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Short Communication

African development corridors intersect key protected areas

Sean Sloan[1]*, Bastian Bertzky[2,3] and William F. Laurance[1,2]

[1]*Center for Tropical Environmental and Sustainability Science, College of Marine and Environmental Sciences, James Cook University, Cairns, Qld 4870, Australia,* [2]*European Commission, Joint Research Centre (JRC), Institute for Environment and Sustainability (IES), Via Enrico Fermi 2749, 21027 Ispra, VA, Italy and* [3]*International Union for Conservation of Nature (IUCN), World Heritage Programme, Rue Mauverney 28, 1196 Gland, Switzerland*

Introduction

Unprecedented growth of mining and agriculture in Africa is encroaching on remaining habitats. Mining in Africa frequently occurs in proximity to protected areas (PAs), more than in other world regions (Durán, Rauch & Gaston, 2013), and at least 23 African PAs have been degazetted or downgraded as a result (Edwards *et al.*, 2014). Even natural World Heritage Sites, the global pinnacle of conservation, suffer mining and oil/gas exploration and exploitation across 31 sites and 18 African countries (WWF, 2015), again more than other world regions (WWF, 2016). The anticipated expansion of transport 'development corridors' related to infrastructure and resource development could impact the ecological integrity of many other PAs as roads and rails link producers with refineries and ports over vast distances (Weng *et al.*, 2013).

Recent analysis highlights frequent intersections between 33 African development corridors and PAs (Laurance *et al.*, 2015b). Only five existing or proposed corridors were considered 'advisable' given their potential environmental costs and agricultural benefits (another 22 were 'marginal' and six 'inadvisable'). However, while insightful, the aggregate analysis of Laurance *et al.* (2015b) overlooked important differences between the conservation objectives of intersected PAs. Protected-area significance and management objectives vary along a spectrum from global importance and/or strict protection to local importance and nominally regulated exploitation. Only half of the 15% of African PAs with reported IUCN management categories had stricter protection levels (Categories I-IV) indicative of greater levels of natural integrity – a low figure by global standards (Deguignet *et al.*, 2014, IUCN and UNEP-WCMC, 2015). It remains unclear which pole of this 'PA spectrum' is most threatened by corridors and to which degree. This uncertainty is compounded by the fact that most of the 33 corridors are in some stage of planning, so that it is also unclear whether the greatest impacts are pending or already realized. The ongoing expansion of Africa's development corridors and mining sector urges the resolution of these uncertainties to inform regional environmental planning (Edwards *et al.*, 2014; Laurance *et al.*, 2014).

Here, we detail actual and potential intersections between African development corridors and a range of PA designations, focusing on designations of the greatest conservation significance, to clarify corridors' potential effects on conservation objectives. We further detail variations in corridors' intersections with PAs according to their development status in order to differentiate between current and potential future ecological impacts. The actual effect of intersections on ecological integrity is inevitably site specific and, in special circumstances, might entail benefits; yet, the weight of historical experience suggests that intersections by transportation infrastructure often pose challenges to ecological integrity insofar as they facilitate deforestation, logging or resource extraction, poaching, fragmentation of ecological communities, or hydrological and climatic changes in PAs (Forman & Alexander, 1998; Wilkie *et al.*, 2000; Walsh *et al.*, 2003; Blake *et al.*, 2007, 2008; Laurance, Goosem & Laurance, 2009; Freitas, Hawbaker & Metzger, 2010; Maisels *et al.*, 2013; Barber *et al.*, 2014; Perz, 2014; Hopcraft *et al.*, 2015a). Our analysis shows that corridors, and particularly proposed corridors, disproportionately intersect, and thus by extension may challenge the ecological integrity of the most important PAs in Africa.

**Correspondence:* E-mail: sean.sloan@jcu.edu.au

Materials and methods

PA boundaries for this analysis come from the World Database on Protected Areas (WDPA) (IUCN and UNEP-WCMC, 2015). We focused on four PA designations generally reserved for areas of special conservation value: World Heritage Sites (WHS), Ramsar Sites, UNESCO Man-and-Biosphere (MAB) Reserves and National Parks. These designations are hereafter termed 'key PAs'. The first three are international conservation designations, and the latter is the most important national designation for tourism (Dudley, 2008). These designations are applied relatively consistently across countries, facilitating continental-scale analysis. We also considered national-level PA designations beyond National Parks but grouped these thematically (Table 1; Table S1) because they are not standardized amongst countries. It was not possible to similarly analyse IUCN management categories because 85% of African PAs lack this information in the WDPA. PAs here are defined as unique WDPA records distinguishing distinct spatio-administrative entities, each with distinct designations, conservation objectives and management regimes.

On some occasions, the WDPA enumerates part or all of a given area twice with each entry assigned a distinct PA designation. For example, a communal forest reserve may partially overlap a national park, or a portion of a national park may also be a WHS. While such entities constitute two PAs both in the WDPA and administratively in practice, this classification scheme slightly exaggerates estimates of the number of PAs intersected by corridors as well as of the total length/area of PA–corridor intersections relative to scenarios overlooking PA overlap (Appendix S1). We controlled for this in two ways to ensure robust and meaningful generalizations. First, we compared PA-designation frequencies between intersected PAs and all African PAs. Any exaggeration in the frequencies of intersected PA designations should be proportional to that of the set of all African PAs if corridors intersect PA designations without bias. Thus, any significant difference in PA-designation frequencies between these two sets of PAs would signal corridors' bias in intersecting PAs of particular designations. Comparisons considered the four key PA designations individually but collapsed groups of national-level PA designations (Table 1) into one group because their individual frequencies could not be determined in the very large set of all African PAs (n = 6,546). Second, to complement the estimates of the total length/area of PA–corridor intersections for all PA designations, we also present estimates of total length/area overlooking PA overlaps (Table 1). The latter 'aggregate' estimates treat coincident but distinct PAs as a single generalized area and thus overlook differences amongst coincident PAs (Appendix S1).

We distinguished corridors as active (n = 10), planned (n = 14) or undergoing upgrades (n = 9) and assessed them at two scales: core road and/or rail infrastructure, and a broader zone of influence defined by a 50-km-wide swath centred on each corridor. The swaths indicate the potential general extent of secondary effects on African PAs on the basis of pan-tropical observations of environmental change nearby roadways, including agricultural conversion in Amazonia (~10 km distant) (Barber *et al.*, 2014), illegal logging in Southeast Asia (~20–30 km) (Linkie *et al.*, 2014) and poaching in Africa (~80 km) (Wilkie *et al.*, 2000; Blake *et al.*, 2008). Rough dirt roads or dilapidated colonial highways may occasionally exist where planned or upgrade corridors are proposed, so that their potential impacts would reflect enhanced traffic flows and land-use change rather than 'forest penetration' per se. Planned corridors are not certain to be developed but are considered here in order to indicate the implications of their development.

We estimated the conservation importance of intersected PAs by their 'irreplaceability scores' for all mammal, bird and amphibian species combined and for the threatened species of these taxa (Le Saout *et al.*, 2013). Scores reflect both the number of species in a given PA and the degree to which these species depend on the PA. They are based on the percentage overlap between species' global distributions and PAs. Higher irreplaceability scores are assigned to PAs hosting larger numbers of species with larger percentages of their distribution within the PA. For simple guidance, a score of 1.0 is equivalent to one species being entirely confined to a given PA, but can also be obtained if multiple species have smaller fractions of their ranges within the PA. Thus, a PA's score is heavily influenced by the extent to which it hosts species with relatively confined distributions. Scores are nondenominational so to aid interpretation, the scores reported here are also expressed as proportions of the corresponding 90th percentile score for all African PAs. The 90th percentile value was selected as the upper value for rescaling because the maximum irreplaceability scores for Africa are many orders of magnitude greater and thus arguably outliers. Irreplaceability scores were available for 4,671 African PAs and

Table 1 Intersections between protected areas and african development corridors, by protected-area designation and corridor status

	Intersections by development corridors						Intersections by development corridor zones							
	All corridors			Planned and upgrade corridors			All corridor zones			Planned and upgrade corridor zones			All African PAs	
Protected Area Designation	PA count	% PAs	Km	PA count	% PAs	Km	PA count	% PAs	Km^2	PA count	% PAs	Km^2	PA count	% PAs
Key designations	**69**	**20.0**	**2,239**	**58**	**24.6**	**1,709**	**129**	**8.0**	**117,683**	**110**	**9.7**	**94,780**	**526**	**8.0**
World heritage site	9	2.6	355	7	3.0	224	13	0.8	18,645	10	0.9	12,627	46	0.7
Ramsar site	9	2.6	527	9	3.8	422	19	1.2	22,893	17	1.5	20,489	108	1.6
UNESCO-MAB reserve	6	1.7	182	6	2.5	182	7	0.4	10,465	7	0.6	10,968	25	0.4
National park	45	13.0	1,175	36	15.3	881	90	5.6	65,680	76	6.7	50,696	347	5.3
National-grouped designations	**276**	**80.0**	**5,102**	**178**	**75.4**	**3,138**	**1488**	**92.0**	**236,121**	**1022**	**90.3**	**162,411**	**6,020**	**92.0**
Forest, nature and state reserves	184	53.3	2,320	119	50.4	1,438	1247	77.1	102,020	855	75.5	70,863		
Other protected areas and sanctuaries	22	6.4	338	19	8.1	295	70	4.3	17,049	61	5.4	15,666		
Game reserves, hunting, and wildlife management	40	11.6	1,630	23	9.7	1,048	99	6.1	82,605	60	5.3	60,260		
Community and communal reserves	20	5.8	645	16	6.8	345	42	2.6	28,270	34	3.0	14,925		
Marine national reserves, parks and protected areas	1	0.3	11	1	0.4	11	7	0.4	965	6	0.5	646		
Recreation and Safari	6	1.7	118	0	0.0	0	11	0.7	5,201	1	0.1	52		
Not reported	3	0.9	41	0	0.0	0	12	0.7	12	5	0.4	0	79	1.2
Total[a]	**345**	**100**	**7,340**	**236**	**100**	**4,847**	**1,617**	**100**	**353,804**	**1,132**	**100**	**257,192**	**6,546**	**100**
Total (aggregate)[b]			**6,115**			**3,948**			**294,536**			**205,983**		

See Table S1 for disaggregated data for national PA designations.

[a]Total lengths, areas and counts of intersection are sums of intersections for the individual PA designations listed in the table. Occasional spatial overlaps between PAs of distinct designations and a corridor/corridor zone means that these totals include partial redundancies reflecting PAs occupying the same space (Appendix S1).

[b]Aggregate total lengths and areas of PA–corridor intersections overlook overlap amongst distinct PAs by ‘dissolving’ their boundaries into generalized protected areas (Appendix S1).

unavailable for 62 PAs intersected by existing or planned corridors.

Results

Development corridors that are planned or undergoing upgrades have particularly frequent intersections with key African PAs. Overall, the 33 corridors intersect 69 key PAs, but the large majority of these (58) intersect with the 23 corridors that are planned or being upgraded (Table 1). The number of key PAs intersected by planned or upgrade corridors is significantly greater than expected given the number of individual corridors of each status (G_{adj}=7.67, P = 0.0056; G-test for goodness of fit with Williams' correction for sample size; Appendix S1). The three international PA designations (WHS, Ramsar, UNESCO-MAB) account for 40% of the key PA intersections with corridors that are planned or undergoing upgrades (Table 1).

The potential PA intersection length of planned corridors is also considerably greater than that of upgrade or active corridors. Planned corridors would intersect 3,612 km of PAs and have greater total, mean and median intersection lengths of any corridor status (Table 2). Further, of the total length of planned corridors (19,943 km), the proportion intersecting PAs (18%) is greater than for active (12%) or upgrade (9%) corridors (Table 2). The lengths of PA intersections by the corridors of each status differed significantly from expected lengths scaled according to the total length of each corridor status (G_{adj} = 515, P < 0.001). Similar post hoc comparisons of observed and expected lengths confirmed the significant extensiveness of planned-corridor intersections specifically (G_{adj} = 418, P < 0.001; Appendix S1), again highlighting their relative prominence.

Development corridors, and particularly those that are planned or undergoing upgrades, disproportionately intersect key PAs (Figure 1). Key PAs are intersected significantly more often than expected given their frequency of occurrence across Africa (G_{adj}=54.2, P < 0.0001 for all corridors; G_{adj}=63.2, P < 0.0001 for planned and upgrade corridors). Key PAs account for 20% of PAs intersected by all corridors and 25% of PAs intersected by planned or upgrade corridors, compared to just 8.1% for all African PAs (Table 1). In contrast, key PAs are intersected at the expected rate (8%) by the broader corridor zones (Table 1). The greater than expected intersections of key PAs by corridors rather than by the broader, more disperse

Table 2 Intersections between Protected Areas and African Development Corridors, for each Corridor Status

Corridors Status	Total	Intersections with corridors				Intersections with corridor zones			
	Length (km)	PA count	Km	Mean Km	Median Km	PA count	Km^2	Mean Km^2	Median Km^2
Planned	19,943	154	3,612	23.5	11.9	609	182,252	299.3	28.7
Upgrade	13,629	82	1,235	15.1	8.2	523	75,069	144.5	8.7
Active	19,654	127	2,493	19.6	7.8	681	128,765	189.1	16.8
Total	**53,226**	**363[a]**	**7,340**	**20.2**	**9.7**	**1813[a]**	**386,086**	**212.9**	**16.6**
Total (aggregate)[b]	–	–	**6,115**	**28.8**	**7.4**	–	**294,536**	**216.4**	**8.1**

[a]Counts above pertain to intersections between a PA and corridors of a given status. Where two or more corridors of different statuses intersect a single PA, that PA is counted once for each status. This occurs rarely for corridors but regularly for broader corridor zones. Table 1 provides true counts of intersected PAs.
[b]Aggregate total lengths and areas of PA–corridor intersections overlook overlap amongst distinct PAs by 'dissolving' their boundaries into generalized protected areas (Appendix S1).

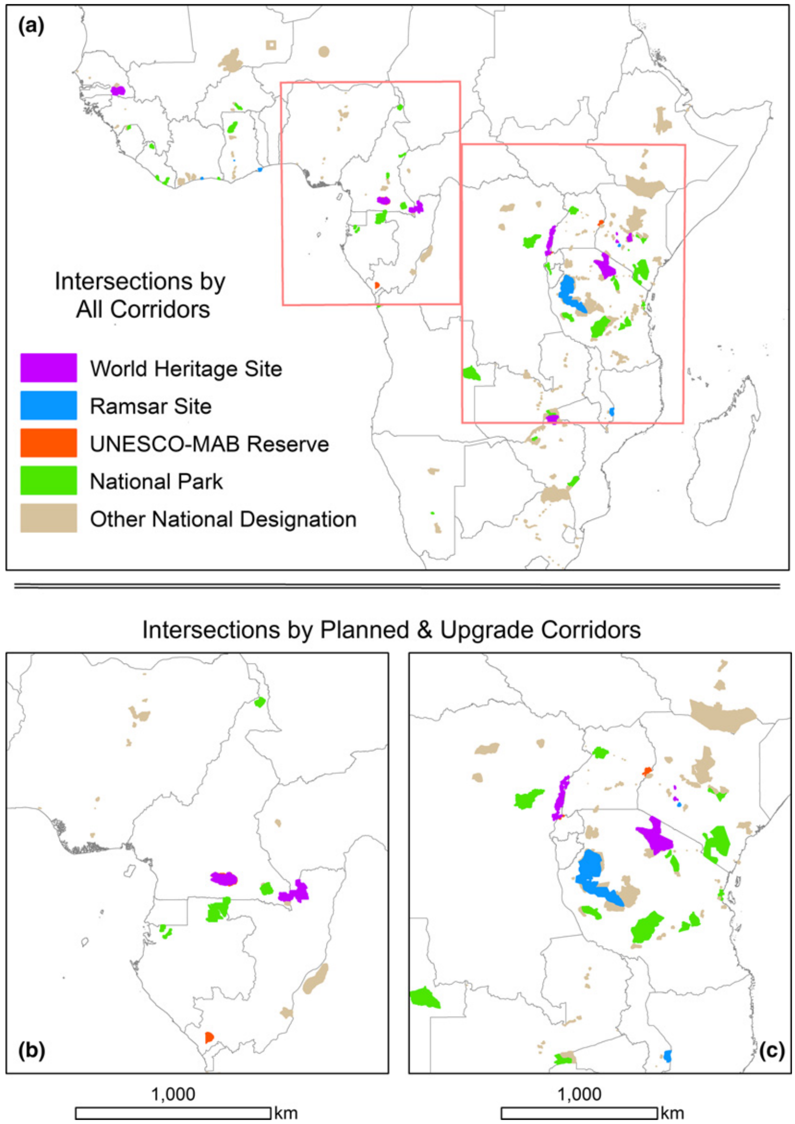

Fig 1 Protected Areas Intersected by Development Corridors in sub-Saharan Africa, by Protected-Area Designation and Corridor Status. Note: Apparently homogenous PAs of a single colour may in fact be composed of multiple contiguous PAs

corridor zones underscores the fact that core corridor road and rail infrastructure constitutes the epicentres of potential impact on key PAs. Two regional epicentres of intersection between key PAs and planned or upgrade corridors are apparent: the Western Central Congo Basin, particularly along the iron belt of southern Cameroon and northern Gabon and The Congo, which is driven largely by mineral resource development (Figure 1b), and the Great Lakes Region extending into the Eastern Savannahs (Figure 1c), where infrastructure and mineral development are both driving forces.

Planned and upgrade corridors also intersect PAs of relatively high conservation value. PA-irreplaceability scores significantly differ amongst planned, upgrade and active corridors (ANOVA; all species $F_{2,280} = 6.2$, $P < 0.05$; threatened species $F_{2,280} = 6.5$, $P < 0.05$). Planned and upgrade corridors each have twice the median score (~0.022; 30% of 90th percentile) of active corridors for all species, and planned corridors alone have twice the median score (0.001; 17% of 90th percentile) of other corridors for threatened species.

Discussion

The scale and distribution of PA–corridor intersections highlight apparent challenges to maintaining the ecological integrity of key PAs. Planned corridors and corridors undergoing upgrade to a lesser degree would intersect key PAs of relatively high conservation value with significantly disproportionate frequency and extensiveness (Table 1, Table 2). While potential impacts might be reduced by re-routing corridors, effective conservation will occasionally demand more substantial revisions (Laurance *et al.*, 2015a). For instance, 30% of all PA intersections are < 4.2 km – a length amenable to re-routing – although this rises to a less amenable 9.0 km for key PAs. Further, many detours would have to be greater to buffer PAs from any 'halo effects' around corridors, such as poaching (Wilkie *et al.*, 2000; Walsh *et al.*, 2003; Barber *et al.*, 2014). Notably extensive intersections by planned corridors include the Malagarasi-Muyovozi Ramsar wetlands (314 km intersected), Dja WHS (74 km), Sangha Tri-National WHS (41 km), Niokolo-Koba WHS (40 km) and Mole National Park (86 km).

Economic development, such as that encouraged by development corridors, is sorely needed in Africa and is held by some as a means of lessening human pressures on ecologically intact hinterlands (Masters *et al.*, 2013). Improved spatial planning is essential to balance economic and environmental imperatives (Wilkie *et al.*, 2000; Laurance *et al.*, 2014). For example, a road circumnavigating Tanzania's Serengeti WHS could integrate a greater human population with economic opportunities and services than a proposed 'paved commercial route' that would bisect the Serengeti (Hopcraft *et al.*, 2015a). Nonetheless, the Tanzanian government remains committed to the latter, imperilling one of the world's greatest animal migrations (Dobson *et al.*, 2010, Africa Geographic, 2014). In certain circumstances, careful planning around a corridor could also enhance PA protection, as where PA surveillance is highly irregular. For economic development or improved surveillance to translate into enhanced *conservation* depends critically on many dynamics beyond access, however. Foremost amongst these are whether corridors actually enhance the economic prospects of pastoralists, farmers and others who (over)exploit PAs' resources (Fyumagwa *et al.*, 2013), whether corridors would even diminish such exploitation, and whether concomitant increases in other deleterious activities such as poaching or land conversion would undo related conservation gains, with such factors weighing more or less depending on whether one's perspective is short term or long term. Opinion is divided, and there are few large-scale precedents to indicate the likely outcome (Fyumagwa *et al.*, 2013; Hopcraft *et al.*, 2015b). The status quo of African PA conservation is wanting, and its deficiencies require resolution for enhanced access to generally enhance PA conservation more than it challenges it. Growing pressures on WHSs and other flagship PAs (Osipova *et al.*, 2014, WWF, 2015, 2016) underscore the urgency of improved spatial planning and enhanced efforts to honour existing conservation commitments.

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Supporting information

Additional Supporting Information may be found in the online version of this article:

Table S1 Disaggregated Data on Intersections between Protected Areas and Development Corridors, by Protected-Area Designation, Corridor Type, and Corridor Status.
Appendix S1 Supplementary Text.