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Game Over? Drivers of Biological Extinction in Africa

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Introduction

Writing in his seminal essay in *Science* on "The Historical Roots of Our Ecological Crisis" 50 years ago, Lynn White Jr. said:

"The greatest spiritual revolutionary in Western history, Saint Francis, proposed what he thought was an alternative Christian view of nature and man's relation to it: he tried to substitute the idea of the equality of all creatures, including man, for the idea of man's limitless rule of creation. He failed. […] Since the roots of our trouble are so largely religious, the remedy must also be essentially religious, whether we call it that or not. We must rethink and refeel our nature and destiny. The profoundly religious, but heretical, sense of the… Franciscans for the spiritual autonomy of all parts of nature may point a direction. I propose Francis as the patron saint of ecologists."[1]

When the article was published I was a high school freshman on the Kenyan shores of Lake Victoria. Over that decade, the western end of the Congo tropical forest had been turned into a semi-arid area. This happened largely because of rapid population growth, changes in land use, and poor government interventions.

When I was born in 1953, the population of sub-Saharan Africa was 190 million. Now, 64 years later, it stands 970 million. It is estimated to grow to 2.1 billion by 2050. This exponential growth, combined with limited economic opportunities, is hardly sustainable. Nearly 94,000 children will be added to Africa's population daily over the next 33 years. This will happen in a world that has less compassion for the poor. It will be a world in which industrialized countries will continue to defend their consumption patterns despite their global ecological impacts.

In the 1950s there were more than 500 endemic haplochromine cichlid species, with four endemic genera among them.[2] This evolutionary marvel of the world had come under tremendous pressure from human activities, and many of the species are now extinct. Many of the diverse terrestrial and riparian species were extirpated in just a decade. This personal story forms the backdrop against which this paper is written.

The paper argues that many of the drivers of species loss in Africa are unique to the continent and cannot be addressed by simply adopting lessons from other regions of the world. Demographic transitions and urbanization in other parts of the world have helped to significantly increase income levels and reduce pressure on natural systems. Africa's case is exceptional. The demographic transition is too slow and occurs with the concomitant industrial development and rapid growth in agricultural productivity. The trends offer no discernible demographic or ecological dividends. To the contrary, they amplify the extinction of many species, many of which disappear before they have been documented. The drivers of species extinction are usually exponential and non-linear whereas conservation programs tend to be linear and additive. They often have a narrow focus on protecting iconic species rather than on enacting policies to protect the wider ecosystems that support a range of species. The disappearance of these iconic species is a tragedy, but equally tragic is the extinction of other species as their habitats get lost or fragmented. Protected areas are reaching their limits as effective conservation measures, in part because many threatened species spend most of their time outside the boundaries of protected areas. Furthermore, in many countries encroachment and internal degradation are reducing those areas. As such, a new approach is needed that aligns conservation efforts with the systems nature of problem.

This paper is divided into four sections. The first section outlines some of the key drivers of species loss in Africa. The next section explores the implications of Africa's exceptional demographic trends on species survival. The

third section of the paper uses the iconic examples of the cheetah, giraffe, and gray parrot to illustrate the limits of current conservation approaches. The final section outlines conservation measures that reflect contemporary African conditions. The measures include the search for new conservation strategies, population management, technological innovation, and sustainable development, with emphasis on agricultural intensification.

1. Trends and drivers of biodiversity loss

1.1 Overview

Africa is a continent of misplaced perceptions. Most projections of continents create a false impression of the actual size of the continent. The most common is the projection first presented by the Flemish cartographer Gerardus Mercator in 1569. The cylindrical map projection became standard for nautical uses for its ability to show constant course lines (loxodromes or rhumb lines) as straight segments conserving the angles with meridians. This projection distorts the size of objects as the latitude increases from the Equator to the poles. As a result, Africa is made to look much smaller than it actually is. This would normally not be an issue, but the projection is widely used and distorts people's perception of the true size of Africa.

The continent and the surrounding islands occupy a vast region equal to the United States (minus Alaska), China, India, Western Europe, Argentina, and Great Britain combined. Put differently, it is three times the size of the United States. It is this vastness and variations in ecological conditions that historically accounted for its incredible biodiversity. This large territory also explains the challenges associated with understanding the full taxonomic extend of biodiversity.

Nearly 25% of the world's 4,700 mammal species live in Africa. The bulk of these are found in the eastern and southern savannahs. They include at least 79 species of antelope. There are more than 2,000 species of birds in Africa, accounting for 20% of the world total. Africa has more fish species (estimated at 2,000) than any other continent.[3] There are nearly 950 amphibian species. In fact, more reptile and amphibian species continue to be discovered. In the 1990s alone, discovery of new reptile and amphibian species in Madagascar alone increased their count by 18% and 25%, respectively.[4] The mainland of Africa is home to between 40,000 and 60,000 plant species, with southern Africa alone having nearly 580 plant families and about 100,000 known species of insects, spiders, and other arachnids.[5]

These figures represent estimates of the vast biodiversity of the continent. They also do not adequately show the scale of the decline of biodiversity due to lack of information. It is estimated that nearly 120 plant species have gone extinct with another 1,771 threatened.

Africa has a large proportion of the world's primate species. Worldwide, they "occur in four regions—the Neotropics (171 species), mainland Africa (111 species), Madagascar (103 species), and Asia (119 species)—and are present naturally in 90 countries; however, two-thirds of all species occur in just four countries—Brazil, Madagascar, Indonesia, and the Democratic Republic of the Congo."[6]

Africa has eight of the world's 34 biodiversity hotspots. These are defined as regions with at least 1,500 endemic vascular plant species, about 0.5% of the world's total. It must also have lost at least 70% of its historical habitat.[7] Madagascar, for example, is home to five bird families and five primate families that are found nowhere else on Earth. Its 72 lemur species and subspecies help to raise global conservation awareness. But 15 of them have gone extinct.[8]

The statistics on the distribution of species in Africa give a glimpse into the magnitude of the challenge. The vastness of the continent provides opportunities for designing large conservation areas that can support a wide array of species. But this same vastness also makes it more challenging to have a detailed understanding of the distribution of species, especially given the low level of research capacity in the region. This reinforces the view that many species are being lost before they have had a chance to be documented.

1.2 Habitat loss and fragmentation

The loss and fragmentation of habitats is a leading driver of species loss in Africa. The key force in this process is deforestation.[9] The patterns of deforestation, however, differ considerably from trends in Asia and Latin America, where large-scale agriculture has played a key role in land-use change. In Africa, two major factors drive deforestation. The first is the slow but steady expansion of smallholder or subsistence agriculture. The second is the extraction of primary products such as wood fuel, timber, and charcoal.[10] Generally "people are poorer, the extractive sectors of economies are larger, and the climate is more arid."[11]

A recent study by Rudel (2013) shows that the "most extensive clearing occurred in dry forest areas, so the countries with less dense forests and lots of arid lands unsuitable for agriculture experienced higher rates of deforestation. Consistent with Dutch disease theory, large oil and gas sector and the large-scale importing of cereals tended to depress deforestation rates, but urbanization accelerated forest clearing, perhaps because

it generated increased demand for agricultural products. In the arid environments of the countries outside the Congo basin, the countries with the denser forests and most potential for rainfed agriculture saw the most deforestation. Population growth, wherever it occurred in these countries spurred deforestation."[12]

The growth of urban populations has helped to spur agricultural expansion in areas close to cities or with good transportation connections to cities. This is illustrated by the case of Kinshasa, whose growth contributed to expansion in smallholder agriculture 400km to the north of the city along the Congo. The river facilitates shipping of foodstuffs downstream to Kinshasa.[13] The expansion of Kinshasa itself has been driven by income from raw material exports. It is one of those examples where commodity exports stimulate urban expansion, which in turn leads to growth in smallholder agriculture. It is the agricultural expansion that then directly leads to species loss.

There are, however, many regions of Africa that have experienced species loss over the centuries due to agricultural expansion independent of commodity exports. Take the case of forests in Madagascar, which are among the most biologically diverse in the world. Analysis of "aerial photographs (*c.* 1953) and Landsat images (*c.* 1973, *c.* 1990 and *c.* 2000) indicates that forest cover decreased by almost 40% from the 1950s to *c.* 2000, with a reduction in 'core forest' > 1 km from a non-forest edge of almost 80%. This forest destruction and degradation threaten thousands of species with extinction."[14]

The traditional farming methods of slash-and-burn and the low levels of agricultural yield have put pressure on natural systems, leading to extensive habit loss and fragmentation. As Slingenberg et al. (2009) point out, deforestation for "large-scale permanent agriculture is, unlike small-scale agriculture, often practised using slash-and-burn techniques. Thousands of hectares of land have been deforested this way. The converted land supports agricultural growth and delivers large harvest for 3-4 years, but then excessive use of fertilisers is necessary to yield a minimum harvest and additional land is needed for agricultural purposes."[15] The main driving force for deforestation in Madagascar and other areas over the centuries has been agricultural expansion.

These patterns are replicated in many parts of the continent where the "proximate causes of deforestation in Africa reflect the global pattern in order of importance with agricultural expansion as the main driver for deforestation with direct conversion of forest area to *small-scale permanent agriculture* accounting for approximately 60% of the total deforestation and direct conversion of forest area to *large-scale permanent agriculture* accounting for another 10%. However, also wood extraction and infrastructure play a significant role in deforestation in Africa."[16]

One of the emerging agricultural threats to biodiversity is the establishment of agro-industries such as oil palm production in tropical forest areas. So far the rate of expansion of oil palm production in Africa has been slow compared to Asia and Latin America.[17] However, an increasing number of countries with suitable habitats such as the Democratic Republic of the Congo are exploring how to expand such industries as part of their effort to diversify their economies. The main question is whether such investments can be pursued in a sustainable manner without contributing to species loss. So far much of the conservation attention has focused on the great apes.[18] However, the focus on single species could lead to the neglect of other species that could be affected by the overall fragmentation and loss of habitats.

There are many factors that contribute to the fragmentation and loss of habitats in Africa, which is a key driver of species loss. Of the drivers, agricultural expansion remains a dominant force. This is mainly because of the combination of factors such as rapid population growth, limited economic opportunities in rural areas, and high urbanization rates. Behind these trends are fundamental structural factors such as low levels of agricultural productivity and the slow pace of industrial growth in urban areas. It is unlikely that emerging trends in agricultural productivity increases and fertility reduction will occur fast enough to significantly reduce the ongoing impact of agriculture on habitat loss and fragmentation.

1.3 Invasive alien species

Invasive alien species are considered among the most significant sources of species extinction worldwide. Concern over alien invasive species is partly tied to the need to protect agricultural and forestry systems from foreign introductions that may have negative consequences. For this reason countries around have adopted phytosanitary measures aimed at restricting unauthorized importation of plants and animals. The larger challenge, however, has been about protecting the wider African environment from invasive species.

Ornamental species such as *Camara lantana*, which originated from South America, has taken root in eastern and central Africa as well Madagascar. Its impact on native species extinction in these regions is not known. However, the plant produces chemicals that inhibit germination and root elongation in surrounding plants. It is also known to be toxic to cattle, dogs, goats, horses, and sheep. Another ornamental alien species that is choking African water systems is water hyacinth (*Eichhornia crassipe*) from the Amazon basin. The plant has

invaded most of the major African water bodies. It is reducing fish reservoirs, suffocating lakes and rivers, and undermining local economies. Controlling it has been difficult because of the challenge of mechanical removal and the absence of natural enemies. Its impact on biodiversity is little known.

Many of the widely studied examples of invasive species were introduced accidentally. Some of those that have had well-documented impacts on African ecosystems were a result of deliberate release of other African species. One of the most dramatic examples of this was the introduction of Nile perch (*Lates niloticus*) into Lake Victoria.[19] The Uganda Game and Fisheries Department introduced the fish in the 1950s through a series of secretive efforts aimed at improving sport fishing and increasing fish production in the lake following overfishing of some of the commercially important species.

The premise of the program was that most of the species of small fish were of little commercial value, and the economy of the lake would be improved if these species served as feed for Nile perch. This argument did not take into account the overall consequences for the lake's ecosystem or the livelihoods of millions of people around the lake that relied on those other species for their livelihoods. Opposition to the introduction by the East African Fisheries Research Organization did not carry sufficient political weight to stop the introduction.[20]

The sudden explosion of the Nile perch population and its impact on native species coincided with other changes in Lake Victoria. The decrease in haplochromine biomass was a result of "changes in algal zooplankton composition, decreased water column transparency, and widespread hypoxia from increase eutrophication."[21] It the complex interaction of external factors that led to the rapid explosion of Nile perch with devastating consequences for other species and local economies. The sudden rate at which this occurred makes it difficult to provide a precise assessment of the impact on species composition. The impact on native species was equally dramatic, mostly between 1975 and 1982. A community of hundreds of species collapsed over a very short period and led to dependence on three species: Nile perch, Nile tilapia (*Oreochromis niloticus*), and omena (*Rastrineobola argentea*).[22]

The ecological consequences of the introduction of Nile perch extended to terrestrial ecosystems. The flesh of the fish is oily and spoils quickly without refrigeration. Traditional sub-drying methods used for cichlids did not work with Nile perch. Smoking it resulted in more pressure on already diminished forests around Lake Victoria. Little is known about the loss of species associated with extensive deforestation to secure wood for smoking the fish.

When refrigeration facilities became available, they were used for storing fish for shipment to urban areas and not for local consumption. In addition to being sold in urban hotels, the fish was also exported to Europe and Israel. The imagery of a new export from Lake Victoria concealed a more disturbing local picture. First, the large fish destroyed nets used by local fishermen that had been designed for smaller fish. In addition, the small-scale subsistence fishery that focused on the native cornucopia took a severe beating, with most species simply disappearing from the marketplace."[23] Fishing Nile perch required heavier and more sophisticated equipment, which most local fishermen could not afford. Thus as fish biomass increased, so too did poverty and malnutrition among artisan fishermen.

The story of the impact of Nile perch introduction in Lake Victoria has been complicated by the resurgence of species that had been considered extinct. Part of this resurgence can be explained by overfishing of Nile perch and a return to coexistence with native species in some parts of Lake Victoria. But a more profound point here is that some of the debate may have arisen due to the lack of adequate taxonomic information of the species the lake. As noted by Witte et al. (2007), until "the 1970s, the fish fauna of Lake Victoria in East Africa was dominated by about 500 endemic haplochromine cichlid species, which comprised about 80% of the demersal fish mass. The cichlids were extremely diverse ecologically; however, the small diversity in gross morphology and the presence of intraspecific variation made it difficult to distinguish among species."[24] This ignorance, confounded with knowledge uncertainty, suggests that extirpation may have occurred in many parts of the lake before the species were even known.

1.4 Illegal hunting

International efforts to regulate and reduce illegal hunting are some of the most visible features of the conservation movement. The focus on illegal hunting has more recently received more attention with studies showing that organized criminal syndicates are involved in trafficking wildlife. The total value of global environmental criminal activities was estimated at the high end US$258 billion for 2016, of which illegal trade in wildlife accounted for up to US$23 billion.[25] Illegal trade in large mammals from Africa such as elephants and rhinos has received most of the attention.

Much of the attention given to these species is linked to the fact they are also the symbols of protected areas and are part of different efforts to sustain trade in tourism. The pressure for trade in ivory and rhino horn is often in conflict with interest to conserve wildlife to support the tourist industry. These differences, for example, are

reflected in tensions between eastern African and southern African countries in various international forums, especially under the Convention on International Trade in Endangered Species (CITES).

The patterns of African international wildlife trade have shifted considerably in the last few decades. Historically, much of the trade was with the United States and Europe, regions that also championed the existing international wildlife trade norms. More recently, Asian countries, particularly China, have become major destinations of wildlife products from Africa. This shift is associated with wider changes in Africa's trading patterns under which China has become the largest trading partner with the continent. China and other Asian countries, however, have not had a long tradition of regulating international trade. Recent efforts to bring China to the negotiating table appear to have yielded some diplomatic victories with the announcement that the country will stop local ivory trade by the end of 2017. It will do so by shutting down registered carving centers. It is not clear whether this will have an impact on illegal international trade as the bulk of it is conducted through the black market.

But behind these trade concerns lie more serious challenges related to the overall impact of hunting on ecosystem degradation and loss of species. The real issue is to understand the forces that make elephants, rhinos, and other species susceptible to extinction. There is a growing body of literature showing that illegal hunting is causing trophic alterations in African forests in ways that increase pressure on a large number of species, most of which have not been documented. Recent studies, for example, show that hunters have access to all of Central African forests. Because of their activities, "trophic webs are significantly disrupted in the region, with knock-on effects for other ecological functions, including seed dispersal and forest regeneration."[26]

The hunting patterns in the forest have dramatically changed in character from traditional practices. A combination of the use of heavy weapons and an increase of access routes due to infrastructure and natural resource exploitation have significantly increase the pace of the degradation of trophic webs.[27] Ecological transect surveys show evidence of hunting such as "snares, gun cartridges and hunting paths, which suggest that hunters are penetrating up to 40km into the forest from the nearest access point such as roads and rivers."[28] The problem is worsened by increasing expansion of road networks without complementary investment in regulation and conservation efforts.[29] Between 2002 and 2011, for example, forest elephant population in the region dropped by 62%. Nearly 90% of the carcasses found during surveys and by guard patrols in Central African protected areas in 2011 showed that they had been illegally killed.[30]

Many of the species that are extirpated play important roles in dispersing seed.[31] The majority of the animals that are hunted for bushmeat are seed-dispersing frugivorous mammals. Their disappearance also leads to the loss of trees whose recruitment depends on them. The cascading effects extend to the species that depend on those trees. Without this function, forests become increasingly degraded leading to the loss of other species. Leopards, which sit at the apex of the food chain, have already been lost in areas where their prey is heavily hunted for bushmeat.

The Central African forest case illustrates the importance of taking a more inclusive and system-wide approach when examining the impact of illegal hunting on species extinction. The loss of iconic species such as elephants, rhinos, and great apes are indicators of serious impacts of hunting on ecosystems that lead to unobservable loss of species but can be inferred from the degradation of trophic webs. Much of the loss also occurs outside protected areas, requiring a different approach to conservation.[32]

1.5 Changing climate

Changing climate has added new uncertainties to Africa's biodiversity. Until recently the implications of changing climate for African biodiversity received little attention. The fact that the international community spent decades focusing on mitigation measures tended to downplay the potential impacts on biodiversity. Early attempts to bring adaptation measures to the global agenda did not receive the attention they deserved, especially from African perspectives.

There is considerable uncertainty over how changing climate might affect Africa's biodiversity. But there are also important lessons that can be learned from past experiences of the interactions between drought, population growth, and species loss. One of the most dramatic examples of ecosystem degradation in the last few decades was the shrinking of the surface area of Lake Chad, the sixth largest lake in the world.[33]

The lake straddles the borders of Cameroon, Chad, and Nigeria. It provides water for nearly 30 million people in the semi-arid Sahel region. Its overall basin is the largest endorheic basin in the world covering 2.5 million square km, or about 8% of the African continent. From the early 1960s to the 1980s the lake shrunk from 22,000 square km to 300 square km.[34]

Much has been written about the socioeconomic impact of the crisis. But little of it shows the extent to which such a sudden loss of the coverage of the lake affected biological systems in general and species loss in particular. There are various accounts of fish species in the lake but not much else.

The main lesson from this case is that prolonged drought reduced the water flowing into the lake. The same drought and population growth pushed people in the catchment area to expand irrigation. This further reduced the flow of water into the lake.

In 1972, the lake split into two because of severe drought and its unique bathymetry. The two lakes were separated by a 40km barrier. The southern lake is shallower and therefore more susceptible to evaporation. To restore the lake level, enough water would need to flow into the southern lake to overflow the barrier and replenish the northern lake. But this has been compromised by drought and irrigation. Simulation studies have shown that the failure "of the lake to merge back into a single lake following wetter conditions in the 1990s is the result of irrigation withdrawals—without irrigation, the lake would have merged in 1999, although it would have split again in 2004."[35]

Little is known about the impact of the split on biodiversity in the lake. On the higher end, 179 fish species have been recorded in Lake Chad. Historical studies show that that fish species were less diverse in the northern part of the lake. Species reductions were observed during the period of the drought. After the split, for example, most of the *Synodontis* species disappeared in the northern lake. Their numbers were also later diminished in the southern lake. The drought also changes the composition of fish species by favoring marshy species that are adapted to surviving in low-water environments, low dissolved oxygen, and high temperatures. The loss of fishing grounds had a dramatic impact on people with limited options for economic diversification. There is considerable land use conflict between fishermen, herders, and farmers in the lake area.[36]

The cascading impact of the shrinking of the lake extends to terrestrial species in the region. Birds have been affected by the declining water levels. Examples of the impact include reductions in nesting sites for the endangered West African subspecies of the black-crowned crane (*Balearica pavonina pavonina*) and inadequate availability of wintering grounds for the intercontinental migrant ruff (*Philomachus pugnax*).

The case of Lake Chad uses drought as a proxy for simulating the potential impact of changing climate on species extinction, especially in cases where such impacts are amplified by human activity such as an increase in water withdrawal to support agricultural activities. A growing body of evidence shows how over time warming climates are contributing to species loss in African lakes.

Historically, species extirpation has often been attributed to human activities. But in the case of Lake Tanganyika, Africa's deepest and oldest lake, a 1,500-year paleoecological record shows that the decline of fishery species and endemic mollusks began long before commercial fishing.[37]

Paleoclimate and instrumental records show sustained warming of Lake Tanganyika over the last 150 years. "Late-20th century fish fossil abundances at two of three sites were lower than at any other time in the last millennium and fell in concert with reduced diatom abundance and warming water."[38] As a result, the study shows that climate warming and intensifying stratification most likely reduced potential fishery production. This helps to explain the decline in fish catches.

Lake Chad offers important heuristics on what to expect. Drought alone was not a sufficient explanation for the shrinking of the lake. But the same drought combined with population growth led to the adoption of inefficient irrigation practices that compromised the replenishment of the lake. No viable options exist on restoring the lake, including proposals for inter-basin water diversion, which have turned out to be too expensive.[39] Lake Tanganyika, on the other hand, provides evidence of the long-term implications of changing climate on species extinction.

2. Population dynamics and biodiversity loss

Population growth is acknowledged as one of the drivers of species extinction. There is, however, a general tendency to view the impact of population through the lens of trends in the industrialized world where fertility rates are low and there has been a long history of decoupling between population growth and direct use of natural resources. The situation in Africa is exceptional because of the low pace of the demographic transition and unique patterns of urbanization that continue to exert pressure on natural resources in rural areas.

2.1 Demographic transition

Africa's rapid population growth of 2.55% per year is emerging as a key global policy theme. More than half (1.3 billion) of the 2.4 billion people added to the global population by 2050 will be in Africa. By 2050 Africa will be adding 42 million people per year, bringing the total population to 2.4 billion, double its current size.[40]

This is the equivalent of adding today's population size of Sudan to the continent annually. Africa alone will contribute nearly 54% of the 2.37 billion population increase projected by 2050.

Africa has a relatively young population with a media age of 19.5 years, compared to a world median age of 29.5 years. There are major variations in the age structure of African countries. South Africa has the highest median age of 20 years while Niger is the lowest at 15.1 years. This age structure compounds the dependence problem, with a small section of the adult population being expected to support a large youth population with limited skills and employment opportunities to contribute to household income.

The persistence of dependence in the age structure is also reflected in leadership with the youngest continent having on average some of the oldest leaders. There are many factors that contribute to the persistence, but there is a clear pattern of a slow pace of political transition to younger leaders whose ideas, at least in theory, would be more aligned with the age structure. This point has ecological relevance because the ethical values that governed interactions with the environment in the past may not be relevant in the age of rapid ecological degradation.

Much of the policy concern about this rapid growth has more been on its future economic consequences and less on its current implications for biological extinction. The main area of interest in international policy circles has been whether this rapid growth will be accompanied by high rates of economic growth or demographic dividend that have historically been recorded in other regions of the world.

Under past scenarios, reductions in child mortality followed by a fall in fertility resulted in a bulge of working-age people and a relatively lower number of dependents. Where employment opportunities existed, high numbers of workers per capita spurred economic growth. Smaller families also allowed individuals and governments to invest in education and health, thereby improving overall labor productivity.

The labor productivity boost is reinforced by savings for retirement arising from increased lifespans. The demographic transition also frees up women to join the labor force, thus expanding income opportunities for families. The full benefits from the transition usually arise from supportive government policies and the development of financial markets.

Contemporary Africa, except for a few countries, doesn't show signs of a demographic dividend. To the contrary, fertility and youth dependency rates are among the highest in the world. The result is "higher poverty rates, smaller investments in children, lower labor productivity, high unemployment or underemployment, and the risk of political instability."[41]

There is evidence of fertility declines in various African countries, especially in urban areas. But the shifts are not occurring fast enough to reduce unemployment. Unlike Asia, which relied on export-led strategies, African countries play an insignificant role in global industrial markets.

There are a number of immediate ecological implications of this scenario. First, African countries continue to depend heavily on agriculture, which accounts for 60% of employment.[42] Much of this agriculture still relies on traditional farming practices that result in habit loss and degradation. The impact is often more severe in semi-arid areas with fragile ecosystems. These regions have also historically been the habitats of much of Africa's biological diversity.

Second, protected areas have increasingly come under pressure from agricultural expansion as well as illegal hunting. Human settlements around protected areas are also limiting wildlife migration, resulting in land-use conflicts.

In fact, much of the early post-colonial migration in countries such as Kenya was rural-rural migration. This pattern continues today in various regions due to limited urban employment opportunities. The problem is compounded by the prevalence of educational systems that hardly impart any new skills. Even if they did, the infrastructure needed to support rural industries is missing in most places.

The key policy challenge arising from this slow demographic transition is its short-term and long-term ecological implications. In the short term, the bulge is putting pressure on biological diversity and contributing to extinction. In the long term, the same pressure may undermine the prospects of a more sustainable transition with ecological dividends that could have arisen from reduced pressure on ecosystems.

2.2 Urbanization

Africa is one of the fastest urbanizing regions in the world. Under the classical scenario, this should lead to an ecological dividend as people leave rural areas, creating opportunities for conservation. Cities are meant to offer agglomeration efficiencies that reduce pressure on the countryside. The situation in much of Africa, however, tells a grimmer ecological story.

Other than the capital cities, most urbanization occurs in smaller centers in rural areas with ready access to natural resources. Trade makes it possible to support the centers through food and bioenergy extracted from forests and woodlands.

There are, however, significant variations in how urbanization affects deforestation across Africa. The variations are accounted for by the nature of national economies as well as the types of forest systems in the regions. As Rudel (2013) points out, deforestation "rates tend to be higher in countries with little potential for rainfed agriculture, less dense forests, small oil–mineral sectors, little reliance on imported cereals and more urbanized populations. Similar analyses of only countries with predominantly dry forests finds more rapid deforestation in dry forest countries with more potential for rainfed agriculture, more dense forests and rapid population growth."[43]

Demographic transitions in other regions involved the movement of surplus labor arising from the growth of agricultural efficiency. This coincided with demand for labor in urban areas. Agricultural mechanization also meant that some of those migrating to urban areas had basic skills that could be deployed in industry.

This is not the general pattern in Africa. Many of those migrating to urban areas are victims of agricultural stagnation or land degradation. Land subdivision among large families, for example, results to ownership of land parcels that are too small to support a family.

According to Lall et al. (2017) cities themselves are "trapped in the production of nontradables for local markets. As the African economies attain 60 percent urbanization, their share of manufacturing in GDP stays flat (or somewhat falling) at about 10 percent. In contrast, the manufacturing share of the non-African economies rises from 10 percent to nearly 20 percent (falling back only when urbanization exceeds 60 percent)."[44] The cities are thus disconnected from the rest of the world, partly because of their low levels of manufacturing capabilities, poor infrastructure and lack of effective urban planning that generates economies of scale.

A large proportion of African cities are slum settlements. For example, nearly 60% of Nairobi's 2.5 million people live in 200 slum settlements. Kibera, Africa's largest slum, has a population of 250,000 people. Lack of access to basic infrastructure, especially electricity, is one of the defining features of such slum areas. Access to "electricity reaches only 16 percent of African citizens, compared to 41 percent in other developing countries. Average power consumption is 124 kilowatts per capita, or 10 percent of that in the rest of the world."[45]

The bulk of the population in African cities relies on charcoal as a source of cooking energy. It is a major traded commodity that supports employment in sourcing areas. Much of this is produced using earth-mound kilns with a maximum conversation efficiency of 12%. The IEA estimated that in 2012 about 36 million tonnes of charcoal were produced in Africa valued at US$11 billion. This figure is projected to rise to US$70 billion in 2040.[46] The charcoal business is so lucrative that in parts of Kenya and DRC organized groups control it and use the revenue to fund militias.

Little is known about the ecological impact of deforestation associated with charcoal production. Wood cultivation and kiln efficiency improvements are unlikely to keep up with the demand for charcoal arising from urban growth.

The prevalence of bushmeat consumption in urban areas is another example of the impact of Africa's urbanization.[47] Both large and small town in west and southwest Africa are fueling bushmeat consumption. The demand is also driven by the emergence of cities whose growth is fueled by raw material exports. Africa's largest bushmeat market, for example, is in Angola. Livestock production in these areas has not kept pace with population growth and demand for bushmeat has soared.

One of the least studied features of urbanization is the persistence of food tastes acquired in rural settings. Many of the slum settlement in urban Africa tend to include people from the same regions or ethnic groups. They bring to these communities their rural practices and often serve as markets for forest and agricultural products from their regions of origin. Recent conflicts in Angola forced local people to resort to bushmeat. This created supply routes that go into the Congo. These are also the same routes that support illicit trade in ivory.

There is evidence that fertility rates are falling across Africa. They are dropping at a faster rate in urban areas. There has also been marked interest among African governments to improve urban infrastructure and expand access to electricity. Similarly, there are indications that agricultural productivity is rising is some parts of Africa, and the proportion of those engaged in agriculture is falling. The question is whether these changes will happen fast enough to help reduce pressure on natural ecosystems and deliver an ecological dividend. The exponential range of population growth, the sudden impacts of many of the pressures, and the irreversible trends already in motion suggest that the prospects of an ecological dividend are quite slim for much of the continent.

3. Game over? The disappearance of iconic indicator species

Much of the conservation effort across Africa has relied on highlighting the fate of iconic species, mostly large mammals such as elephants, to call for stricter protection of endangered species. The focus on individual species has historically been accompanied by efforts to maintain protected areas as a key method for reducing species loss. These two approaches have their validity, but today's situation calls for a different approach. The iconic species are important in their own right. Their loss is a tragedy. But what is worse is that the forces driving them to extinction are also affecting many other species that are being extirpated before they have even been studied.

The cases of the cheetah, giraffe, and grey parrot illustrate the need to view such iconic species as indicators of a much larger challenge that require a different conservation ethic. The focus on individual species and protected areas need complementary measures that take into account the need to view conservation from a more systemic perspective and to acknowledge that today's ecological crisis is qualitatively different from the conditions that led to the creation of the national parks model. These examples also underscore the fact that the forces that lead to species extinction are exponential and non-linear but most conservation efforts tend to be incremental and hardly keep with the pace of ecological degradation.

3.1 Cheetah

In a dramatic display of conflict between humans and wildlife in Africa in 2013, herders in Northeastern Kenya chased down and caught two cheetahs responsible for killing their goats. The men dutifully presented the cheetahs to wildlife authorities seeking compensation for their goats. Nowhere in the news was there a discussion of the underlying sources of the conflict, especially the loss and fragmentation of cheetah habitat or loss of prey due to human activity.[48] Even more alarming is the lack of appreciation that the fate of the cheetah was linked to wider patterns of ecological change and species loss that hardly received public attention.

The world cheetah population is estimated to be 70,100 adults and adolescents across 33 populations in Africa and Asia. The bulk of the cheetah population is found in Africa, where they live in 30 fragmented populations confined in only 13% of their historical distribution range. Much of this range (77%) is unprotected land supporting nearly 67% of the cheetah population.[49] The cheetah is thus exposed to multiple human-induced threats that include "prey loss caused by overhunting and bushmeat harvesting, habitat loss and fragmentation, and illegal trade."[50]

Much of the information available on the cheetah population is based on surveys carried out in protected areas. But since most of the cheetah live outside such areas, the assessments provide a limited overall information and declines are likely to go unnoticed. The challenge is compounded by the fact that cheetah are elusive and wide-ranging.

In Zimbabwe, for example, cheetahs lost 63% of their distributional range between 2007 and 2015, an annual decline of about 11%. The cheetah population dropped by 85% between 1999 and 2015.[51] This is an annual decline of 13%. Much of this loss was due to land use changes in unprotected areas. In other parts of Africa the range contraction is a result of changes in land tenure, land grabs, large-scale fencing, and political conflict.

Overall, it is estimated that the cheetah range in Africa has contracted by 89%, from 25.3 million square km to 2.7 million square km. The annual contraction rate is estimated at 2.26% over the last 100 years.[52] Today cheetahs only persist in 10% of its historic range. They have been extirpated in their historical range in Cameroon, DRC, Ghana, Guinea, Ivory Coast, Mauritania, Nigeria, Senegal, Tunisia, and Western Sahara.

Southern Africa is home of the largest regional cheetah presence with a population of 4,190 adults and adolescents in 10 subpopulations, of which the largest has 3,940 individuals. Their range spans Botswana, Namibia, northern South Africa, southwestern Mozambique, and southwestern Zambia. The estimate for eastern Africa is 1,960 and 440 for western, central, and northern Africa.[53]

Illegal international trade is adding more pressure on the cheetah. The main source of cubs for pet trade is eastern Africa and the Horn region, with the Gulf States being the main destination. Customs officials have reported up to 70% of transit death. Some of the cheetahs come from conflict areas such as Somalia where criminal syndicates operate illegal trade in ivory and charcoal.

3.2 Giraffe

The rapid disappearance of the giraffe is an illustration of the critical conservation challenges facing Africa. Effective conservation measures require reliable knowledge about the status of a species, scale of the threats, and confidence in institutional preparedness. In the case of the giraffe, the scale of the threats is only starting to unfold. This is compounded by the scientific discovery that there are in fact four giraffe species, not one. This reinforces the view that species are going extinct before they are documented. Taxonomic revisions also create operational uncertainty in the conservation community.

The giraffe stands out as one of the most iconic African animals. It is an emblem of the African savannah and woodlands. Its long neck inspires people to cross the limits of conventional thought. When Pliny the Elder (25-79 AD) encountered the ostrich for the first time, he proclaimed that the new creature must by a cross between a gnat and a giraffe. When the giraffe arrived in medieval China in 1413, it was considered to possess the characteristics of a cross between a horse and a dragon (or *quilin*). The reasons for the rise of the long neck were a puzzle for early evolutionists.

Giraffes have gone extinct in Burkina Faso, Eritrea, Guinea, Mali, Mauritania, Nigeria and Senegal. They inhabit 18 countries (Angola, Botswana, Cameroon, Central African Republic, DRC, Ethiopia, Kenya, Mozambique, Namibia, Niger, Somalia, South Africa, South Sudan, Tanzania, Uganda, Zambia and Zimbabwe). They have been reintroduced in Malawi, Rwanda and Swaziland. The South African giraffe has been introduced in Senegal.[54]

Giraffes now live in fragmented populations in noncontinuous habitats ranging from woodland to desert regions. The fragmentation is reflected in the general decline in their sizes. The general threats to giraffes include habitat loss, conflict, illegal hunting, and land-use change. Overall, the giraffe population has dropped from 140,000 in the 1990s to less than 80,000 today.[55]

The giraffe has been known to be one species with several subspecies based on their coat patterns and habitats. This formed the basis for assessing their population status and designing conservation strategies.

But recent genetic studies now show that there are four giraffe species rather than one. The study is based on the existence of four distinct lineages that do not interbreed in the wild. These generic differences exist despite the giraffe's high mobility, which increases their chances of interbreeding. The study used 190 biopsies of giraffe skins to analyze their mitochondrial DNA. They were found to be distinct, suggesting that they were four different species.

As a result, the study recommends replacing the current species name, *Giraffa camelopardalis*, with four new ones. These are: the northern giraffe (*G. camelopardalis*) found in eastern and central Africa; the reticulated giraffe (*G. reticulata*) found in Kenya, Somalia, and southern Ethiopia; Masai giraffe (*G. tippelskirchi*) found in Kenya, Tanzania, and Zambia; and the southern giraffe (*G. giraffa*) in Botswana, Namibia, and South Africa. This leaves out subspecies, the Nubian giraffe (*G. camelopardalis camelopardalis*) of Ethiopia and South Sudan.[56]

These findings and proposals have two major implications. First, they underscore the fact that we are losing large numbers of species before we have had a chance to identify them. This case suggests that the taxonomic work is larger that we imagined it. In addition to documenting new species, work is also needed to reassess some of the documented species. An example of this was the 2010 study that used DNA analysis to show that there were two species of African elephants: savannah elephants (*Loxodonto africana*) and forest elephants (*Loxodonto cyclotis*).

The second implication is the realization that the individual giraffe species are each under greater threat of extinction given their small numbers. This demands a change in conservation strategies, some of which may be resisted. In the case of the elephant it has been argued that splitting the species would lead to the neglect of hybrid elephants.

3.3 Grey parrot

The catastrophic decline of the grey parrot (*Psittacus erithacus*) in Ghana over the last few decades illustrates how international trade, human population growth, local economic factors, and habitat loss interact to drive species loss. Like the fate of other iconic indicator species, the case of the grey parrot provides a lens through which to examine the loss of many other species irrespective of their place international trade.

The grey parrot is known for its long lifespan and remarkable ability to mimic human sound and interact with its owner. These attributes have made it an ideal pet that is traded globally. But these qualities have also made its survival vulnerable. The process of its decline has also exposed how other human-induced forces such as deforestation drive species loss.

Examining the demographic and economic context of Ghana is essential in understanding some of the pressure points that have influenced the decline of the grey parrot. Between 1970 and 2010 Ghana's population grew at an annual rate of 3%, rising from 8.5 million to 24.2 million people. This growth occurred at a period immense economic hardship for the country, which operated under the austerity programs imposed by the World Bank and the International Monetary Fund.

The lack of industrial growth over the period led to heavy reliance on expansive agriculture and extractive forestry. The high population growth shortened fallow periods and increased demand for land. Forest cover, a critical habitat for the grey parrot, dropped from 74,480 square km in 1992 to 49,400 square km in 2000.[57]

The extensive felling of large trees to remove overmature trees as part of the national forest management policy compounded the problem. Those same tall trees were where the grey parrot typically nested. It is not known how many other species were affected by these practices, but the impact on the grey parrot is an indication of the possible impacts.

The impact of logging on grey parrot population extended beyond forest areas. About 70% of the people interviewed reported that the parrot nested and roosted outside the forest. The parrot preferred to nest and roost in tall trees such as *Terminalia superba* and *Ceiba pentandra*, which are commercially important species.[58] Over half of the timber harvested in Ghana in 1972–92 occurred outside the forests. Farmers had no legal rights over trees on their land and were not compensated by licensed loggers from any damage caused to their crops during felling. The practice resulted in preemptive felling of large trees from farmlands by farmers outside forest areas.[59]

The historical distribution of the grey parrot covered much of Ghana's forest zone, estimated at 75,000 square km. This included "the whole of Western and Central Regions of the country, nearly the whole of Ashanti Region as well as the semi-deciduous forest areas of Brong-Ahafo Region, the western part of the Eastern Region, and parts of the Greater Accra Region."[60] The parrot also existed in the riparian forests of the northern region's savanna zone.

The combined impacts of trapping for trade and habitat loss have resulted in the loss of 90–99% of the grey parrot in Ghana since 1992.[61] The population collapse drove trappers into other economic activities such as farming, while others switched to trapping other species or migrated to continue the practice in other countries.

The case of Ghana is not unique. There are signs that trade in the grey parrot from DRC to South Africa, which imports nearly 10,000 birds annually, is declining possibly due to population reduction and trade restrictions. The historical destination of the grey parrot was Europe, the United States, and the Middle East, but more recently China has been added to the export market.[62]

In conclusion, the reason that we are finally able to see the obvious loss of the tallest land mammal is because of the degradation of ecosystems and the loss of many other species. The fact that we can now pay attention to the fate of the cheetah, and even discover that it does not have the endurance of human runners despite being the fastest land mammal, is because its habitats have been destroyed and its prey depleted by human activity. The same is true of the grey parrot, whose habitats are being decimated and its numbers depleted by trappers for trade. Behind these iconic examples lie deeper concerns about the disappearance of species before they have even been documented. The species are special cases in their own right. But more importantly, their decline is a sign of a much deeper problem that demands a change in the way we think about the relationship between humans—especially those rendered vulnerable by economic forces—and other equally vulnerable species.

4. Options for stemming biological extinction

4.1 In search of new conservation approaches

Africa's species loss is usually lumped together with trends from other regions to create global overviews. But as this paper argues, the African situation is exceptional in many respects and requires special consideration. It is possible that many of the proposals put forward to address species extinction in Africa can be applied to other regions of the world. Such convergence is likely, but it is not a reason to ignore the unique features of the African crisis and craft approaches that reflect its contemporary circumstances.

The first critical starting point is to question the underlying thinking behind Africa's conservation efforts. The fundamental thinking that Africa inherited in the 19th century was shaped largely by prevailing European worldviews. At its core lay ideas such as the supremacy of humans over other species, Cartesian ideas that supported the creation of isolated protection areas (PAs), and reductionist views that focus on individual species rather than ecosystems. The PAs are also largely national, and therefore the movement of wildlife is constrained by political boundaries. Protected areas that are based on these principles have not effectively protected species.

As the examples of the cheetah, giraffe, and gray parrot show, no conservation program can work well without taking into account the importance of spaces outside protected areas, which are critical to the survival of wildlife. The effectiveness of protected areas for forests in East Africa show mixed results.[63] According to a study by Pfeifer et al. (2010), "the most successful PAs were National Parks, although only 26 out of 48 parks increased

or maintained their forest area (i.e. *Effective* parks). Forest Reserves (*Ineffective* parks, i.e. parks that lose forest from within boundaries: 204 out of 337), Nature Reserves (six out of 12) and Game Parks (24 out of 26) were more likely to lose forest cover. Forest loss in buffer zones around PAs exceeded background forest loss, in some areas indicating leakage driven by *Effective* National Parks."[64]

New conservation approaches need to integrate humans and other species in ways that reflect the African context. The general expectation of low conflict between wildlife and humans was based on the assumption that species richness declined and human impacts rose with primary productivity. But as Balmford et al. (2001) showed, "human population density is positively correlated with species richness of birds, mammals, snakes, and amphibians. This association holds for widespread, narrowly endemic, and threatened species and looks set to persist in the face of foreseeable population growth."[65]

This findings lead to the need for acknowledging that enlightened coexistence between humans and other species is possibly the best way to pursue a new approach to conservation. So far efforts to promote such coexistence have not worked well. This is partly because they were not designed to earn community trust, which is problematic given the history of conservation activities in Africa. A more inclusive philosophy that acknowledges the needs of both humans and wildlife must be developed.

The conservation challenges facing Africa transcend national boundaries. Until recently there were limited mechanisms for promoting transboundary efforts, except where each program is negotiated by the participating countries. Today, Africa is negotiating new regional integration arrangements that allow countries to maintain their autonomy while being able to engage in trade across national boundaries. These negotiations are founded on the existence of eight Regional Economic Community (RECs).The RECs have been designated by the African Union as the building blocs for economic integration. The RECs might offer Africa new opportunities to rethink how to design transboundary conservation measures, which are essential for species survival.

A regional conservation approach would also provide opportunities for governments to agree on large protected areas that could support wide-ranging wildlife or sites that require special protection. Some of these areas could be designated as public trusts because of their critical role in species survival. Many of such areas, for example, the migration routes for wildebeest in Kenya and Tanzania, are threatened by habitat fragmentation and loss.

4.2 Population and species survival

There is ample evidence that Africa's exceptional population dynamics amplify the pressures of species survival. Africa has not demonstrated the kind of demographic transition that other regions of the world have gone through. In addition, its urbanization trends do not necessarily relieve pressure on rural resources. In some case, they even worsen the situation. There are, however, signs of reductions in fertility, mostly in urban areas. Emerging evidence also shows improvements in agricultural productivity, especially in those countries that have increased R&D funding over the last decade. These positive signs are not a reason to discount the need to address population growth. To the contrary, the evidence from urban areas suggests approaches for expanding population management programs in rural areas.

One of the critical features of African fertility trends has been the organization of households as economic units with children providing a wide range of inputs from labor to care. Given the low level of the use of labor-saving technologies, children become a key component of the survival of families as economic units. High fertility rates were an essential strategy for ensuring that at least enough children would survive to sustain the family economy. But with advances and availability of medical care and cultural persistence, mortality rates have fallen while fertility rates, especially in rural areas, have remained high relative to other regions of the world.

There are, however, other factors that contribute to high fertility rates. As Dasgupta and Dasgupta (2016) point out, "patrilineality, weak conjugal bonds, communal land tenure, and a strong kinship support system of children, taken together, are a broad characteristic of the region. In principle they provide a powerful stimulus to fertility."[66] These factors operate under conditions where women have limited rights over key assets such as land. They generally have diminished voices despite the fact that they carry the burden of raising families.

A faster demographic transition is important because of the income gains it confers to families. The benefits of the demographic dividend are directly reaped by families that delay the birth of the first child, optimize birth spacing, and curtail the total number of births. These choices help to improve health, enhance work opportunities for women, raise the health and educational standards of children, and increase household incomes and savings.[67] Policies that "allow families to make informed decisions and provide the means to implement these decisions are critical. Gender equality is an important part of decision making regarding family size because women bear most of the direct costs of childbearing. All of the policies for accelerating the transition are worthwhile regardless of the potential demographic dividend and independent of their effect on fertility. A healthier and better educated population with the ability to make choices about family structure is an inherent good."[68]

Overall, “policies in three key areas would help to accelerate the fertility transition and increase the demographic dividend: reductions in child mortality, increases in female education, and improved access to comprehensive family planning services. Improvements in these three areas are desirable regardless of the potential economic payoff s, but they should receive even higher priority than they do today.”[69]

Such policies will not automatically result in a demographic dividend. Complementary economic policies that focus on industrial growth, agricultural improvement, skill enhancement, and capital market development are essential for bridging the gap between the promise and realization of the demographic dividend. In many cases, urgent measures need to be put in place to align educational institutions on contemporary and emerging market needs.

Similarly, new policies are necessary to help facilitate the sustainability transition needed to reduce species loss. Planning for overall economic development must take into account ecological consideration. So far policies aimed at promoting demographic transition have been the preserve of national governments. Measures needed to promote species survival, however, are likely to involve groups of countries through the various RECs. It is at the regional level that African countries can best cater for more integrated conservation strategies.

One of the critical links between demographic transition and sustainability is the role of women. Promoting demographic transition entails acknowledging women’s reproductive rights and their role in family planning. Most of Africa’s agricultural production is carried out by women, which puts them at the frontline of ecological management. It is for this reason that programs aiming at skills development should prioritize women. Failure to do so will not only compromise the question of demographic dividend, but it will also undermine efforts to promote measures aimed at species protection.

4.3 Environmental monitoring and systematics

Effective environmental management and species conservation are dependent on the quality of the data available. One of the limitations of African conservation efforts is the lack of reliable data on the distribution of species and ecological changes that influence species loss. In many cases the critical ecosystems linkages that support species survival are little understood. In fact, species loss is often used as an indicator of ecosystem disruptions. This method tends to rely on easily observable species and is hardly an effective tool for determining losses arising from subtle changes in the environment.

The field of systematics is generally underfunded in African countries. Large parts of Africa remain of partially unexplored and their species distribution undocumented. Many of the international specimens collection and identification programs that existed last century have also been compromised by the emergence of legal regimes that put biological resources under sovereign control. The need to derived development benefits from biological resources motivated African countries to push the stronger national control over their national resources.

But one of the consequences of some of the provisions of the United Nations Convention on Biological Diversity (CBD) was extended uncertainty over the status of biological material collected from those countries. The adoption of new rules for the international transfer of biological material came long after many collaborative research programs has been be stopped or scaled back. This also undermined interest in international partnerships in training young Africans in systematics.

Technological advancement, especially in the area of gene sequencing, has created new opportunities for African countries to join a new age of rapid systematics. The dramatic fall in the reduction of genome sequencing has played a key role in low-cost identification of species. In the past, species identification was a laborious process that took years. Preliminary species identification work can be undertaken with potable sequencing devices that cost less than US$1,000. The use of such devices can also help to motivate young people to take interest in systematics. But even where such possibilities exist, African governments are exploring ways to regulate gene sequencing, which would in turn undermine the prospects of renewing international partnerships in systematics.

Much of the cartographic information and data used for environmental planning and management in Africa are either out of date. In addition, the existing knowledge base is being rendered obsolete by the same ecological changes that need to be addressed. The first step in seeking lasting solutions to the problem is to conduct real time monitoring of ecological trends. This will involve leveraging the power of emerging earth observing technologies, especially satellites.[70]

Part of the slow adoption of satellite technology is the perception that space technology is too expensive. The popular and false image of the technology is derived from the last century, when the space programs were too expensive for emerging countries. This perception has persisted despite the dramatic fall of costs of developing such programs. African countries can now establish startup space programs with about US$300 million. The

costs could be shared by neighboring countries. The East African Community, for example, could have one regional space program instead five separate ones.

More countries around the world are starting to focus on small satellites, which are easier to build and launch in modular constellations. This is also making it possible for students in South Africa to participate in the design of small satellites and the accompanying scientific experiments.

The other major concern is that the few space initiatives that exist in Africa focus more on turnkey projects. Instead, they should stress building the requisite human capacity needed to rise up the space ladder. The best place to build such capacity is in universities, not in secretive departments in government ministries.

The lifespan of a satellite is about 10 years. Countries that do not invest in continuous training quickly see their ground facilities rendered obsolete by technological change. A space program only functions effectively when it is supported by a strong human resource foundation on the ground.

The future of environmental monitoring is being transformed by the increased use emerging technologies such civilian drones, digital imaging and moisture sensors. The changing climate offers Africa yet another reason to leverage the drones to complement satellite technology. Increasing the installation of weather stations across Africa would provide additional support for environmental monitoring. The land mass of sub-Saharan Africa is 35 times that of Texas.[71] Yet the two have nearly the same number of weather stations.

The long-term contribution of such efforts lies in building strong institutions of higher learning attached to major infrastructure projects. Such universities can then work with networks of technical institutes and high schools to broaden the base for competence in environmental management. The adoption of such technologies will also increase options for citizen engagement in environmental monitoring, monitoring and enforcement.

4.4 Innovation and economic transformation

One of the most salient features of Africa's development history has been the low level of technological innovation and industrial growth. Reliance on raw material extraction still remains the dominant development model. This has direct and indirect impacts on the fate of species. The direct impacts arise from human activities such as agricultural expansion and logging. Indirect effects are driven by urbanization patterns that have no ecological dividend.

This is the background against which African leaders have in recent years been stressing the importation of science, technology, and innovation in long-term economic transformation. One example is the African Union's decision to adopt the 10-year Science, Technology and Innovation in Africa Strategy (STISA-2024). The strategy seeks to reposition African countries as technology-driven economies, away from a supplier of raw materials for the global economy.

One of the transitional approaches advocated by African countries is to add value to their natural resources. Policymakers hope that by adding value to exports they can capture more financial returns from their commodities. At the moment, most of the benefits go to nations that process the commodities for the re-export market. For example, in 2014 Africa exported $2.4 billion of coffee. Germany, which is not a producer but a processor, re-exported nearly $3.8 billion worth of coffee worldwide. The standard response to the disparity is to call on Africa to add value to its coffee.

Value addition, however, should not be the primary model for industrial transformation. There is little evidence to support the view that countries industrialize by adding value to their raw materials. Rather, the causality runs in the opposite direction. Countries add value to raw materials because they already have the requisite technological capacity to do so.[72] Africa's traditional focus on its minerals has caused it to lag far behind in such efforts.

There is a common perception that industrialized countries advanced mainly because they exploited low-cost natural resources from their colonies. Developing countries then conclude that they too can industrialize and grow by adding value their natural resources. The evidence from countries such as Australia, Canada, and the United States does not support the claim.[73] Commodity booms are often a result of policy incentives, improvements in exploration technology, and investment in resource-related public research.[74]

African countries have the benefit of being latecomers. Unlike its predecessors, Africa has access to a much wider range of technologies that can serve as platforms for industrial learning. These technologies cover fields such as electronics, digital technologies, genetics, synthetic biology, and new materials. Harnessing these technologies requires building among the youth an ethic of innovation that is driven by learning and not extraction.

A critical entry point for creating the learning that cultures need for rapid economic transformation lies in making educational systems more relevant to contemporary needs. The reforms must stress practical approaches to

problem-solving, which should include addressing ecological challenges. But more importantly, fields such as engineering need to have priority in order to expand productive opportunities for the youth.[75]

The challenge for Africa is not just to industrialize, but to do so upon an ethical foundation that includes strong emphasis on conservation. It is only by pursuing such an approach that Africa can avoid the environmental damage caused around the world by industrial development. Technological leapfrogging strategies are likely to backfire if they are not guided by the need to make the sustainability transition. This logic applies to all economic sectors, especially agriculture, given the role of the sector in species loss.

4.5 Agricultural intensification

Agriculture will continue to play a major role in Africa's economic transformation. The manner in which the sector is developed will have significant implications for species survival. A recent study by van Ittersuma et al. (2016) shows that sub-Saharan Africa is unlikely to meet its cereal needs under current productivity growth rates without major cropland expansion and food imports.[76] The study assessed trends in Burkina Faso, Ghana, Mali, Niger, Nigeria, Ethiopia, Kenya, Tanzania, Uganda, and Zambia.

It focused on whether self-sufficiency can be achieved in five main cereals (maize, millet, rice, sorghum, and wheat) by 2050. The 10 countries account for 54% of Africa's total population and 58% of the arable land area. The article shows "that although yield gap closure on existing cropland and a large acceleration in yield growth rates are essential to achieve cereal self-sufficiency, they are most likely not sufficient. For instance, increasing maize yields from the approximately 20% of yield potential in 2010 to 50% by 2050 implies a doubling of annual yield increases compared with the past decades. Even then, cereal areas must increase by more than 80% to realize self-sufficiency in the 10 countries."[77]

Achieving self-sufficiency will entail closing the yield gap, increasing cropping intensity, and expanding irrigated land areas in suitable regions. Pursuing these sustainable intensification options will involve considerable private and public investment in research and development. But even more importantly, it must be guided by specific policy measures that reduce its ecological impact. Leveraging emerging technologies needs to be accompanied by a wide range of institutional innovations that help to align agricultural expansion with ecological considerations.

Efforts to find alternative livelihoods for people living relying on direct utilization of natural resources such as bushmeat hunting show little evidence of success. A study of 64 such projects in Central Africa shows that many projects are "funded through small, short-term grants, and are struggling to meet their objectives with the available time, funding and capacity."[78] The projects are most managed by non-governmental organizations focusing on small localities. Their impact is largely negligible despite their efforts to involve local communities.

The way forward will involve major efforts to make African agriculture more knowledge-intensive and entrepreneurial.[79] There are a number of measures that can help achieve this objective. These include harnessing emerging technologies, investing in research and development, strengthening technical education, expanding rural infrastructure, and promoting regional trade. These measures must be pursued with sustainability objectives in mind.

Africa is seeking to expand its agriculture at a time when it has access to wide range of emerging technologies that can help to facilitate the adoption of sustainable intensification practices. Technologies such as transgenic crops, satellites, drones, and sensors can be deployed to provide critical information on weather and moisture that could assist in optimizing the use of water. Drones are already being used in countries such as Nigeria to carry out surveys to determine the most optimal regions for crop production. Other technologies such as mobile phones are already being adapted to a wide range of agricultural uses and will become critical tools in the creation of a new agricultural extension system throughout the continent. Further adaptations in smartphones, for example, will turn them into mobile labs supporting activities such as plant disease identification and nutrient testing.

Transgenic crops have been a subject of considerable controversy in Africa. The debates have made it difficult to consider each application on its own merit and to identify those that can contribute to agricultural intensification by reducing the amount land used in production, cutting back on the use of insecticides, and reducing the need for tillage. One of the arguments against transgenic crops is that they lead to monoculture, which is detrimental to biodiversity. The use of monoculture, however, is a choice of farming system, not the method used to confer certain traits to crops. Monocultures are common in crops that do not use transgenic crops. Advances in gene editing are also ushering in new techniques that could achieve the same goals without the transfer of genes across species.

A more pressing challenge, however, is increasing R&D expenditures not only for plant breeding but also for adapting existing technologies to local conditions. Closely related to this point is the need to provide training

programs that prepare young people for modern farming methods both in rural and urban areas. This will require reforms in existing educational institutions to make them more practical and experiential. Currently, many agriculture departments in Africa still train student for nonexistent government positions. The challenge is to reform curricula so that they can focus on sustainable agribusiness.

The prevalence of subsistence agriculture in much of Africa is a result of poor infrastructure, especially energy, transportation, and irrigation. Investment in such infrastructure will not only facilitate sustainable intensification with the appropriate support, but it will be easier for farmers to increase their incomes through local and regional trade. Only about 4% of African agriculture is irrigated, whereas the share is 45% in Asia and 18% worldwide. A growing number of African countries are already taking advantage of emerging technologies to adopt solar irrigation. This is just one example by which new technologies could help in redesigning rural infrastructure so that it meets sustainability requirements.

Agricultural trade among African countries is vital to sustaining agriculture. In 2013 only 17% of the food imported by African countries came from within the continent. Regional trade in agricultural produce could help countries decide on regional specialization, which would help them avoid attempting to fulfill their food needs without the benefits of economies of scale and sustainable intensification.

The establishment of the Tripartite Free Trade Area (TFTA) in 2015 created a market of more than 300 million people in 26 countries valued at US$1.5 trillion. Africa is currently negotiating a Continental Free Trade Area (CFTA) that will cover a billion people in 54 countries with a combined GDP of over US$3.5 trillion. Agriculture could be one of the key beneficiaries of this market. In addition to incorporating produce, the market will also provide opportunities for trade in agricultural technology and services. Technologies and services for sustainable intensification could be part of this market.

Conclusions

Africa's biological diversity is at an inflection point. Over the last five decades the continent is pursuing economic strategies that in theory could foster rapid economic growth and help reduce pressure on natural systems. Much of the concern over the fate of Africa's biological diversity has been based largely on relying on past trends on relationships between population growth and natural habits. However, evidence shows the exceptional nature of key drivers of ecological changes such as demographic change and urbanization. The impact of population on the environment is not just driven by the sheer growth in human numbers, but by their amplification effects.

Unlike in other regions of the world, Africa's population growth has not been accompanied by industrialization and improvements in agricultural productivity. Urban centers are largely populated by poor people with limited access to modern infrastructure such as electricity. Large proportions of urban dwellers rely on the extraction of wood fuel as well diverse sources of nutrition—including bushmeat—which lead to species extirpation. The low levels of agricultural productivity are associated with farming methods that lead to habitat loss and fragmentation.

There are, however, indications that fertility rates are starting to decline, especially in urban areas. Emerging evidence also shows that agricultural productivity is rising, especially in countries that have increased their agricultural research funding. Overall, these positive trends are too slow to deliver the kind of changes needed to reduce pressure for species survival. Additional measures are needed to facilitate economic transformation in ways that are sustainable.

Urgent measures are needed to facilitate the demographic transition, an essential starting point for sustainable development. Policies that promote reproductive rights and family planning are needed for sustainable development. But such policies will not be enough to reduce species loss unless they are accompanied by new approaches that focus on the need integrate conservation with economic activity. Some of these policies could take advantage of the growing emphasis on regional integration in Africa by creating transboundary wildlife conservation programs.

The way forward entails the construction of a new ethic that acknowledges the importance of co-existence between humans and other species. Such a new ethic will also involve massive ecological education, legal change and institutional adjustments which take into account the exceptional nature of the African setting. The desirability and benefits of such innovation will not be sufficient to guarantee their adoption. There will be many incumbent forces that will stand in the way of such efforts. Additional time and energy will need to be invested in addressing the sources of resistance to change.[80] Much of this work will involve close partnerships between government, academia, the private sector, civil society and private individuals. Achieving this fast enough to stall the pace of species loss will require leaders of all types to become champions on a new contract between humans and nature, the kind of approach foreshadowed by Saint Francis.

End notes

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