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Deforestation in Brazilian Amazonia and Global Warming

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Abstract: Deforestation in Brazilian Amazonia makes a substantial contribution to global emissions of greenhouse gases because of the high rates of forest clearing and the high biomass per hectare of forest. Half of the dry weight of the trees is carbon, and this is released primarily as CO_2 or CH_4 when the felled trees are burned or when any unburned wood decays. Amazonia is not only important to global emissions because of the emissions today, but also because the region has a vast area of forest that remains uncleared. While some tropical forest regions of the world also have rapid clearing and high emissions today, this will not last long because the forest in these areas is coming to an end. The large unreleased carbon stock in Amazonia means that any policy changes that affect deforestation will have an important effect on future emissions. Uncertainty is still high regarding the magnitude of net emissions from Amazonia, including estimates of biomass and carbon stock, burning efficiency (and related trace-gas emissions), and the biomass and carbon dynamics of the landscape that replaces the forest. Substantial progress has been made in reducing the uncertainty surrounding these key components, but the additional information also serves to reveal the scale of our ignorance. Despite these uncertainties, it is clear that deforestation emissions are large and that the environmental gain from reduced deforestation and degradation (REDD) is therefore also large.

Key words: Carbon, environmental services, ecosystem services, greenhouse effect, rainforest, tropical forest.

Deforestation Emissions from Primary Forests

The stock of carbon in primary forests in Brazilian Amazonia is enormous, and avoiding the release of this carbon to the atmosphere therefore represents an important environmental service by avoiding the corresponding impacts of global warming. The term "primary" is used here to refer to forests that are present since European contact. They are not "virgin" in the sense of being uninfluenced by the indigenous people who have inhabited them for millennia, nor are they necessarily free of impact from selective logging and ground fires from recent human influence.

Estimates vary widely as to the amount of biomass and carbon stocked in Amazonian primary forests. However, because of known errors in some of the estimates, the range of genuine uncertainty is much less than the range of numbers that have been published and quoted. Part of this stems from an extremely low value for forest biomass estimated by Brown and Lugo (1984), who calculated that Amazonian forests have an average live biomass of only 155.1 Mg (megagrams

= tons) per hectare, including the roots. This is approximately half the magnitude of present-day estimates. This estimate and a subsequent revision (for above-ground biomass only) to 162 Mg ha^{-1} from the forest volume surveys by the Radar in Amazonia-Brazil Project (RADAMBRASIL) and 268 Mg ha^{-1} from forest volume surveys by the Food and Agriculture Organization of the United Nations (FAO) (Brown and Lugo, 1992a), then revised to 227 and 289 Mg ha^{-1}, respectively (Brown and Lugo, 1992b), were the subject of a colorful dispute, during which this author was accused of being "clearly alarmist" (Lugo and Brown, 1986) for defending higher values for biomass (see Brown and Lugo, 1992c; Fearnside, 1985, 1986, 1992, 1993). While Brown and Lugo themselves no longer use their very low biomass estimates of that period, the ghost of these numbers is still with us to this very day, especially the notorious 155.1 Mg ha^{-1} estimate. This is because many discussions of Amazonian biomass confine themselves to reporting a range of published values, from "X" to "Y" (e.g., Houghton, 2003a,b; Houghton *et al*., 2000, 2001). Readers unfamiliar with the details of the controversies usually assume that the "real" value lies in the middle of the range. This is the "Goldilocks fallacy," or assuming *a priori* that the middle value is "just right." Unfortunately, if the terms are defined in the same way there can only be one correct value for the average biomass of the Amazon forest. That value will depend on the quality and quantity of the underlying data and on the validity of the interpretation applied to these numbers. There is no substitute for understanding and evaluating the arguments involved.

The vast area of Amazonia, diverse types of forest in the region, and the high variability of biomass from one hectare to the next within any given forest type mean that a large number of sample plots is required to adequately represent the region's biomass. The principal sources of data are the RADAMBRASIL survey, with over 3000 one-hectare plots where trees were measured in the 1970s and early 1980s (Brazil, Projeto RADAMBRASIL, 1973-1983) and the 1356 ha of plots surveyed by the FAO (Heinsdijk, 1957, 1958; Glerum, 1960; Glerum and Smit, 1962). Estimates based on much smaller data bases will necessarily carry substantial uncertainty. Examples include the estimates by Saatchi *et al.* (2007), based on 280 plots in primary forests (approximately half of which were in Brazil), and the study of Malhi *et al.* (2006), which interpolated (followed by adjustments for the effects of various environmental variables) based on 226 plots of which 81 were in Brazil, these being heavily clustered in the Manaus, Belém and Santarém areas. One estimate (Achard *et al.,* 2002) was based on a mean of two values, one of which (Brown, 1997) was for a single plot located in the Tapajós National Forest in Pará (FAO, 1978) and made no claim to represent the whole of Amazonia (see Fearnside and Laurance, 2004). Houghton *et al*. (2000) derived an estimate interpolated from 56 plots, while Houghton *et al*. (2001) produced an estimate interpolated from 44 samples, of which only 25 were in Brazilian *terra firme* (upland) forests; these authors then averaged the resulting 192 Mg C ha^{-1} value with six other regional estimates to produce the 177 Mg C ha^{-1} average biomass carbon stock used by Ramankutty *et al.* (2007)

in calculating emissions. This also applies to studies that have based calculations on the Houghton *et al.* (2000) estimate, such as Soares-Filho *et al.* (2004, 2006) and DeFries *et al.* (2002). An additional factor adding uncertainty to interpolation from the small number of samples used in the estimates by Houghton and coworkers is the effect of a pronounced clustering of sample locations, which both exacerbates the lack of coverage for most of the region and reveals the large uncertainty of estimates based on small sample areas, which display high variability among nearby locations. The present study uses 2860 of the RADAMBRASIL plots and includes the information in the RADAMBRASIL vegetation maps.

The placement of the RADAMBRASIL plots is highly non-random, with the samples heavily concentrated along rivers and roads. The concentration of samples near rivers means that riparian vegetation is proportionately more heavily sampled than the upland interfluves between the rivers. Simply converting the RADAMBRASIL volume estimates to biomass and interpolating between the locations will therefore over-emphasize the lower biomass riparian vegetation types and will tend to underestimate average biomass in the region (i.e., the "RADAMBRASIL" estimates in Houghton *et al.*, 2001). The computational ease of using geographical information system (GIS) software to interpolate between the sample points using Kriging techniques produces visually attractive maps but throws out the tremendous amount of labor that the RADAMBRASIL teams invested in classifying and mapping the vegetation.

Another approach is to use remote-sensing information to estimate biomass by associating a variety of parameters detected from space with the biomass measured at a series of reference points on the ground. This has been done by Saatchi *et al.* (2007) using 1 km resolution satellite-borne radar data, from which a number of characters were extracted and associated with published or otherwise available data from plots surveyed since 1990. The older, but much larger, data sets from the RADAMBRASIL and FAO surveys were not used for calibrating the satellite-borne radar results, nor were the vegetation maps that the RADAMBRASIL project derived from high-resolution airborne radar coupled with extensive field observations.

Using the RADAMBRASIL dataset requires considerable effort due to confusion regarding the vegetation types in the map legends. Among the 23 volumes into which the coverage of Brazilian Amazonia is divided, the map codes corresponding to different vegetation types change from one volume to another. The level of detail in the codes is not consistent throughout the survey, some volumes using four-letter codes and others simplified to three. In Brazilian Amazonia there are 145 vegetation types in the RADAMBRASIL data set. These can be translated into the 19 forest types used in 1:5,000,000-scale maps by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) and 1:2,500,000-scale maps by the Brazilian Institute of Geography and Statistics (IBGE), using equivalences that change depending on the RADAMBRASIL volume.

Table 3. Marginal climate effects on livestock species choice in Africa

	Beef	Dairy	Goats	Sheep	Chickens
Species choice: All farms					
Baseline	6.26%	28.30%	19.84%	23.46%	22.14%
Temperature	-0.31%*	-0.02%	0.51%*	1.75%*	-1.94%*
Precipitation	0.05%*	-0.04%*	0.11%*	-0.14%*	0.03%*

** denotes significance at 5% level; * Seo and Mendelsohn, 2008a.

livestock farms make different species choices (Seo and Mendelsohn, 2008d). Large farms tend to rely on beef cattle and dairy cattle while small farms resort more often to chickens and goats. When temperature warms, large farms, but not small farms, move away from owning beef cattle. This is because large farms in Africa have specialized in highly profitable but heat-sensitive breeds of beef cattle. Large farms also turn away from chickens as temperatures warm and move towards dairy cattle, goats, and sheep. As temperatures warm, small farms shift towards sheep. As precipitation increases, small farms move away from sheep and substitute goats.

Using the microeconometric approach, authors also examine expected changes in the profitability of each livestock species after correcting for selection biases (Seo and Mendelsohn, 2008a). For example, if temperature increases by 1 degree Celsius, the numbers of beef cattle and chickens decrease but herds of goats, sheep, and dairy cattle slightly increase. A slightly abundant precipitation increases the numbers of chickens and beef cattle but decreases the number of goats, sheep, and dairy cattle.

Livestock as a Component of Agriculture: South American Example

Livestock is an essential component of agriculture. Most farms in developing countries have both crops and livestock. In this section, we shift our focus to the farms that own both crops and livestock. We also shift our attention to another developing continent, Latin America.

In South America, there are 56% of farms that own crops and livestock, 33% of farms specializing in crops, and 12% specializing in livestock (Seo, 2008a). The data were based on the surveys collected from seven countries across South America: Argentine, Brazil, Chile, Uruguay, Colombia, Ecuador, and Venezuela (Seo and Mendelsohn 2008c). In Table 4, livestock species holdings of South American farmers are shown. A major difference from African farms, shown in Table 1, is that the South American farms that chose beef cattle as the primary animal accounts for almost 30% of the whole farms and more than 50% of the livestock farms. In Africa, only 7% of farmers specialized in beef cattle. About 40% of South American farms have only crops. Other animals such as pigs, sheep, and chickens account for about 10% of the farms.

Empirical analyses of South American farms show that joint farms and specialized farms react to climate variation differently (Seo, 2008a). Specialized farms are chosen more often in the middle temperature zones avoiding either climate extremes. On the

Table 4. Livestock holdings in South America

	Beef cattle	Dairy cattle	Pigs	Sheep	Chickens	Only crops
Number of farms	275	186	42	35	14	414
Percentage of farms	29%	19%	4%	4%	1%	42%
Mean temperature (°C)	17.3	19.5	17.2	14.7	19.3	17.5
Mean precipitation (mm/month)	98.6	112.7	98.7	84.9	108.9	102.3

* Seo, 2008.

contrary, mixed farms are chosen in extreme climates, i.e. in too cold zones or in too hot zones. The optimal temperature for specialized livestock farms is slightly higher than that for specialized crop farms.

Three types of farms are also preferred in different rainfall zones. When rainfall is abundant, there are more farmers adopting crops only. More farmers also mix crops with livestock as rainfall increases, but not in too high rainfall. Livestock only farmers are found most often in dry zones.

The results are consistent with the findings in Africa. Farmers in arid zones can specialize in commercial livestock such as cattle but they mix crops with goats and chickens when climate becomes wetter. In South America, beef cattle are raised commercially most often in temperate dry zones of Brazil and Argentina.

The results imply that the impact of climate change cannot be estimated solely based on crops. If farmers can add or subtract livestock as climate changes, they will have more leverage to cope with climate change. In the above analysis, if farmers can move from a specialized crop farm to a mixed portfolio with both crops and livestock, they will be able to offset some losses. Farmers will be able to adopt more beef cattle if climate turns dry. Studies from Africa and South America indicate that the impact of climate change is smaller when farmers are allowed to switch between crops and livestock within the models (Seo *et al.*, 2009a; Seo, 2008a).

Discussions

Although economists have studied climate change impacts on agriculture extensively for the past two decades, the literature on the economic effects of climate on animal husbandry is sparse. Scientific experiments reveal that livestock are affected by climate conditions directly or indirectly. Recent economic models also indicate that net revenue from livestock is sensitive to climate.

Most economic studies regarded arid zones as one of the most vulnerable regions under global warming because crop varieties are highly vulnerable. Recent studies, however, find that arid zones are more suitable for livestock husbandry than for crops. Net revenues from livestock are higher in drier zones in Africa for both small farms and large farms. Therefore, as long as there is enough precipitation to support grassland, farmers can still generate revenue even if they lose large profits due to crop failures.

Large livestock farms are particularly vulnerable under global warming because they tend to specialize in beef cattle, which are most profitable. If temperature increases, revenues from large commercial farms fall precipitously in Africa. On the other hand, small livestock farms usually own a mixed portfolio of numerous crops and livestock species, which make them more resilient than large commercial farms in Africa.

Farmers in both Africa and South America should be able to adapt as climate changes. If climate turns out to be hot and dry in the future, farmers should avoid specializing in crops. They should instead diversify their portfolios into both crops and livestock. They should also choose livestock species that are better suited to such conditions, e.g., sheep. If on the other hand, climate becomes wetter, farmers should adopt more crops. These adjustments should be made in careful consideration of the agro-ecological conditions of the farms.

Policy makers who attempt to design a global climate policy which would last centuries should consider agriculture as the mixture of crops and livestock (Nordhaus and Boyer, 2000; Nordhaus, 2007). If livestock effects are carefully considered, the impact of climate change on agriculture is not devastating even in Africa and South America (Seo *et al.*, 2009a; Seo, 2008a). However, a mild climate damage estimate is contingent upon the assumption that all the necessary adaptation measures, explained in detail in this survey, can be taken in a timely manner and without transition cost (Kelly *et al.*, 2005). Policy makers should assist farmers to adapt by providing appropriate information to make better decisions. Governments or international organizations can help credit constrained farmers by providing credits to take necessary measures. Policies should avoid a blanket approach in assisting adaptations. Rather, adaptations should be taken in a mosaic pattern in which farmers in different agro-ecological zones take measures that suit them best (Seo *et al.*, 2009b). Finally, future researchers should examine whether there exist differences among various breeds of a certain species or whether a heat tolerant species can be developed to adapt to climate change (Johnson, 1965).

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