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The Dynamics of Deforestation in the Wet and Dry Tropics: A Comparison with Policy Implications

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Abstract: Forests in the dry tropics differ significantly from forests in the humid tropics in their biomass and in their socio-ecological contexts, so it might be reasonable to assume that the dynamics that drive deforestation in these two settings would also differ. Until recently, difficulties in measuring the extent of dry tropical forests have made it difficult to investigate this claim empirically. The release of high resolution LANDSAT satellite imagery in 2013 has removed this impediment, making it possible to identify variations in the extent of wet and dry forests within countries by measuring variations in the canopy cover of their forests. These metrics have in turn made it possible to investigate human differences in the dynamics of deforestation between dry forested and wet forested nations in the tropics. Cross-national analyses suggest that international trade in agricultural commodities plays a more important role in driving deforestation in the wet tropics than it does in the dry tropics. The variable salience of international trade as a driver has important implications, described here, for the success of policies designed to slow deforestation in the dry tropics and the wet tropics. Curbing dry forest losses, in particular, would appear to require locally focused and administered policies.

Keywords: dry tropical forests; humid tropical forests; tropical deforestation

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1. Introduction

Over the past ten years a consensus has gradually emerged about the chief drivers of tropical deforestation worldwide. A series of studies [1–6] have identified large scale, commercial agriculture, frequently engaged in the export of agricultural products, as a primary driver of deforestation in both Latin America and Southeast Asia. A different pattern seems to have characterized deforestation in sub-Saharan Africa. In this region, the small-scale production of agricultural commodities like charcoal, millet, and cassava for local consumption has played a larger role in deforestation [7,8].

Recognition of these regional differences in the dynamics of deforestation has no doubt made investigators more aware of the diverse, conjunctural nature of the forces that have destroyed tropical forests in different places. In many ways though, the emphasis on regional differences just raises a new set of questions. To what do we attribute the regional differences in deforestation? One conjecture might attribute these differences to variations in climate and associated forest types that, in interaction with rural societies, have produced distinctive regional deforestation dynamics. I explore this possibility here with particular attention to possible differences between wet and dry forests in the dynamics of tropical deforestation. This analysis, if convincing, would help us 'unpack' the continental differences in deforestation dynamics observed by many analysts.

Differences in rainfall, in particular, may have had a cascading set of effects on forests and deforestation processes, so, following this logic, the dynamics of deforestation might differ from dry to wet forests. It would be useful to identify these different deforestation dynamics because, once identified, they might suggest efficacious, location specific policies for reducing rates of deforestation. An investigation of these wet and dry forest dynamics takes on added importance right now because global models of climate change project an expansion in the extent of subtropical dry zones and, conceivably, dry forests in the coming decades [9].

To this end, this paper uses newly available, high resolution remote sensing data [10] of recent forest cover changes in the tropics to analyze and compare the dynamics of deforestation in dry and wet forested countries in the tropics. The prevalence of different types of canopy cover in a country, calculated from LANDSAT data, serves as a proxy for the prevalence of dry and wet forests in a country. This canopy cover measure makes it possible to identify predominantly dry and predominantly wet forested countries, analyze the dynamics of deforestation in each set of countries, and then compare these dynamics. I pursue this intellectual agenda through the following steps. I begin by assessing the forest canopy measure for the prevalence of dry forests. I then offer a theory about differences in the dynamics of deforestation between dry and wet forests, describe the data and methods for examining the theory, present the results of the quantitative analyses, and finally, discuss the results and their policy implications.

1.1. Dry Forests and Canopy Cover

Dry forests and woodlands constituted around 42% of the world's tropical forests during the 1980s [11]. Dry forests include a range of different land covers. Shrublands, thickets, open woodlands, and wooded grasslands would all be classified as dry forests. Large expanses of dry forests exist in the Brazilian northeast, in the Paraguay-Parana river basin of South America, in southern and eastern Sub-Saharan Africa, and in South Asia. The inhabitants of dry forest dominated countries in the tropics are among the world's poorest peoples [11,12]. Women in these communities rely to an extraordinary extent for their sustenance on the non-timber forest products (NTFPs) that they can collect in forests [13]. The NTFPs supplement small-scale agricultural and livestock production for both household consumption and for sale in nearby urban centers [14]. The poverty of the dry forest's inhabitants stems from a range of historical conditions, some of which, like the status of these peoples as colonial subjects of European countries during the 19th and 20th centuries, have little or nothing to do with the dry forests that cover the land where they live.

Despite the large extent of the dry forests and the clarion calls to protect them from destruction at the hands of humans [15], their status has been largely neglected by land change scientists [12,16,17]. Analysts have identified threats to forests like population growth in rural areas, but no one has investigated empirically at a global scale whether or not a particular dry forest dynamic of deforestation exists. This paper uses cross-national data on deforestation in the wet and dry tropics to identify this dynamic.

The paucity of studies of the dry tropics most likely reflects the difficulties of defining and therefore delimiting dry forests. Most deforestation data sets, like those of the Food and Agriculture Organization of the United Nations' (FAO) Forest Resource Assessment (FRA) report, do not distinguish between dry and wet forests [12]. The measures for dry forests and woodlands changed with the introduction of new measurement technologies during the 1990s. Prior to the advent of remote sensing, definitions of dry forests emphasized the seasonality of the climate and the stature of the trees in a place. Dry forests occurred in places that experienced pronounced dry seasons and had trees that were shorter in stature than the trees in places with more humid climates [11]. Canopy cover became a more salient measure of dry forests with the increased use of remote sensing technologies after 1990 [16].

Canopy cover has long been a defining feature of forests. For most of the post-WWII era, the FAO defined a landscape as a forest if the canopy cover provided by trees exceeded 15%. More recently, analysts working at the global scale began to use the extent of canopy coverage to distinguish between wet and dry forests. In 2006, Miles and her colleagues [16] used the higher resolution (250 m) of the then newly available MODIS (Moderate Resolution Imaging Spectroradiometer) data to estimate the extent of dry forests globally. They categorized landscapes with canopy coverage between 40% and 80% as dry forests and forests with canopies between 80% and 100% as wet forests. Landscapes with less than 40% canopy coverage were not considered to be forests. In effect, open canopy forests became dry forests, and closed canopy forests became wet forests. I take the same approach here, using a new, global scale data set of LANDSAT images, with a still higher resolution than the MODIS data used by Miles and her associates [16]. The 30 m resolution of the LANDSAT data makes it possible to reliably discriminate between landscapes with differing amounts of canopy cover [10]. Countries in which most canopy cover fell between 25% and 75% would be categorized as dry forest countries while countries in which most canopy cover fell between 75% and 100% would be categorized as wet forest countries. Countries in which most canopy cover fell between 0% and 25% would be classified as non-forested countries.

Data on precipitation and canopy cover by nation supports this approach. Nations in which dry forests exceeded wet forests in extent in the LANDSAT data averaged 881 mm in annual precipitation compared to 1513 mm per year for those nations in which wet forests exceeded dry forests in extent (See Table 1 for data sources). Creating a binary in the tropics of dry forest nations and wet forest nations sacrifices ecological detail about these places, but the use of nations as the unit of analysis makes it possible to bring together in a single, cross-national data set ecological data on forests and socio-economic data on people. It then becomes possible to use this data set to investigate the human drivers of deforestation in wet and dry forested countries. To implement this analytic strategy, I created separate subsamples of (1) tropical nations in which humid forests exceeded dry forests in extent; and (2) tropical nations in which dry forests exceeded humid forests in extent. Analyses of each subsample should reveal whether or not different social and economic forces appear to drive deforestation in wet forest predominating and dry forest predominating countries.

1.2. The Dynamics of Deforestation in Dry and Wet Tropical Forests

While there are important differences, noted below, between the dynamics that drive deforestation in dry and wet tropical forests, there are also some important similarities in the two deforestation processes. In both wet and dry forests, roads provide links to urban areas, so in both places growth in the numbers and affluence of urban consumers would indirectly increase economic pressures to exploit forests at unsustainable rates [16,18]. In both settings, corridors of deforestation emerge along newly constructed or improved roads. Shifting cultivation and charcoal production clusters in corridors along highways in the dry forests of Zambia [19]. Similarly, smallholders, ranchers, and farmers have created corridors of cleared land along roads in the humid forests of the Brazilian Amazon [20]. Pepper farmers in the outer islands of Indonesia established their smallholdings on roads built by the loggers who first exploited these regions [21].

Stagnant economic conditions in both wet and dry forest countries would contribute to deforestation in both settings by making people reluctant to abandon long practiced agricultural livelihoods that entail slashing and burning forests on a regular basis [22]. The same stagnation in economic activity would slow the climb up the energy ladder [23] from wood to charcoal to natural gas, which in turn could contribute to the persistence of high deforestation rates in dry forest regions. In both wet and dry regions, migration to cities would encourage shifts in fuels because more compact fuels, like charcoal as opposed to firewood, would reduce the transportation costs incurred in getting the fuel to the end user.

Differences in the dynamics of deforestation between the two types of regions would begin with differences in building farm to market roads in wet and dry zones. In the wet zones, it takes considerable capital to build roads: to chop down the trees, dig drainage ditches, surface the road with gravel or tar, and construct bridges across the numerous streams and rivers. Private, not public enterprises have built most of the recently constructed or improved roads in the Amazon [24], so the deforestation associated with the recent construction of the new roads in wet zones like the Amazon has usually been carried out by highly capitalized, private enterprises. Roads in dry forests extend out in myriad directions from cities, creating cutover zones around cities that are readily visible in satellite imagery [25]. These roads usually take the form of 'tracks' caused by the repeated passage of vehicles. The tracks open up areas for exploitation, but their construction does not require the capital expenditures necessary to build roads in the humid tropics. Roads cross fewer streams, so they require fewer bridges. In addition, roads do not have to be constructed with gravel or paved surfaces to resist the mires that often occur on roads in regions with frequent rains. For this reason, among others, expenditures on roads to gain access to forests are less in dry zones, and enterprises that exploit dry forests might be expected to have less capital, on average, than those that exploit wet forests.

The clearing of dry forests should also differ from the clearing of wet forests because the agro-ecological productivities of these lands differ so much. Insufficient rainfall limits the productivity of lands in dry forest tropical biomes [26]. Dry tropical forests contain much lower levels of biomass than do humid tropical forests because the low levels of moisture in the soils of dry forests inhibit plant growth [11]. The insufficient rainfall reduces crop yields and diminishes the amounts of standing wood that loggers can cut [27]. The lower levels of agricultural productivity in dry biomes affect the economic geography of agricultural activities that people pursue in these places. The lower yields imply that cultivators will only be able to profit if they can minimize their input and transportation costs. These cost constraints contribute to small-scale and locally oriented agricultural economies in dry zones. The owners of small enterprises do not increase the scale of their operations because they cannot afford to pay the higher wages to workers outside of the family. The same logic applies to costs of transportation. To earn livelihoods from small harvests, cultivators in the dry forest zones must minimize their transportation costs, and this constraint makes it advantageous to sell products in local markets. Limited networks of penetration roads in dry forest regions, particularly in Sub-Saharan Africa [28], place an additional constraint on the long-distance transport of agricultural commodities. For these reasons, international trade would drive trade in the dry tropics to a lesser extent than it does in the wet tropics. In the dry tropics, the size of nearby consuming populations, as well as the continuing economic importance of agricultural livelihoods among rural peoples, would promote the rapid depletion of forests. Given these localized dynamics and the urban influences mentioned above, the loss of dry forests might occur primarily in peri-urban zones.

A different dynamic would appear to apply in humid tropical forests. The higher yields in the more humid zones enable cultivators to pay the relatively high costs of transporting their product to distant, sometimes overseas markets and still make a profit on the lumber that they extract, the soybeans that they grow, or the beef cattle that they raise. In this setting, a large volume of international trade, supported by a worldwide expansion in the size of markets, would play an important role in providing the impetus for the rapid destruction of wet forests [29]. International trade would also encourage the growth of large agricultural enterprises because their large scale would make it possible for the owners of these enterprises to take advantage of the economies of scale provided by the expansion in trade.

These dynamics suggest that different types of enterprises drive deforestation in the dry and wet tropics. Most deforestation in the dry tropics takes an artisanal form, in which small groups, sometimes extended families, work in labor intensive ways with few tools, cutting down trees in dry forests and woodlands in order to produce foods, wood-based fuels, and construction poles for local and regional markets. In the humid tropics, a contrasting dynamic, industrial in form, would prevail. It would consist of large agricultural enterprises that use machinery to clear land and produce for distant, urban markets. These hypotheses can be put to a partial test through statistical analyses of variations in the dynamics of deforestation in wet and dry nations in the tropics.

2. Materials and Methods

Table 1 provides information on the measures and sources for the data used in the univariate and multivariate analyses reported in Tables 2 and 3. The countries in the wet tropical forest and dry tropical forest subsets are listed in Appendix A (Table A1). The data set used for the analyses reported in Tables 2 and 3 is attached in Appendix B (Figure A1).

Table 1. Data Sources for Variables in Tables 2 and 3.

Agricultural Exports, Value in 2000: World Bank. Agricultural raw materials exports (% of merchandise exports) [30].
Cereal Production, 2000: World Bank. World Development Indicators [31].
% of People Economically Active in Agriculture, 2000: Food and Agricultural Organization of the United Nations (FAOSTAT). Food and agriculture data [32].
Forest Area, 2000: The total area in km^2 containing trees with canopy coverage that exceeded 25% in 2000. Supplementary materials—Table S3 in Hansen et al. [10].
Forest Losses, 2000–2012: Removal of a tree canopy at a pixel (30 m) scale. Supplementary materials—Table S3 in Hansen et al. [10].
Forest Gains, 2000–2012: Appearance of tree cover in more than 50% of a pixel between time 1 and time 2. Supplementary materials—Table S3 in Hansen et al. [10].
GDP per Capita, 2000: World Bank. Gross Domestic Product per Capita [33].
Precipitation: World Bank. Average precipitation is the average in depth (over space and time) precipitation in a country [34].
Urban Population, %: 2000: United Nations, Department of Economic and Social Affairs. World Urbanization Prospects, the 2014 Revision [35].

Table 2. Differences between Nations with Closed and Open Canopy Forests *,†.

Tropics (90 Nations)	Wet Forest Countries Closed Canopy Forests Predominate (More than 50% of Forested Land)	Dry Forest Countries Open Canopy Forests Predominate (More than 50% of Forested Land)
% Pop. Active in Ag., 2000	37.1	60.4
% Econ. Activity in Ag., 2000	17.8	30.6
Value ($) PC of Ag. Exports, 2000	34.75	9.96
Cereal Yields (kg/hectare)	2502	1552
% Urban, 2000	51.0	34.8
% Change in Pop., 2000–2005	8.9	11.7
GDP, 2000 per capita	3243	725
% of Forests Lost, 2000–2012	2.82	1.46
% Reforested, 2000–2012	0.79	0.25

* All of the mean differences reported in this table are statistically significant at $p < 0.05$ or lower. † Open canopy forests (25%–75% canopy closure) predominate if they exceed in extent closed canopy forests (75%–100% canopy closure). Similarly, closed forests predominate when they exceed open forests in extent. With these data it was difficult to draw a forest–non-forest dividing line which affected the calculation of the total area in forests, which in turn led to some very skewed results for deforestation rates in arid countries with very little forest. To reduce the influence of these extreme values, we calculated the areal extent of forest losses over the 12-year period (2000–2012) as a proportion of a country's land area. Pop., Population; Ag., Agriculture; Econ., Economic; PC, Per Capita.

Table 3. Forest Losses (logged), 2000–2012, across Wet and Dry Forested Countries.

Variables	Robust Regression Coefficients (with Std. Errors)	
	(#1) Nations with More Closed Canopy (Humid) Forests	(#2) Nations with More Open Canopy (Dry) Forests
Area of Forests with Canopy >25%, Logged	0.980 *** (0.129)	0.661 *** (0.089)
Value of Ag. Exports, 2000 Logged	0.091 * (0.044)	0.052 (0.038)
% Urban Population, 2000	−0.024 (0.089)	0.033 * (0.018)
GDP Per Capita, 2000	−0.090 (0.065)	−0.057 * (0.029)
N of Cases	41	37
F	35.34	24.48
Prob. of *F*	0.000	0.000

$p < 0.001$ = ***, $p < 0.10$ = *.

High resolution LANDSAT data enabled this analysis by making it possible to reliably measure the extent of dry forests in a country, classify those countries into sets of predominantly dry forested and wet forested countries, and then carry out multivariate analyses of the social and economic dynamics of deforestation in each set of countries. Where to draw the cut points between the wet, dry, and no forest categories remains a source of some uncertainty in the analysis. I used the 0%–25%, 26%–75%, 76%–100% categories of canopy coverage for no forests, dry forests, and wet forests, respectively, because Hansen et al. [10] used them. Previous researchers [16] have used a somewhat different set of canopy cover categories for the same forest designations, 0%–39% for no forest, 40%–80% for dry forests, and 81%–100% for wet forests.

The dependent variables in these analyses are the forest losses for a twelve-year period, from 2000 to 2012. The remote sensing analysts used a conservative decision rule to determine whether or not forest cover change occurred in a pixel. For a forest loss to have occurred, forest cover would have to have declined below 50% of the area in a pixel between times A and B. Under this rule a pixel with a closed canopy could experience selective logging and, because the overall canopy coverage did not decline below 50%, the pixel would not register as having experienced deforestation. Similarly, a dry forest with an open canopy could experience a decline in forest cover from 45% to 30%, and it would not register as deforested. This distorting effect applies as much to open as to closed forests, so it would not seem to bias an analysis like this one that compares deforestation processes across the dry and wet tropics.

This study only looks at forests in the tropics, defined as countries with land areas located between the Tropics of Cancer and Capricorn. Because large forest losses can only occur in places with large forests, the equations in Table 3 contain a forest area variable that serves in effect as a control variable for the size of countries. The demographic and economic variables come from compendia of data on nation states published by the United Nations and the World Bank. To correct for skewed distributions, I logged three of the five variables in the multivariate analyses, the dependent variable, forest losses, and two independent variables, the size of forests in 2000 and the value of agricultural exports in 2000. The other two independent variables, GDP per capita and % urban were not sufficiently skewed in their distributions to warrant logging.

Cross-national data sets like this one that contain data from very large countries like Brazil and very small countries like Brunei frequently exhibit problems of heteroscedascity (unequal variances) and influential outlier cases that can produce misleading results when analyzed using ordinary least squares (OLS) approaches. A Breusch-Pagan test confirmed the presence of heteroscedascity in OLS regressions on these data, so, to limit the magnitude of these disturbances, I employed robust regression techniques in the multivariate analyses reported in Table 3. The equations do not exhibit problems of multi-collinearity. The variance inflation factors for the independent variables are all 1.41 or lower.

3. Results

In Hansen's post-2000 data, dry forests constitute 43% of the forests in the tropics, close to the 42% estimate in Murphy and Lugo's [11] work in the 1980s. The descriptive statistics assembled in Table 2 indicate some surprisingly large differences between nations with predominantly dry forests and nations with predominately wet forests. The rates of deforestation in Table 2 were higher in wet forest countries than they were in dry forest countries. The value of per capita agricultural exports was much higher in the wet forested countries than it was in the dry forested counties. In 2000, the value of agricultural exports from the wet forested countries was eight times greater than the value of agricultural exports from the dry forested countries. As might be expected from the differences in rainfall, regrowth occurred less frequently in the dry forest nations. As noted above, countries with more dry forests than wet forests have very poor, predominately rural populations with very large numbers of people earning their livelihoods from agriculture. Populations in the dry forest countries are increasing in size more rapidly than the populations in countries with humid tropical forests. Consistent with the line of reasoning offered above about the agro-ecology of dry forests, the agricultural productivity of cereal crops is lower in the dry forest countries than it is in the wet forest countries.

The results from the multivariate analyses in Table 3 largely support the line of reasoning presented above about the differences in the dynamics of land clearing in wet and dry forested countries. The dry forest equation (#2 in Table 3) suggests that consumer demands from large and growing populations of urban residents spur forest losses. This pattern suggests that deforestation may concentrate in the more accessible rural areas with unprotected forests [36]. The association between lower levels of economic activity and higher deforestation in the dry forest countries in Table 3 underscores how poverty and economic stagnation reinforce a people's dependence on the agricultural sector for their livelihoods and increase the pressure that they put on forests and other natural resources.

A primary difference between the two types of deforestation reported in the multivariate analyses in Table 3 has to do with the geographic scope of the associated agricultural economies. Exports of large volumes of agricultural products to distant, overseas markets spurs wet forest losses, as indicated by the findings in column 1 of Table 3. Malaysia, Indonesia, and Brazil exemplify this humid tropical pattern of voluminous agricultural exports and relatively high rates of deforestation. Agricultural exports have no discernible effect on forest losses in countries where dry forests predominate, as reported in column 2 of Table 3. In these places, significant numbers of people exploit the forests to produce goods for nearby consumers.

4. Discussion

The finding about the variable influence of agricultural exports on deforestation, a driver in countries with humid tropical forests but not in countries with dry tropical forests, is consistent with the depiction of the organization of wet tropical deforestation as 'industrial' and dry tropical deforestation as 'artisanal'. Deforestation in the humid tropics involves large-scale producers of agricultural commodities for distant markets, while deforestation in the dry tropics mostly involves small-scale producers who produce in labor intensive ways for local markets. The finding about deforestation in the wet tropics identifies one of the same drivers, agricultural exports, as did earlier, worldwide, remote sensing based analyses of tropical deforestation [1,6].

The binary association of dry forest losses with an artisanal organization of work and wet forest losses with an industrial organization of work can be carried too far. The most rapid rates of deforestation between 2000 and 2012, in analyses of the LANDSAT data, occurred in the dry forest regions of Paraguay and Argentina, where a wave of large-scale, industrialized agricultural expansion occurred [10,37]. Similarly, very detailed remote sensing analyses of deforestation in the wet forests of the Congo River basin between 1990 and 2010 demonstrated that small-scale cultivators drove much of the deforestation by opening up new fields adjacent to old fields close to the villages where they resided [38]. These admittedly large exceptions aside, the binary of artisanal production in dry tropical forests and industrial production in wet tropical forests finds some empirical support in this analysis, and could serve some useful heuristic purposes in future policy making and research on tropical deforestation.

In thinking about the characteristics of efforts to reduce deforestation in wet and dry tropical biomes, it is important to note the disjuncture between research on tropical deforestation in Latin America and Southeast Asia [29,39] and research on forest governance in Sub-Saharan Africa and South Asia [40–42]. Researchers interested in tropical deforestation almost never reference research on forest governance. This disjuncture reflects, more than anything else, the different dynamics that shape processes of land cover change in wet and dry forests. One often involves worldwide trade of agricultural commodities, while the other usually stems from trade in local markets for food and wood products.

The different loci of these market-driven deforestation processes have led policymakers to focus on different institutions. Wet forest analysts have focused on centralized controls from federal governments, as in Brazil [43], or on the governance of global flows of commodities to places where a significant fraction of consumers want to purchase green certified products [44]. These policy instruments make sense given the industrial scale of many producers in the wet forests and the long-distance flows of the commodities that they produce. Dry forest analysts have attended to the decentralization of political controls over forests and the clarification of smallholder tree tenure [40–42]. This focus follows from the localized circuits of production and trade in and around dry forests. In these smaller scale, more localized trading networks, local authorities would have distinct advantages in crafting and enforcing rules for the artisanal exploitation of the forests. They would be more likely to have the detailed knowledge necessary to discover the small, but cumulatively significant, transgressions in managing dry forests that frequently occur [45].

REDD+ (Reducing Emissions from Deforestation and Degradation) systems could be used to reduce either kind of deforestation, but the organizations through which REDD+ programs would be implemented would look quite different in dry forests compared to wet forests. Where small groups of local people deplete dry forests, community based organizations would play an important role in implementing REDD+. Where the agents of deforestation are larger enterprises, more centralized administering structures, including international certification groups and national governments with remote sensing tools, would probably play a more crucial role in administering REDD+.

5. Conclusions: Research Agendas for Wet and Dry Deforestation

The preceding analyses of deforestation in wet and dry tropical forests suggest several common and several different foci for further research. Some questions about deforestation dynamics seem important to investigate wherever they occur. First, landowners and land managers, wherever they are, must manage their forests for multiple uses, but how does one do that sustainably [46,47]? Two, the role of fire in forests remains poorly documented. How does it interact with climate change and the challenges of limiting greenhouse gas emissions? Finally, climate change has almost certainly begun to spawn coupled natural and human feedback effects in tropical biomes. Climate change induced droughts would accelerate forest losses, not only directly through a lack of rain, but also indirectly through shifts in rural livelihoods. In one recently documented instance in Madagascar [48], farmers, after suffering through crop failures caused by droughts, decided to become charcoal producers. In so doing, the farmers accelerated the rates of deforestation in Madagascar's dry forests. How large in magnitude are these feedback effects, and what do they portend for continued deforestation in tropical biomes?

Several research questions seem particularly important to investigate in one type of forest. Forest losses in the humid tropics now seem tied to long, transnational commodity (value) chains. Further research might focus on the organization of these commodity chains and the way that subcontracting has allowed some companies to endorse compacts for sustainability at the same time that they purchase products harvested from humid tropical forests in unsustainable ways by subcontractors. Deforestation in the dry tropics, with its artisanal organization of work, would seem likely to produce a more fragmented forest than the industrial-scale deforestation in the humid tropics. This circumstance, coupled with the presumed deleterious effect of forest fragmentation on biodiversity, would make it particularly important to investigate the deforestation–biodiversity crisis in dry forest as well as wet forest settings in the tropics.

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Appendix A.

Table A1. Tropical Nations with Predominantly Closed Canopy (Wet) Forests or Open Canopy (Dry) Forests: Ordered beginning on left in column, then top to bottom, by Largest to Smallest Forest Losses, 2000–2012 in km^2 (Top to Bottom): Source: Hansen et al. [10].

Closed Canopy Forests > 50%	Open Canopy Forests > 50%
Brazil, East Timor	Paraguay, Reunion
Indonesia, Brunei	Mozambique, Mauritius
DRCongo, Trinidad Tobago	Tanzania, Cape Verde
Malaysia, Puerto Rico	Angola
Bolivia, Bhutan	Cote D'Ivoire
Colombia, Vanuato	Madasgascar
Mexico, Martinique	Zambia
Peru, Gaudeloupe	Nigeria
Myanmar	India
Venezuela	Ghana
Cambodia	CAR
Vietnam	Liberia
Laos	Guinea
Thailand	Zimbabwe
Guatemala	Uganda
Nicaragua	Benin
PNG	Chad
Philippines	Kenya
Ecuador	Ethiopia
Honduras	Burkina Faso
Cameroon	Sierra Leone
Republic of Congo	Mali
Panama	Malawi
Dominican Republic	Senegal
Gabon	Togo
Cuba	Guinea Bissau
Costa Rica	El Salvador
Belize	Bangladesh
Sri Lanka	Haiti
Guyana	Burundi
Suriname	Rwanda
Solomon Islands	Namibia
French Guinea	Gambia
Equatorial Guinea	Pakistan
Nepal	Somalia
Jamaica	Sudan
Fiji	Botswana

Appendix B.

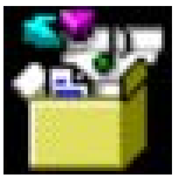

Figure A1. Data and Variable Definitions—SPSS v. 24.

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