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LETTER

Assessing the impact of international conservation aid on deforestation in sub-Saharan Africa

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Abstract

International conservation donors have spent at least $3.4 billion to protect biodiversity and stem tropical deforestation in Africa since the early 1990s. Despite more than two decades of experience, however, there is little research on the effect of this aid at a region-wide scale. Numerous case studies exist, but show mixed results. Existing research is usually based on community perception or focused on short-term donor objectives rather than specific conservation outcomes, like deforestation rates. Thus, the impact of billions of dollars of conservation aid on deforestation rates remains an open question. This article uses an original dataset to analyze the effect of international conservation aid on deforestation rates in 42 African countries between 2000 and 2013. We first describe patterns of conservation aid across the continent and then assess its impact (with one to five-year lags), controlling for other factors that may also affect deforestation, including rural population, protected areas (PAs), governance, and other economic and commodity production variables. We find that conservation aid is associated with higher rates of forest loss after one- or two-year lags. A similar result holds for PA extent, suggesting possible displacement of deforestation from PAs. However, governance quality in high forest cover countries moderates these effects such that deforestation rates are reduced. Rural population is the most consistent factor associated with forest loss, confirming previous studies of this driver. Our results suggest that in heavily forested countries, development projects designed to support conservation work initially in conditions of good governance, but that conservation aid alone is insufficient to mitigate larger deforestation drivers.

1. Introduction

Since the early 1990s, international and domestic conservation actors have spent billions of dollars to protect global biodiversity and stem tropical deforestation. Despite more than two decades of experience, however, there is little research on the effect of this conservation aid expenditure at the regional scale. Evidence is especially scant in Africa, where more than $3 billion has been invested by bilateral and multilateral aid agencies (Miller *et al* 2013), NGOs (Brockington and Scholfield 2010), and other sources (Waldron *et al* 2013) over the past two decades.

Numerous studies evaluate the effect of individual conservation projects (Hackel 1999, Alexander and McGregor 2000, Miller *et al* 2015) or the efforts of particular donors (Hicks *et al* 2008, Kareiva *et al* 2008) in Africa, but these are usually evaluated based on community perception or project-specific goals rather than more objective measures of conservation outcomes, like deforestation rates. Research on conservation impacts at eco-regional (Green *et al* 2013) or continental (Nelson and Chomitz 2011) scales has focused on protected areas (PAs) rather than the broader range of biodiversity-friendly interventions implemented in sub-Saharan Africa (SSA). At the same time, regional studies of the drivers of deforestation in SSA have devoted little attention to the role international funding may play in mitigating or moderating the effects of deforestation drivers.

The impact on deforestation rates of billions of dollars spent by multilateral and bilateral donors on conservation activities in SSA (hereafter referred to as conservation aid; see supporting information) thus remains an open question (Ferraro and Pattanayak 2006, Miteva *et al* 2012). This study marks a first attempt to answer this question at a continent-wide scale using an original panel dataset on covering SSA countries from 2000 to 2013.

An extensive theoretical and empirical literature examining factors affecting deforestation in developing countries finds that deforestation dynamics in Africa differ from other world regions (Rudel and Roper 1997, Angelsen and Kaimowitz 1999, Geist and Lambin 2002, DeFries *et al* 2010). Rates of deforestation across the continent are generally lower (e.g. 2.5% in tropical rainforests from 2000 to 2012 compared to 3.9% in South America and 8.7% in Asia) (Hansen *et al* 2013) and are affected by a different set of drivers. In this article we test the effect of a set of key drivers of deforestation identified in this literature and other variables that may moderate or mitigate their effects (table 1).

Expanding smallholder agriculture and direct use of forest products such as wood fuel, timber and charcoal for domestic use have been identified as major drivers of deforestation in SSA (Fisher 2010, Norris *et al* 2010, Rudel 2013). Agricultural expansion affects forest cover through direct clearing of forests, the rate of which is affected by agricultural productivity and commodity prices (Allen and Barnes 1985, Rudel *et al* 2009). Timber extraction is usually practiced selectively, but can lead to higher rates of clearing by opening up roads that can provide access to settlers (Asner *et al* 2006). Fuelwood collection is also described as a driver of land clearing in SSA (Fisher 2010), particularly in peri-urban areas to sell as charcoal in cities (Rudel 2013).

Other commonly cited factors include rural and national population (Geist and Lambin 2002) and per capita income (Fearnside 2005, Sunderlin *et al* 2005). At the national level, the effect of income on deforestation is thought to follow a forest transition curve (Rudel 1998, Bhattarai and Hammig 2001) in which a country first experiences deforestation as income increases, but later deforestation slows, and eventually reverses to net reforestation after a certain income threshold. Foreign direct investment (FDI) may also be linked to deforestation as this factor reflects economic growth (Li and Liu 2005) and includes information on economic engines of deforestation (e.g. agricultural trade DeFries *et al* 2010). Similarly, official development assistance (ODA) can affect deforestation by contributing to household or national income or by supporting economic activities that result in forest clearing.

Governance may have a positive or negative influence on tropical deforestation (Humphreys 2006). For example, high governance quality can affect a country's ability to enforce conservation policies (Nolte *et al* 2013) but corruption can lead to the exploitation of valuable forest resources (Geist and Lambin 2002, Barbier 2004). Governance, including the extent to which a country is democratic, is also a factor predicting the forest transition (Bhattarai and Hammig 2001, Buitenzorgy and Mol 2011).

Conservation aid and PAs may act as counterbalances to drivers of deforestation. For example, PAs have been found to prevent forest loss within their boundaries (Andam *et al* 2008), but PAs may also lead to displacement of deforestation outside them (DeFries *et al* 2005, Ewers and Rodrigues 2008, Newmark 2008). Much conservation aid is focused on PA management (Mee *et al* 2008), which implies that aid could also have positive or negative effects on deforestation at larger spatial scales. Aid funded integrated conservation and development projects (ICDPs) can be expected to mitigate the effects of deforestation drivers by providing economic alternatives to forest clearing (e.g. agroforestry, community forestry, or ecotourism), strengthening government and other forest management institutions, or increasing enforcement of PAs. In SSA, aid may prove more effective than other areas of the world because of the lower opportunity costs of conservation, as agricultural income is low (Naidoo and Iwamura 2007).

The specific content of conservation aid may limit its effectiveness as a counterbalance, however. For example, forest-related aid on the continent and elsewhere has historically concentrated on development of management plans and provision of technical assistance, which do not directly address key drivers (Kaimowitz 2000). Further, many ICDPs and other conservation aid projects may focus predominately on livelihoods activities rather than conservation ones thus minimizing their ability to reduce deforestation. In Africa as globally, some 70% of conservation aid has supported such 'mixed' projects compared to 30% for more narrowly focused biodiversity conservation projects such as protected area management (Miller 2014). Research also suggests that conservation aspects in integrated projects in SSA have been weaker than comparable projects elsewhere in the world (Milder *et al* 2014).

As studies on aid effectiveness generally (Collier 2007, Wright and Winters 2010) and regionally (e.g. (Miller *et al* 2015) demonstrate, national level governance will likely affect the impacts of conservation aid. The effect of aid may also depend on a country's position on the forest transition curve, as deforestation drivers and deforestation rates evolve. In Africa, total aid has been found to support economic growth (Juselius *et al* 2014) and democratic transition (Gibson *et al* 2015).

The foregoing leads us to two main hypotheses. First, conservation aid will not be associated with reduced forest loss at the national scale (H1). We expect that conservation aid will have an uphill battle in addressing key drivers, not least because most of

Table 1. Hypothesized relationship of key variables to deforestation in Africa.

Variable	Effect	Causal pathway	References
Economic			
Agricultural expansion	−	*Direct.* Clearing of forests for smallholder and other forms of agriculture.	(Allen and Barnes 1985, Rudel *et al* 2009, Fisher 2010, Norris *et al* 2010, Rudel 2013)
Timber and fuelwood extraction	−	*Direct.* Cutting or collecting of wood from forests, which reduces forest area; *Indirect* by providing access (via new roads) to settlers.	(Asner *et al* 2006, Fisher 2010, Rudel 2013)
Livestock production	−	*Direct.* Clearing of forests or selective use of forest resources for grazing.	(Hosonuma *et al* 2012)
Per capita income	−	*Indirect.* Greater household incomes enable greater means to clear forest land (e.g. chainsaws).	(Fearnside 2005, Sunderlin *et al* 2005)
FDI	−	*Indirect.* Effect depends on type of FDI (e.g. agricultural trade) but generally suggests economic growth which can lead to deforestation early in the forest transition curve.	(Rudel 1998, Bhattarai and Hammig 2001, Li and Liu 2005, DeFries *et al* 2010)
Development aid	−	*Indirect.* To the extent that it increases household incomes, can lead to greater demand for food and wood or greater means to directly clear forest land.	(Mak *et al* 2009)
Demographic			
Population	−	*Indirect.* Level of demand for food and wood from forest land.	(Geist and Lambin 2002)
Population growth	−	*Indirect.* Increases demand for food and wood from forest land.	(Geist and Lambin 2002, DeFries *et al* 2010)
Political			
Governance	+/−	*Indirect.* Governance quality will affect a country's ability to enforce conservation policies (+). Corruption incentivizes forest resource exploitation (-), but corruption may hinder economic development, thus limiting forest clearing (+).	(Bhattarai and Hammig 2001, Humphreys 2006, Buitenzorgy and Mol 2011, Nolte *et al* 2013)
Regime type	+/−	*Indirect.* Democratic governments may be more responsive for the country's needs of economic development, and thus result in forest clearing (−, but more democratically advanced countries may provide greater support for institutions, NGOs, and conservation activities (+).	(Bhattarai and Hammig 2001, Buitenzorgy and Mol 2011)
Conservation			
Protected areas	+/−	*Direct.* Protect forest areas (+) or lead to spillovers to non-protected areas (−).	(DeFries *et al* 2005, Andam *et al* 2008, Ewers and Rodrigues 2008, Newmark 2008, Meyfroidt *et al* 2010)
Conservation aid	+/−	*Indirect.* Support protection of forest areas (+), lead to spillovers to non-protected areas (−), or mitigates negative effects of other variables (e.g. by providing economic alternatives to land clearing or strengthening forest management institutions) (+).	This article.

what counts as such aid may not be devoted to conservation or activities that mitigate deforestation. Moreover, many African countries remain at the early stages of the forest transition and commercial pressures for agricultural expansion pose considerable threats to forest conservation across the continent (Ernst *et al* 2013, Laurance *et al* 2014). Despite successes over the past two decades, many countries in the region struggle to consolidate democratic gains or remain autocratic or politically unstable (Cheeseman 2015). Our second hypothesis is that conservation aid will interact with national governance quality such that it will be associated with decreased deforestation rates in relatively better governed countries (H2).

2. Materials and methods

2.1. Data

To examine the effect of aid on deforestation, we compiled a dataset that includes longitudinal data on

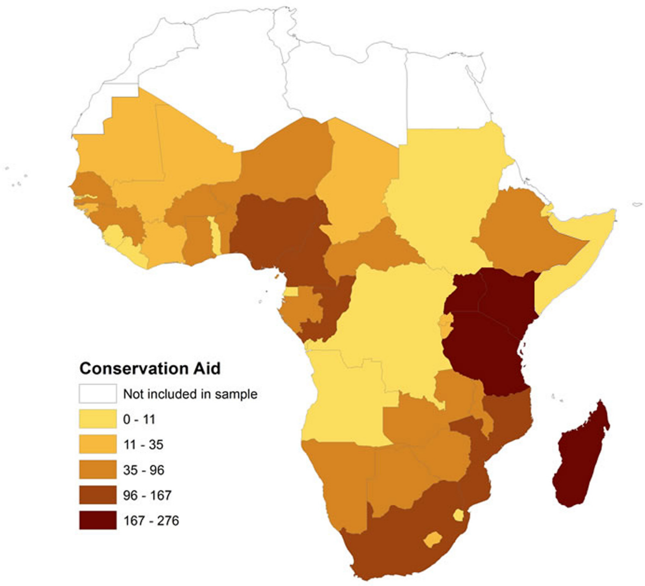

Figure 1. Total conservation aid received by country, 1996–2008 (US$ millions).

country-level measures of deforestation, conservation aid, other drivers of deforestation, and various controls for 42 SSA countries[4]. Our panel data includes deforestation rates from 2000 to 2013 (see below and SI). To analyze lagged effects up to five years, the dataset includes measures of key independent variables going back to 1996. Due to limitations in data availability, some variables only include data through 2008, which is sufficient to analyze five-year lagged effects on deforestation rates through 2013.

Our dependent variable, *deforestation rate*, is the annual percent loss in forest cover for a given country (Hansen *et al* 2013), defined as an aggregation of $30m^2$ areas where forest cover dropped below a specific threshold, either 20% or 50%. Deforestation is measured at these different thresholds to examine varying forms of land use change and forest ecosystems in tropical regions.

The key predictor variable, *conservation aid*, derives from the dataset developed by Miller *et al* (2013) based on the AidData (2012) compilation. This dataset includes nearly 10 000 biodiversity-related aid projects from 1980 to 2008 identified based on a keyword search and systematic coding methodology. Here we use data on all of the projects designated for individual countries in SSA for 1996–2008 (figure 1; $n = 1795$). This period was chosen as it enables up to a five-year lag between aid allocation and its impact on deforestation through 2013.

The dataset includes the full range of conservation aid projects including those 'mixed' projects that explicitly address both ecological and economic objectives, such as sustainable agriculture, local land use planning, and irrigation and watershed management, as well as 'strict' projects with a more narrow biodiversity focus, such as PA management, compliance with environmental treaties, and scientific research (Miller 2014; SI). It excludes industrial forestry projects as the effect of these projects is uncertain: they may increase deforestation through clearing primary forests, they may reduce it by sustainably managing forests for timber, or they may establish new plantations and increase forest cover. The dataset includes coastal and marine conservation projects as some of these may relate to mangroves or coastal trees, though such projects comprise less than 1% of total aid spending for the study sample. Nearly all projects in the dataset should thus have some degree of connection with forest cover, and thus, deforestation. However, the amount of funding allocated within each project for activities that would mitigate deforestation may vary widely, and the dataset does not include this level of detail (SI). Aid data includes money from multinational and bilateral donors administered by NGOs, but does not include NGO money raised internally or from private sources. See the SI for further explanation of the conservation aid dataset.

Consistent with donor practice and the literature on international aid (Hicks *et al* 2008), aid calculations are based on amounts committed rather than disbursed. All aid figures are listed in constant 2000 USD unless otherwise noted. Other variables include *governance*, a composite score derived from the World Governance Indicators for rule of law, effectiveness, and corruption (Kaufmann *et al* 2009), *democracy*, which used Polity IV scores, *PA*, *FDI*, *GDP per capita*, ODA, *population density*, *rural population density*,

[4] Our analysis includes all countries of SSA, except for Eritrea, which was excluded due to extremely low forest cover, and South Sudan, which only became independent at the very end of our time series.

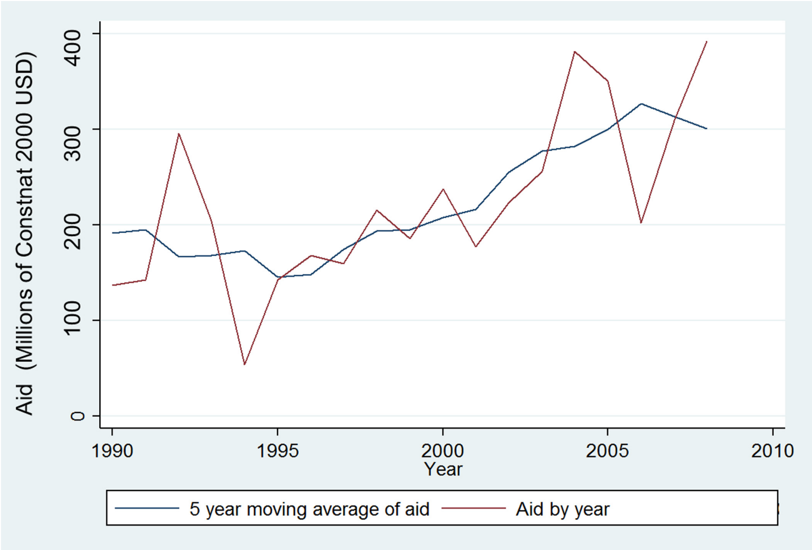

Figure 2. Temporal trends in conservation aid to Africa, 1980–2008.

agricultural area, a *livestock production* index, and *roundwood production* (SI).

2.2. Modeling the effect of conservation aid on deforestation

We modeled the effect of aid on deforestation using multiple OLS regression models with the data described above. Data availability allowed us to construct a panel dataset covering the years 1996-2013. All models controlled for fixed effects and time trend. The independent variables included were chosen for their theorized effect on deforestation as described above. Several variables were logged to ensure a normal distribution (table 3; SI). An independent variable of democracy squared was created to indicate the country's position on the forest transition curve (Buitenzorgy and Mol 2011). To account for different potential time periods between the allocation of aid and other independent variables and their effects on deforestation, we tested models with 1–5 year lags, as is the norm in the aid effectiveness literature (e.g. Bearce and Tirone 2010, Wright and Winters 2010). This lagged approach also helps to address the possibility of an endogenous relationship between conservation aid and deforestation (i.e., that donors may direct conservation aid to where deforestation rates are highest).

Because we expect aid effectiveness to be mediated by democracy and governance quality, we included an interaction term for conservation aid and governance. Deforestation dynamics are known to differ in SSA countries of different forest densities (Rudel 2013), so we also compared sample populations of high and low forest cover countries (SI). Below we present the results of models with two measures of deforestation in two sample populations, one with all SSA countries and another with only highly forested countries (forest area greater than the median for SSA countries). SI and tables S3–S5 contain additional detail and results of the models tested.

3. Results

3.1. Conservation aid flows

Approximately \$2.82 billion USD in conservation aid was allocated to the 42 sub-Saharan African countries in our model from 1996 to 2008 (figure 1; table S1). An additional \$465 million was designed for regional or transboundary projects in Africa not traceable to a specific country. The mean size for the 1795 aid projects was \$1.56 million.

Aid flows to Africa mirror those to the rest of the world during this time period (Miller *et al* 2013), with an overall upward trend punctuated by a spike around the Rio conference in 1992 (figure 2). The top ten recipient countries (table 2) account for 63% of total aid during the study period. Two donors, the World Bank and GEF, accounted for 48% of all conservation aid to Africa. Bilateral donors provided 36% of total conservation aid, led by the US at \$305 million. Despite the increase in funding over time, several African countries remain highly underfunded given the biodiversity they steward, with Senegal and the Democratic Republic of Congo, ranking among the 20 most highly underfunded countries globally in a recent analysis (Waldron *et al* 2013).

3.2. The effect of conservation aid and other variables

We find evidence that conservation aid is associated with increased forest loss after a two-year lag (table 3). On average across SSA countries, a 10% increase in conservation aid is associated with a small but significant (0.17%; $p < 0.01$) increase in deforestation

Table 2. Top 10 conservation aid recipients in sub-Saharan Africa, 1996–2008 (in current 2000 US$).

Rank	Country	Total aid committed (current USD)	Total forest loss 20% threshold	Total forest loss 50% threshold
1	Kenya	$276 226 762	5.82%	9.83%
2	Uganda	$252 052 694	3.59%	9.73%
3	Madagascar	$240 398 026	8.43%	11.20%
4	Tanzania	$235 015 197	4.65%	8.08%
5	Congo, Rep.	$166 568 536	1.17%	1.31%
6	Mozambique	$141 492 071	5.06%	8.86%
7	Cameroon	$130 702 353	1.45%	1.72%
8	Nigeria	$118 407 148	3.63%	3.76%
9	South Africa	$105 164 082	12.73%	26.95%
10	Ghana	$96 192 082	6.19%	9.17%

*Note: forest loss denotes total net forest loss at the country scale from 2000 to 2013.
Source: Hansen *et al* 2013.

rate. Results are similar for heavily forested countries (0.10%; $p < 0.05$). Thus, an increase in aid from the median of roughly $1 million to $6 million (the 75th percentile) is associated with a 10% increase in the deforestation rate. This result held for models with all countries at both the 20% and 50% forest cover levels and for high forest cover countries at the 20% forest cover level for one- or two-year lags. However, it did not persist in models using longer lag periods (3–5 years).

Governance was not statistically significant on its own, but appears to affect the impact of conservation aid in high forest cover countries: conservation aid is associated with reduced forest loss in the short-term in better-governed countries with high forest cover. This interaction had no effect in the model of all SSA countries. Increased democracy scores were correlated with lower rates of forest loss in the short term, while large changes in democracy (democracy squared) was associated with higher rates of forest loss. Increases in the size and amount of PAs were associated with higher rates of forest loss, a finding robust across time lags, forest cover, and country group. Rural population was the strongest and most robust predictor; it was associated with increased forest loss across time periods and forest cover and country groups. Other economic and demographic variables were not consistently significantly correlated with changes in forest cover.

4. Discussion

Model results support the hypothesis that conservation aid is not associated with reduced deforestation rates at the national scale in countries across SSA. On the contrary, during the short term, conservation aid was associated with higher rates of forest loss, while its effect attenuated over the medium term (i.e. 3–5 year lags). Possible explanations for these findings include: (1) the larger context of deforestation drivers in SSA, including rural population the forest transition, and sparse natural forest cover; (2) the spillover effects of deforestation outside of PAs; (3) a donor selection effect, in which conservation aid is allocated to countries with high deforestation rates, and (4) the uncertain amount of resources devoted to deforestation-mitigating activities in conservation aid projects.

Our findings are consistent with earlier arguments that rural population density is a key driver of deforestation across SSA (Geist and Lambin 2002, Fisher 2010, Norris *et al* 2010, Rudel 2013). A larger population implies higher levels of demand for food and forest products, which can lead to forest clearing. Conservation aid may also indirectly encourage some degree of forest clearing to the extent it increases incomes of populations relying of forests for their livelihoods. This finding has been observed in other contexts, such as in Indonesia (Angelsen 1995) and Mexico (Alix-Garcia *et al* 2012), where increasing smallholder income led to greater forest clearing.

At a broader level, our findings also indicate that many SSA countries may be at an early stage of the forest transition, where small advances in democracy (measured by the democracy variable) have little or negative effect on forest loss, but more substantial advances in democracy (measured by democracy squared) are correlated with forest loss, via agricultural expansion and land use transitions (Buitenzorgy and Mol 2011). Countries exhibiting this pattern of greatly improving democracy scores and high deforestation include Kenya and Ghana (forest loss of 5.8% and 6.2%, respectively). These countries, along with others that have maintained high democracy scores such as Benin, Mozambique, South Africa, and Namibia, are characterized by high levels of conservation aid coupled with continued forest loss, likely due to the stronger deforestation pressures associated with countries in early stages of the forest transition. Similarly, a few countries have improved democracy scores by ending or reducing violent conflict (Sierra Leone, Liberia, and DRC); these countries also witness increased forest loss as a consequence of a peace dividend, which has been observed other world regions (Kaimowitz 2002, Davis 2005).

The effect of aid also appears to vary across countries with different levels of forest cover. For example, in East Africa and Madagascar, the combination of sparse natural forest cover and high rural population is likely to place high pressure on forests, which higher conservation aid levels even struggle to counteract. At the same time, countries such as Cameroon, Zambia, Ethiopia, and Botswana, all with moderate natural forest cover, have used medium levels of conservation aid to help maintain low deforestation rates (table S2). Some heavily forested countries such as Republic of Congo and Gabon, which have received comparatively large levels of conservation aid, have been able to

Table 3. Results for regression model with deforestation as dependent variable and conservation aid and governance interaction.

	All countries			All countries			High forest cover countries			High forest cover countries		
	20% deforestation			50% deforestation			20% deforestation threshold			50% deforestation threshold		
Time lag	1 year	2 year	3 year	1 year	2 year	3 year	1 year	2 year	3 year	1 year	2 year	3 year
Conservation aid	0.0165^{**}	0.0009	0.00265	0.0165^{**}	0.00477	0.000114	−0.00257	0.0105^{*}	0.00461	0.00462	0.00673	0.00046
Governance	0.0396	0.0859	−0.0693	0.0639	0.0388	0.0646	0.000689	−0.0168	−0.0952	−0.0192	−0.113	−0.147
Conservation aid*governance	0.00286	−0.00236	0.00142	0.00379	−0.00176	−0.00121	$-.00670^{*}$	−0.00228	0.00470+	$-.00757^{*}$	−0.00126	0.000307
Democracy	-0.0714^{*}	0.018	0.0109	−0.0115	0.0439	0.0381	-0.0582^{*}	−0.0216	−0.0248	−0.0325	0.00876	−0.0133
Democracy^2	0.00717	−0.00343	−0.0056	−0.000876	−0.00581	−0.00244	0.0144^{**}	0.0016	7.39E-06	0.0140^{**}	0.000201	0.00461
Protected areas	0.0758+	0.0359	0.0256	0.166^{**}	0.0736	0.0678^{*}	0.0978	0.247^{*}	0.025	0.16	0.282^{*}	−0.00787
FDI	−0.0596+	0.0412	0.0570^{*}	−0.0684+	0.00181	0.0576+	0.0274	−0.0263	0.0467	−0.000501	−0.017	0.0483
GDP / capita	−0.333	−0.0589	−0.0978	−0.136	−0.0148	−0.364	0.464	−0.594	0.0814	0.177	−0.222	−0.0434
Total ODA	0.0197	−0.0467	−0.0546	0.0294	−0.0407	−0.124	0.0468	−0.0111	−0.0761	0.0484	−0.0418	−0.0685
Pop. density	−0.482	0.592	−1.454	−1.137	0.881	−1.019	0.486	1.263	−0.169	−4.206	−1.824	−0.52
Rural population	4.615^{*}	1.715	3.191^{*}	3.989	1.412	3.996^{*}	4.659^{**}	2.616	1.765	5.254^{**}	4.632^{*}	1.9
Agricultural area	−0.0492+	0.0186	0.00256	−0.0174	−0.0295	6.21E-05	−0.00492	0.00964	−0.0029	0.0269	0.00776	−0.00196
Livestock	−0.00523	−0.00368	−0.00176	−0.00228	0.00209	0.00151	−0.00371	−0.000694	−0.00277	−0.00146	−0.00324	−0.00474
Roundwood	0.225	−0.103	0.744+	0.434	−0.166	−0.263	−0.277	−0.236	−0.332	0.316	−0.15	−0.349
Constant	-70.43^{*}	−27.68	-7.47^{**}	-64.37+	−21.1	-52.13^{*}	-78.93^{**}	−40.7	−20.6	-80.35^{**}	-67.28^{*}	−23.48
Model *F* value	9.979	5.643	7.976	7.06	4.779	5.277	12.494	8.541	8.354	11.361	8.591	7.6399
Model *P* value	0.0^{***}	0.0^{***}	0.0^{***}	0.0^{***}	0.0^{***}	0.0^{***}	0.0^{***}	0.0^{***}	0.0^{***}	0.0^{***}	0.0^{***}	0.0^{***}
Observations	285	281	320	285	281	320	164	163	184	163	162	183
R-squared	0.34	0.229	0.263	0.271	0.202	0.192	0.554	0.438	0.417	0.538	0.437	0.389
No. of countries	39	38	39	39	38	39	22	22	22	22	22	22

Note: conservation aid, GDP, ODA, population density, rural population density, and roundwood variables were (natural) log transformed. Coefficients for year control variables not shown. $^{***}P < 0.001$; $^{**}P < 0.01$; $^{*}P < 0.05$; $^{+}P < 0.10$.

maintain low deforestation rates (1.2% and 0.9% respectively).

Our findings also suggest that conservation aid may indirectly lead to deforestation spillovers from PAs, as noted early in case studies in Africa, (Struhsaker *et al* 2005, Newmark 2008) and worldwide (Ewers and Rodrigues 2008, Meyfroidt *et al* 2010). A significant portion of conservation aid (32%) is 'strict' aid largely focused on PAs (Miller 2014), which in our analysis are associated with increased deforestation. Although PAs in SSA make crucial contributions to the conservation of biodiversity, this leakage underscores the importance of national level land use planning, as well as future research about the displacement effects of PAs.

Our results accord with a growing number of studies on natural resource outcomes generally (Collier 2007) and forest policy outcomes specifically (Agrawal *et al* 2008, Nolte *et al* 2013) that highlight the importance of governance. This article presents evidence that better governance enables conservation aid to be more effective in reducing deforestation in high forest cover countries. This finding is intriguing as it implies better governance helps address spillover issues.

It is possible that the positive relationship between conservation aid and deforestation we observe is due in part to donor allocation of conservation aid to places with high deforestation rates. This explanation aligns with existing research that finds donors are responsive to biodiversity need (Miller *et al* 2013). By using lagged conservation aid indicators in panel regression we sought to address this potential explanation. We also regressed conservation aid on deforestation rate to test it and did not find a significant correlation in most time periods (table S6). It is possible that conservation aid coincidentally correlates with deforestation given that donors prefer countries with higher governance and democracy scores, which may also happen to be countries with higher deforestation rates; potential examples include Ghana, Kenya, and South Africa).

That conservation aid appears to have negative near-term effect on national deforestation rates and no longer term effect may also be due to limitations in our conservation aid data. For instance, some projects include transfers to host countries for administration of their environmental ministries, which may not have much direct impact on activities affecting deforestation. Other projects contain only a small conservation component with the bulk of funding devoted to economic development activities (such as agriculture and infrastructure), which may actually increase deforestation. Indeed, we find that 'mixed' conservation and development aid has become more prevalent in SSA, with 49% of projects classified this way in the 1990s compared to 71% from 2000 to 2008.

NGO and other non-aid funding sources for conservation may also help mitigate deforestation, but data on these expenditures were not available at the country level on an annual basis. Such funding, however, is estimated to be relatively small (Balmford and Whitten 2003, Waldron *et al* 2013). Our conservation aid data also only covers the period until 2008, and thus does not include REDD+ and other climate change-related aid commitments (Nhamo 2011).

5. Conclusion

In SSA, conservation aid faces an uphill battle against a number of demographic and economic drivers of deforestation. This study marks a first attempt to explore the impact on deforestation of two decades of international conservation aid. We find that conservation aid and PAs were correlated with higher rates of forest loss in the short term, suggesting a leakage of deforestation. Rural population is the most consistent factor associated with forest loss, while most other economic factors are inconclusive. Governance quality was also a significant factor, helping conservation aid to be more effective at a national scale in highly forested countries. Cameroon, Ethiopia, Botswana, Republic of Congo, and Gabon stand out as potential aid success stories where high to moderate levels of aid were associated with low deforestation. It is worth noting that although many of the top aid recipients witnessed high rates of forest loss, it is possible, even probable that deforestation would have been *even greater* in these countries if conservation aid was not present.

We underscore that our regression results show correlation and therefore are likely best suited to generating hypotheses to be tested with models better able to identify causal relationships. Nevertheless, our findings suggest that conservation donors and policy makers should carefully consider the potential deforestation leakage and direct greater attention to programs that address larger-scale drivers of land use change. In the years since our data on conservation aid was collected, the focus in much forest policy and related aid has turned to carbon finance and REDD+, which promises greater attention to national planning and leakage. However, these efforts should be more carefully integrated with other conservation investments, notably relating to PAs. New research is needed to update and automate the collection of data on flows of conservation-related aid, in greater detail, and to examine the effect of leakage outside of PAs in more detail. Finally, finer-grained studies that tease out the relationship between governance factors such as property rights and enforcement and conservation aid are needed to better understand the pathways through which such funding can mitigate key drivers of deforestation.

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