Current Biology
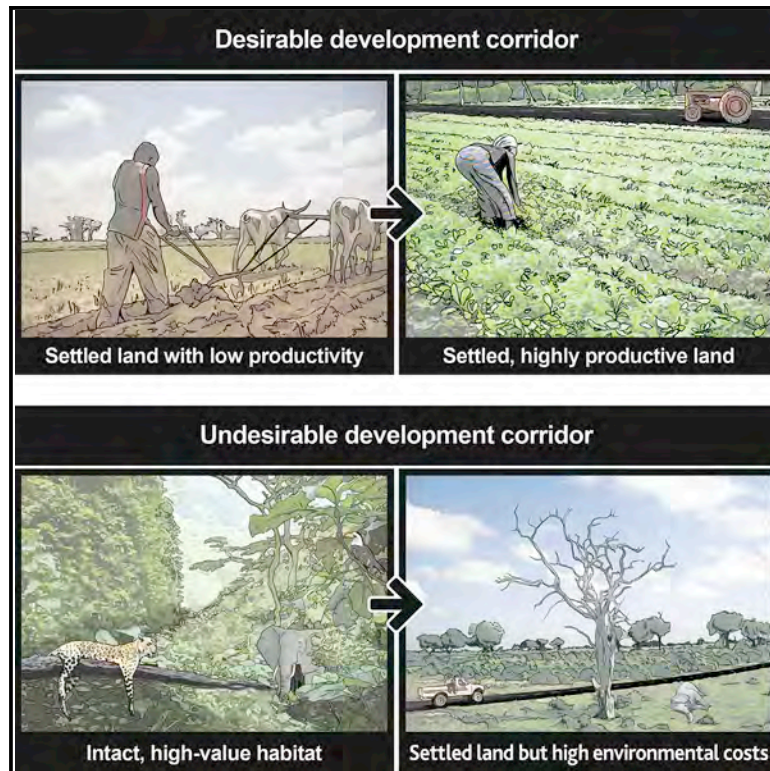
Estimating the Environmental Costs of Africa's Massive "Development Corridors"

Graphical Abstract

Highlights

- Massive new "development corridors" will crisscross the African continent

- The corridors would open up sparsely populated regions to major development pressures

- Environmental costs would most likely be greatest in equatorial forests and savannas

- Some corridors have only limited prospects for increasing agricultural production

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In Brief

Laurance et al. assess the potential environmental costs of 33 planned or progressing "development corridors" in Africa. If completed, the corridors would total over 53,000 km in length and are likely to imperil many African ecosystems. New corridors in equatorial forests and savanna woodlands are projected to have the greatest environmental costs.

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Report

Estimating the Environmental Costs of Africa's Massive "Development Corridors"

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SUMMARY

In sub-Saharan Africa, dozens of major "development corridors" have been proposed or are being created to increase agricultural production [1–4], mineral exports [5–7], and economic integration. The corridors involve large-scale expansion of infrastructure such as roads, railroads, pipelines, and port facilities and will open up extensive areas of land to new environmental pressures [1, 4, 8]. We assessed the potential environmental impacts of 33 planned or existing corridors that, if completed, would total over 53,000 km in length and crisscross much of the African continent. We mapped each corridor and estimated human occupancy (using the distribution of persistent night-lights) and environmental values (endangered and endemic vertebrates, plant diversity, critical habitats, carbon storage, and climate-regulation services) inside a 50-km-wide band overlaid onto each corridor. We also assessed the potential for each corridor to facilitate increases in agricultural production. The corridors varied considerably in their environmental values, and many were only sparsely populated. Because of marginal soils or climates, some corridors appear to have only modest agricultural potential. Collectively, the corridors would bisect over 400 existing protected areas and could degrade a further ∼1,800 by promoting habitat disruption near or inside the reserves. We conclude that many of the development corridors will promote serious and largely irreversible environmental changes and should proceed only if rigorous mitigation and protection measures can be employed. Some planned corridors with high environmental values and limited agricultural benefits should possibly be cancelled altogether.

RESULTS

Assessing the Development Corridors

We evaluated the development corridors using the framework for a "global road-mapping strategy" that aims to maximize the agricultural benefits of new or improved transportation projects while minimizing their environmental costs [8, 9]. This strategy involves limiting road expansion within relatively intact ecosystems with high environmental values while focusing road building in arable, already-settled lands where sizeable gaps exist between current and potential farm yields.

Improving agricultural yields and food security is a frequently invoked justification for the African development corridors [1–4], given the continent's rapidly growing human population, which is projected to increase nearly 4-fold this century [10]. Africa has large expanses of arable, settled land where farm yields are far less than optimal [11]. In these areas, new or upgraded roads could potentially help to raise yields by improving access to urban markets and promoting rural investments and better farming methods [1, 8]. With increasing agricultural productivity and rising profits, such areas might also act as "magnets" for colonists, drawing them away from vulnerable frontier areas and helping to promote land sparing for nature conservation [12, 13].

Spatial Scale of Corridors

We identified 33 unique development corridors (Figure 1), of which ten are active, nine are proposed for upgrading, and 14 are planned (Table 1). We separately classified different segments of a given corridor if they differed in being (1) already active, (2) slated for or undergoing major upgrading, or (3) planned for the future (Supplemental Experimental Procedures).

According to our analyses, the 33 corridors will total 53,226 km in length if completed in their entirety. Individual corridors would range in length from 363 km to 4,825 km, with a median length of 1,262 km (Table 1). Seven of the 33 corridors are spatially dominated by forests, three by desert shrubland habitats, and the remainder by savanna woodlands (Table 1).

Human Occupancy

To generate standardized comparisons, we overlaid a 50-km-wide band onto each corridor, centered on the road and/or railroad at the core of the corridor. We used satellite data to estimate relative human occupancy within the corridor-band based on the spatial distribution of persistent night-lights, using an ∼1-km^2 pixel size. We employed a very low night-light threshold sufficient for detecting even dispersed, electrified rural settlements, although this would not reveal settlements entirely lacking night-lights (Supplemental Experimental Procedures).

We found two striking results. First, the corridors differed greatly in their apparent human occupancy, with the incidence
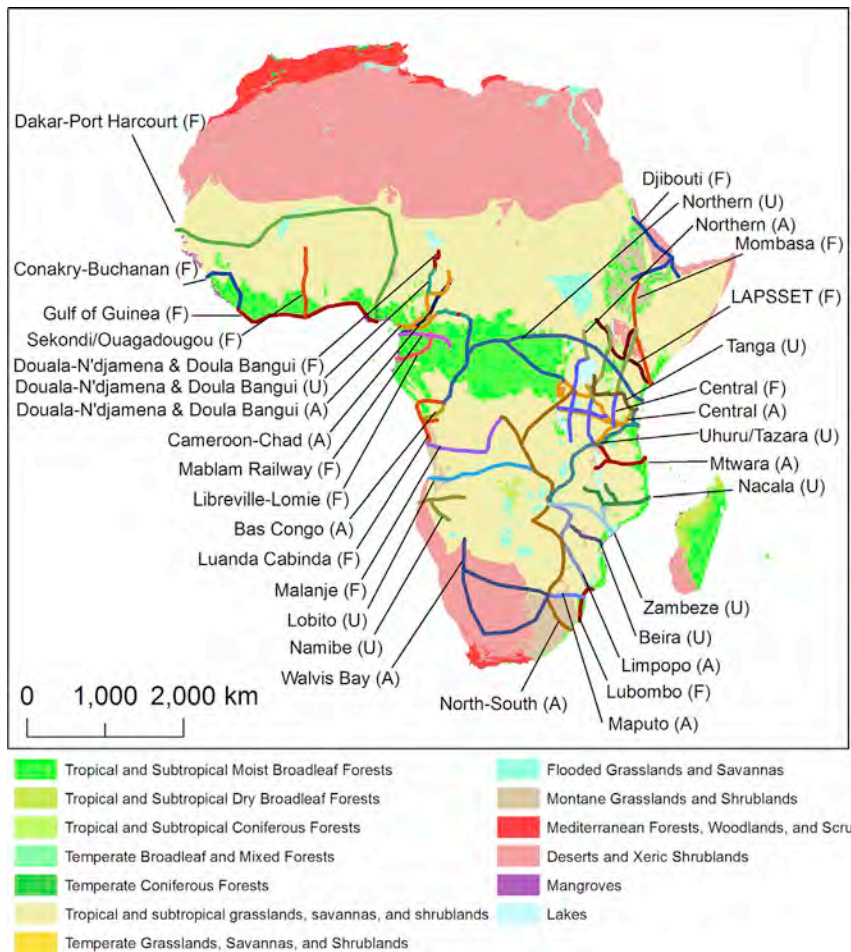
Figure 1. Development Corridors in Sub-Saharan Africa

Nearby or overlapping corridors are distinguished by different colors. The current status of each corridor is indicated in parentheses (A, already active; F, planned for the future; U, upgrade planned or underway).

tests) on average than those dominated by savanna woodlands (0.25 ± 0.07) or desert shrublands (0.19 ± 0.06).

Conservation Priority

We reasoned that corridors that combined both high environmental values and low human occupancy should be regarded as having the highest overall conservation priority, and vice versa. Environmental and human-occupancy values were not significantly correlated ($r = 0.069$, $p = 0.70$; Pearson correlation with arsine-squareroot-transformed occupancy data). To combine the two metrics into a single index, we rescaled values for each from 0 (lowest priority) to 1 (highest priority) and then averaged them for each corridor.

Conservation-priority values differed significantly among biome types ($F_{2,30} = 6.77$, $p = 0.0037$; one-way ANOVA), with forests (0.75 ± 0.19) and savanna woodlands (0.62 ± 0.10) having higher values on average ($p < 0.01$ and $p < 0.05$, respectively; Tukey's tests) than desert shrublands (0.40 ± 0.18). Exceptionally high (>0.75) conservation values were evident for equatorial corridors in densely forested areas of the greater Congo Basin (M'Balam Railway, Libreville-Lomie, and Northern Upgrade) and West Africa (Conakry-Buchanan), as well as some equatorial savanna woodland areas (Uhuru-Tazara and Mtwara) in East Africa (Table 1; Figure 1). On average, there was no significant difference ($t = 0.49$, degrees of freedom [df] = 31, $p = 0.63$; two-sample t test) in conservation-priority values between the 14 planned corridors (0.65 ± 0.17) and the 19 corridors that exist or are currently being upgraded (0.62 ± 0.16).

Protected Areas

The 33 corridors would have major impacts on existing protected areas (Figure 2; Supplemental Experimental Procedures). Using spatial data from the World Database on Protected Areas (http://www.protectedplanet.net), we found that the roads and/or railroads at the heart of the corridors would bisect a total of 408 protected areas while cutting through a total of 5,742 km of protected habitat (Table 1). Among the affected protected areas, 29 would be intersected by two or more corridor systems.

If one includes the 50-km-wide band overlaying each corridor, then 2,168 protected areas would fall at least partially within one corridor band. Of these, 675 would be overlapped by two or

of detectable night-lights varying from 0.7% to 45.7% of the total area of each corridor band (Table 1). These occupancy values did not differ significantly among forested, savanna woodland, and desert shrubland biomes ($F_{2,30} = 2.76$, $p = 0.08$; one-way ANOVA). Second, most corridors were only sparsely populated, with only eight having >10% of their pixels with night-lights and just two having >30% of their pixels with night-lights. These results were robust to the size of the sampling unit used and differing spatial patterns of human settlement (Supplemental Experimental Procedures).

Environmental Values

We estimated a composite index of environmental values for each corridor band based on a previously integrated dataset [8] on threatened vertebrate species, vascular-plant diversity, key wildlife habitats and wilderness values, and the carbon storage and local climate-stabilizing capacity of native vegetation, generated for Earth's entire ice-free land surface (Supplemental Experimental Procedures). Index values for each 1-km² pixel were averaged across each corridor band (0, lowest value globally; 1, highest value globally).

The 33 corridors had widely varying environmental values (Table 1). Values differed significantly among biomes ($F_{2,30} = 13.17$, $p = 0.0001$; one-way ANOVA), with those dominated by forests ($\overline{X} \pm SD = 0.41 \pm 0.09$) being higher ($p < 0.001$; Tukey's

Table 1. Attributes of 33 Development Corridors in Sub-Saharan Africa, Ranked from Their Highest to Lowest Estimated Conservation Priority

Corridor Name	Status	Type	Length (km)	Environ. Value[a]	Human Occupancy[b]	Conservation Priority[c]	Agricult. Potential[a]	Bisected by Road and/or Railroad		Overlapped by 50-km-wide Corridor Band		Major Biome[e]
								No. PAs[d]	Length (km)	No. PAs[d]	Affected Area (km²)	
M'Balam Railway	future	road/rail	715	0.53	0.7	0.989	0.36	19	438.9	38	19,180	forest
Libreville-Lomie	future	road/rail	636	0.54	4.2	0.961	0.38	2	40.9	22	4,999	forest
Northern	upgrade	road/rail	4,825	0.40	2.9	0.820	0.59	40	545.3	247	29,865	forest
Uhuru/Tazara	upgrade	road/rail	1,902	0.38	1.4	0.815	0.70	29	301.7	252	15,503	savanna
Conakry-Buchanan	future	rail/pipeline	803	0.36	2.0	0.786	0.64	6	50.9	23	2,498	forest
Mtwara	active	road/rail	1,054	0.33	1.8	0.755	0.68	8	120.6	147	4,729	savanna
Douala-N'djamena and Douala- Bangui	active	road/rail	1,857	0.33	1.9	0.754	0.53	6	75.5	21	3,942	savanna
Tanga	upgrade	road/rail	922	0.33	4.2	0.728	0.71	17	140.3	190	11,981	savanna
Central	active	road/rail	3,379	0.32	3.3	0.727	0.70	42	824.5	235	41,170	savanna
Central	future	road/rail	2,820	0.31	2.4	0.726	0.68	50	1141.1	359	56,891	savanna
Lobito	upgrade	road/rail	1,419	0.29	3.5	0.692	0.65	2	6.4	16	1,700	savanna
Cameroon-Chad	active	rail/pipeline	951	0.29	3.8	0.688	0.50	7	58.7	9	2,065	forest
Mombasa Corridor	future	road/rail	1,325	0.27	2.6	0.679	0.49	4	229.7	18	13,291	savanna
Nacala	upgrade	road/rail	1,291	0.27	4.1	0.662	0.64	3	47.2	37	2,324	savanna
Northern	active	road/rail	2,221	0.24	2.8	0.644	0.58	28	326.3	211	17,203	savanna
Malanje	future	road/rail	1,262	0.24	3.1	0.640	0.66	0	0	1	64	savanna
Zambeze	upgrade	road/rail	1,148	0.20	1.5	0.614	0.55	4	146.4	54	8,722	savanna
LAPSSET	future	rail/pipeline	1,617	0.19	0.8	0.611	0.46	30	327.2	132	15,481	savanna
Namibe	upgrade	road/rail	945	0.23	4.8	0.610	0.68	0	0	2	1,307	savanna
Sekondi/Ouagadougou	future	road/rail	899	0.30	12.3	0.605	0.54	14	213.8	81	8,597	savanna
Djibouti	future	road/rail	1,571	0.22	4.4	0.603	0.48	4	134.5	10	6,752	desert
Lubombo	future	road/rail	499	0.36	18.7	0.600	0.53	5	22.6	30	2,340	forest
North-South	active	road/rail	4,441	0.28	12.0	0.586	0.61	34	315	252	18,591.3	savanna
Douala-N'djamena and Douala- Bangui	upgrade	road/rail	698	0.16	1.5	0.570	0.52	1	3.1	6	2,133	savanna
Douala-N'djamena and Douala- Bangui	future	road/rail	363	0.11	1.2	0.516	0.51	4	3.5	6	2,205	savanna
Luanda Cabinda	future	rail/pipeline	1,089	0.23	13.3	0.516	0.65	5	71.9	9	1,933	savanna
Limpopo	active	road/rail	1,424	0.16	6.4	0.515	0.54	20	336.5	77	18,764	savanna
Beira	upgrade	road/rail	479	0.24	14.5	0.514	0.58	0	0	3	325	savanna
Bas Congo	active	road/rail	415	0.20	14.6	0.468	0.67	0	0	8	871	savanna
Walvis Bay Corridors	active	road/rail	3,454	0.10	8.4	0.426	0.47	14	422.5	86	17,326	desert

(Continued on next page)

Table 1. Continued

Corridor Name	Status	Type	Length (km)	Environ. Value[a]	Human Occupancy[b]	Conservation Priority[c]	Agricult. Potential[a]	Bisected by Road and/or Railroad		Overlapped by 50-km-wide Corridor Band		Major Biome[e]
								No. PAs[d]	Length (km)	No. PAs[d]	Affected Area (km²)	
Dakar-Port Harcourt	future	road/rail	4,349	0.09	8.4	0.415	0.56	20	280.0	114	18,888	savanna
Gulf of Guinea	future	road/rail	1,995	0.37	37.1	0.407	0.56	14	213.7	79	11,072	forest
Maputo	active	road/rail	458	0.24	45.7	0.167	0.46	5	6.4	68	1,206	desert

See also Figures S1–S4.
[a]Relative to all terrestrial ecosystems globally (0–1 scale), as estimated by [8].
[b]Percentage of all 1-km² cells within each polygon with persistent night-lights.
[c]Scaled from 0–1, with 1 indicating the highest relative conservation priority.
[d]Protected areas (PAs) mapped in the World Database on Protected Areas (http://www.protectedplanet.net).
[e]"Forest," tropical and subtropical broadleaf forests, mangroves, temperate broadleaf and mixed forests, coniferous forests, and boreal forests; "savanna," grasslands, savannas, shrublands, and woodlands at varying latitudes; "desert," deserts and xeric shrublands, montane grasslands and shrublands, and tundra.

more bands (Table 1). An estimated 276,236 km² of protected-area habitat would fall within at least one corridor band.

Among the 33 corridors, corridor length was the only significant predictor of the magnitude of impacts on protected areas. Longer corridors altered a significantly greater number, intersected length, and amount of habitat ($F_{1,30}>16.4$, p $\leq$ 0.0003) of protected areas, whereas biome type was not significant ($F_{1,30} \leq 2.9$, p $\geq$ 0.11) in any case (analysis of covariance with log-transformed values).

Potential Agricultural Benefits

The estimated potential for transportation improvements to increase agricultural production [8] varied considerably among the corridors (Table 1; Supplemental Experimental Procedures). Mean values varied among biome types ($F_{2,30}$ = 6.22, p = 0.0055; one-way ANOVA), being significantly (p < 0.05) higher in savanna woodlands ($\overline{X} \pm$ SD = 0.60 $\pm$ 0.07) than in forests (0.51 $\pm$ 0.10) or desert shrublands (0.47 $\pm$ 0.01).

Notably, the 14 planned corridors had lower agricultural potential (t = 2.03, df = 31, p = 0.05; two-sample t test) on average (0.53 $\pm$ 0.10) than did the 19 corridors that already exist or are being upgraded (0.60 $\pm$ 0.08) (Table 1). This might arise because a larger fraction of the planned corridors occur in forested areas (36%), which have lower agricultural potential than do those in savanna woodlands, compared to the corridors that exist or are being upgraded (11%).

Finally, the agricultural-potential index was not significantly correlated with the environmental-value ($r = -0.011$, p = 0.63), human-occupancy ($r = -0.129$, p = 0.47), or overall conservation-value ($r = 0.025$, p = 0.89) metrics (Pearson correlations, n = 33). This suggests, optimistically, that there may be only limited direct tradeoffs between the environmental costs and potential agricultural benefits of the 33 corridors (Figure 3).

DISCUSSION

Explosive Change

It is possible that, in recorded history, no continent has ever changed as rapidly as is presently occurring in Africa. For instance, the extractive-industries boom in Africa is notable not so much for its direct effects—which will be substantial [5, 14]—but for the powerful economic impetus it is providing for new roads and railways needed for extracting high-volume minerals such as iron and coal [1, 5]. Development corridors promoted by Africa's mineral boom are also seen as prime locations to expand and intensify agriculture [1–4]. Will these corridors focus and improve agriculture in already-settled areas, thereby sparing other lands for nature conservation, or will they simply increase the scale and pace of environmental degradation?

Our analyses suggest that different development corridors in Africa are likely to have highly variable agricultural benefits and environmental costs. Many corridors are likely to attract large-scale immigration, including legal and illegal miners, commercial agricultural interests, and colonists seeking newly accessible farming or grazing areas [1, 5]. Our comparisons suggest that (1) the vicinities of most (>75%) corridors are currently only sparsely populated; (2) the proposed corridors will be most numerous and extensive in the vast Guinea and Miombo savanna woodlands but will also have sizeable impacts on
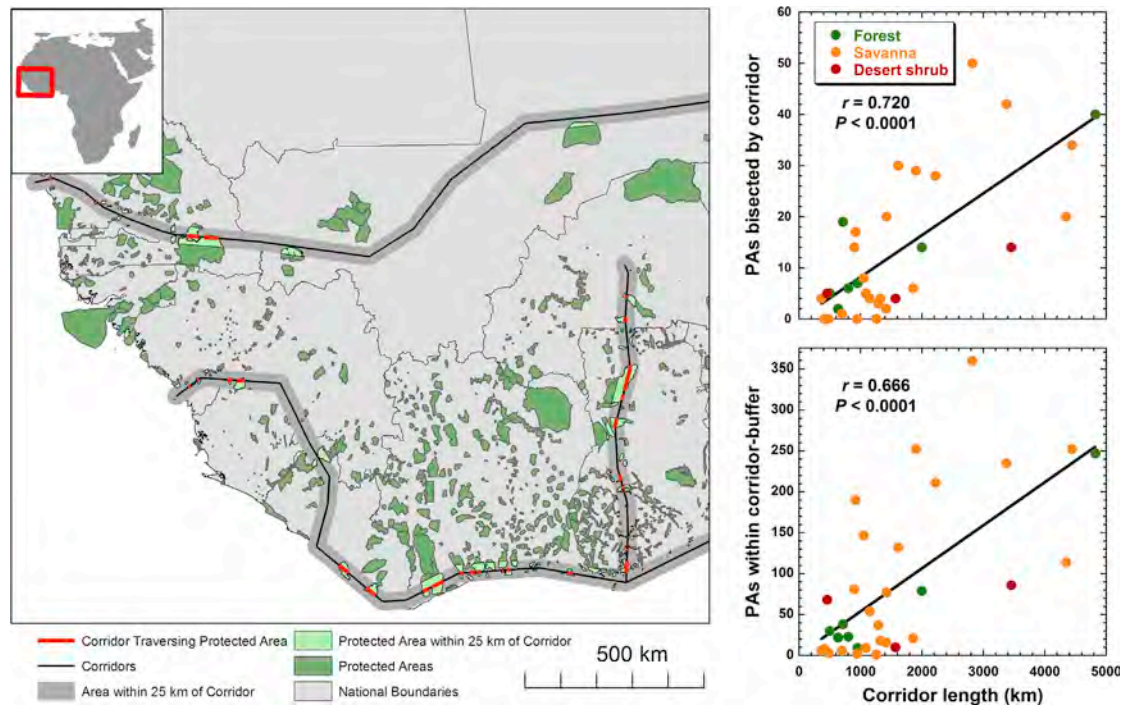
Figure 2. Effects of 33 Development Corridors on Protected Areas in Sub-Saharan Africa

Left: West African protected areas bisected by a corridor road or railroad (red lines) or overlapped by a 50-km-wide band centered on the road or railroad (pale green). Right: For each corridor, the number of protected areas bisected by the road or railroad (above) or overlapped at least partially by the 50-km-wide band (below), as a function of corridor length.

tropical forests and some desert shrublands; (3) the environmental and conservation values of affected habitats will be especially high for forests and savanna woodlands in equatorial regions; (4) the corridors (especially longer corridors) will impact on many protected areas, either by bisecting them (over 400 designated protected areas) or by increasing land-use pressures around reserves and hunting and encroachment inside reserves [15]; (5) the potential for the corridors to generate agricultural benefits is generally greater in savanna woodlands than in dense forests or desert shrublands; (6) the 14 corridors that are currently being planned (Table 1; Figure 3) are likely to yield relatively low agricultural benefits; and (7) there is little association between the potential agricultural benefits and estimated conservation value of each corridor (Figure 3).

Development corridors are seen in many quarters as desirable for Africa, particularly given the continent's escalating population [10], generally underperforming agriculture [11], and growing food-security concerns [1–4, 16]. For such reasons, the corridors are likely to be the focus of near-term investment and development assistance. Our findings suggest that a carefully selected subset of the existing and proposed corridors could generate sizeable agricultural benefits while having limited environmental costs. Based on our analysis, the 33 corridors appear to be divisible into three broad categories (Figure 3): (1) five "promising" corridors with relatively low conservation values and a large potential to benefit agriculture; (2) 22 "marginal" corridors, evenly divided between those with either high conservation values and high potential agricultural benefits or low agricultural benefits and low conservation values; and (3) six "inadvisable"

corridors with high conservation values and low potential agricultural benefits.

We assert that corridors in the "marginal" and especially the "inadvisable" categories (Figure 3) should be implemented only with a clear focus on limiting their environmental impacts via stringent land-use zoning, improved law enforcement, and other mitigation and offset strategies [5, 16, 17]. The high environmental costs and modest agricultural benefits of some corridors could provide a rationale for curtailing or cancelling them. Notably, three of the inadvisable corridors (M'Balam Railway, Libreville-Lomie, and Mombasa Corridor) and ten of the marginal corridors (Conakry-Buchanan, Central-Future, Melanje, LAPSSET, Sekondi/Ouagadougou, Djibouti, Lubombo, Douala-N'djamena and Douala-Bangui-Future, Dakar-Port Harcourt, and Gulf of Guinea) are still in the planning stages (Table 1). On average, these planned corridors have significantly lower agricultural potential than do those that already exist or are currently being upgraded (Table 1). This suggests that at least some of the planned corridors are poorly justified from a food-security perspective.

Further Considerations

At least three additional factors are relevant to cost-benefit analyses for the 33 development corridors. First, a number of the corridors are being promoted by plans for large-scale mining projects [1, 5–7], which can yield considerable (although not necessarily socially equitable) financial benefits. This clearly will be a consideration for affected governments, investors, and other corridor proponents. The second is the physical length
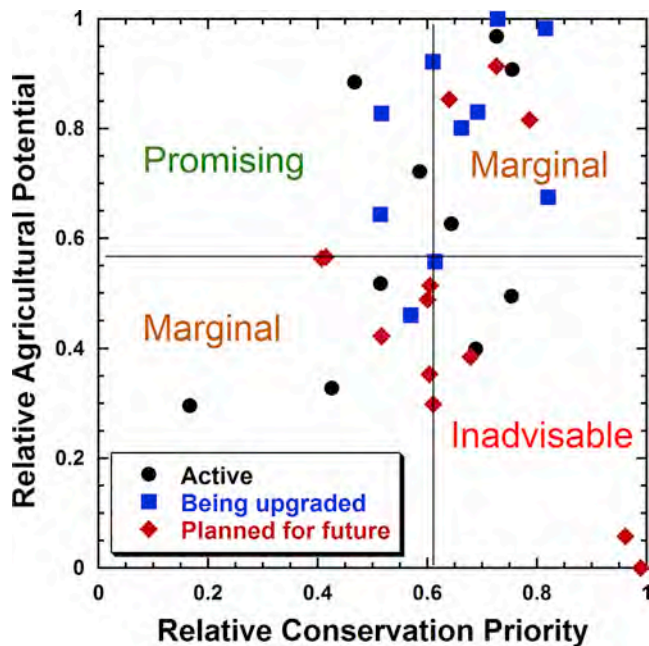
Figure 3. Categorization of 33 African Development Corridors by Estimates of Their Relative Conservation Priority and Potential to Yield Agricultural Benefits

Both axes were rescaled from 0–1 to facilitate comparisons. Dark lines indicate median values on each axis. There is no significant relationship between the two variables ($r = 0.025$, $p = 0.89$; Pearson correlation).

of the corridor, because longer corridors impact larger areas of habitat and promote the degradation of more protected areas relative to shorter corridors. The impact of an individual corridor on protected areas is approximately linearly proportional to its length (Figure 2; Table 1).

Finally, in terms of their environmental costs, one can make a strong case for limiting the geographic spread of new corridors, especially into sparsely populated areas and those in environmentally important regions. Habitat disruption tends to spread contagiously around roads and other transportation infrastructure [13, 18], with the first colonists arriving in an area typically causing more habitat degradation per capita than do those who arrive later [13]. To facilitate commercial agriculture, the best locations for new or improved roads are within a few hours of urban areas, to limit transportation costs and shipping-related crop spoilage [8]. In the coming decades, cities, which provide major markets for commercial farmers, are projected to grow very rapidly in parts of Africa [19]. Hence, consolidating and geographically focusing the development corridors within populated areas or those projected to grow rapidly would be highly desirable from an environmental perspective [20], rather than having them penetrate remote hinterlands or crisscross large expanses of the African continent. That some projected urban-growth areas overlap strongly with critical biodiversity hotspots, such as the Eastern Afromontane region and Guinean forests of West Africa [19], underscores the urgent need for strategic land-use planning and zoning in sub-Saharan Africa.

Our conclusions should be qualified by two caveats. First, the size of the 50-km-wide band that we used to estimate the land-scape-scale impacts of new roads or railroads is arbitrary—a plausible value that allowed us to make standardized comparisons among the different development corridors. Halo effects from human activities around roads and other transportation infrastructure can range from ~10 km wide (for Amazon deforestation [21]) to ~80 km wide or more (for Amazonian fires [22] and hunting-related declines of African forest elephants [23]). Furthermore, major paved roads often spawn networks of secondary and tertiary roads that can greatly increase the spatial scale of habitat disruption [24]. For instance, the first paved highway in the Brazilian Amazon, completed in the early 1970s, has today evolved into an ~400-km-wide slash of forest destruction across the eastern Amazon basin [13]. Hence, our conclusions, particularly regarding the potential for the development corridors to degrade current protected areas (Figure 2; Table 1), could be conservative. This is an alarming prospect, given that protected areas already fail adequately to conserve the diverse range of African ecosystems [25, 26] and wildlife [27–29].

Second, our analysis focuses on the largest and most ambitious slate of projects in Africa—the massive development corridors—but it is not all encompassing. Africa is, for example, also experiencing rapid expansion of energy infrastructure, such as complexes of major hydroelectric dams, construction roads, and power lines in the Congo Basin [30]. Like the development corridors, some of these projects will have far-reaching impacts on African ecosystems.

Conclusions

African environments are being altered at an explosive pace. A key priority in the coming decades will be increasing agricultural production and efficiency to improve food security and alleviate poverty for Africa's rapidly growing population [31] while harnessing the unprecedented scale of foreign investments focusing on land [32] and natural-resource [5–7, 33–35] exploitation. The success or failure of these efforts will be influenced heavily by Africa's development corridors, which will strongly affect future patterns of mining, land occupation, agriculture, and associated development pressures. Our analysis suggests that, as currently planned, a number of the development corridors would yield only limited agricultural benefits while severely degrading African ecosystems and wildlife. Concerted efforts are needed to reduce and mitigate these impacts.

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