past half-century in the Central African forests has initiated profound ecological change across the forest ecosystem leading to serious declines in large mammal species and now jeopardizes rural food security and livelihoods.
4. The enormity of the global illegal wildlife trade means that Central Africa cannot protect its iconic wildlife species if their import and use remains legal or uncontrolled in buyer countries, thus international cooperation is now imperative for the survival of several Central African species.
5. Rural population densities, overall urbanization levels, and economic wealth and stability broadly determine the environmental trajectory of the Central African countries, with three different likely pathways emerging in the region.
6. The development and formalization of the value of intact standing forests, whether that be through the REDD+ process or new innovation in governance and land use policies, will be critical to the strength of Central Africa's forest governance and the region's resistance to deforestation.

FUTURE ISSUES

1. Will the 2015 UNFCCC Paris Agreement be able to support developing nations such as the DRC to limit deforestation and secure renewable and environmentally sane solutions to energy demands and industrialization?
2. Can we muster sufficient international cooperation to save Central Africa's iconic large wildlife in the face of the current global illegal wildlife trade?
3. Will pollution, particularly from urban centers, industrial agriculture, and specific mineral production sites, become a major public health burden for Africa, as it has for Asia?
4. How and when will sea level rises impact the Central African economies and how will this change popular support for environmental planning?
5. Can innovative research and new conservation and development paradigms improve resilience to zoonotic disease epidemics for both wildlife and people?

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