The opportunity costs of reducing carbon emissions in an Amazonian agroindustrial region: the Xingu River headwaters

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Abstract

Negotiations are proceeding for a new international climate change regime that will compensate tropical nations that reduce their carbon emissions from deforestation and forest degradation. In anticipation of this new mechanism designed to slow deforestation, regional projects to reduce tropical deforestation will provide important training grounds for the development of deforestation-reduction programs that are compensated by the carbon market. One of the world's largest regional forest carbon "products" is under development in the headwater region of the Xingu River in the southeastern Brazilian Amazon. This approximately 177,000 km^2 area contains the Xingu Indigenous Park at its core, home to 14 indigenous tribes. Surrounding the park is a rapidly expanding soy and cattle sector. We estimated annual deforestation-driven carbon emissions in this region for 2000 through 2007 as a basis for estimating the historical baseline of emissions. We then estimated the opportunity cost of maintaining forestlands using spatially-explicit rent models for soy production, cattle ranching, and sustainable timber harvest. We estimated a baseline of 10.9 million tons of annual carbon emissions. The average annual opportunity cost of reducing carbon emissions from deforestation to nearly zero was $270 million and $23 per ton of reduced carbon emission. Over a five year period, ca. 55 million tons of carbon emissions reductions could be achieved for a total opportunity cost (of foregone profits from soybean cultivation and ranching) of $1.2 billion. By law, however, private landholders are not allowed to clear more than 20% of their forests (in the forest biome) or 65% of their *cerrado* savanna vegetation. If this law were enforced within each tributary of the Xingu River headwaters, and compensation of opportunity costs were applied only to forests in excess of the legal requirement, then costs would decline to nearly zero, since the vast majority of landholders in this region are not in compliance with the law. If the maintenance of those forests required to comply with the law are compensated at the rate of 50% of opportunity costs as an incentive to keep forests standing, then the five-year cost of reducing deforestation to zero declines to $600 million and $12 per ton of reduced carbon emissions. To provide each of the 940 indigenous families in the Xingu Park with a forest subsidy of $2400 per family per year would cost $2,300,000 annually, which translates to a mere $0.06 per ton of carbon emission reductions. Given the historical baseline for deforestation in the Xingu region, it would take nearly 50 years to completely clear the forests that lie outside of protected areas, providing a long-term stream of revenue for the region that is tied to ongoing success in maintaining forest carbon stocks.

Keywords: carbon emissions, land use and land cover change, avoided deforestation, carbon market, land use policy, Amazon, tropical deforestation

Introduction

Tropical deforestation is the cause of 8 to 25% of world-wide, human-induced emissions of carbon to the atmosphere (Canadell et al. 2007). Despite this, the Kyoto Protocol provides no incentives for reducing deforestation (Schlamadinger et al 2007). In 2005, at the Montreal Conference of the Parties of the UN Framework Convention on Climate Change, a proposal was formally made to include deforestation in the post-2012 UNFCCC regime (Santilli et al. 2005, Gullison et al. 2007, Skutsch et al. 2007, Sedjo and Sohngen 2007). Negotiations of this important new component of climate change policy must be completed by December of 2009. One important challenge in developing the "Reductions in Emissions from Deforestation and forest Degradation" (REDD) regime is to determine the cost of deforestation reduction programs, and the possible flow of benefits to indigenous peoples (Griffiths 2007). In this paper, we present an analysis of the opportunity costs of reducing deforestation to zero in a large agroindustrial Amazon landscape with a large indigenous population.

Brazil is the world's biggest emitter of carbon from deforestation. In 1995, deforestation in the Brazilian Amazon hit a record high of 29,000 km^2 cleared in that year (INPE 2007). News of the Amazon forest's accelerating destruction precipitated an international crisis, and the Brazilian government responded with widely publicized policy interventions, the most prominent of which was the increase from 50 to 80% forest cover of rural properties in the "legal reserve" mandated by the Brazilian Forest Code in the Amazon region. Annual deforestation tallies declined markedly thereafter, hovering around 18,000 km^2 per year for the next 5 years. However, starting in 2001, deforestation surged again, climbing approximately 3500 km^2 per year to a high of 27,429 km^2 in 2004. Much of the increase in deforestation was associated with the expansion of agroindustry and ranching in the state of Mato Grosso, where more than 1/3 of the Brazilian Amazon's deforestation took place from 2002 to 2004 (Nepstad et al. 2006). In the face of an ever-increasing number of regional and global drivers—including increasing demand for soybeans for feed and biodiesel, range-fed beef, and ethanol from sugarcane—the extraordinary profits to be gained by private landowners who convert forests and woodlands to soy in the southeast Amazon region greatly overshadow the revenues to be gained by managing forests for timber or nontimber products. Although deforestation rates have declined steadily in 2005, 2006, and 2007 as soy and beef prices have fallen (INPE 2007), a 7% increase in the area of soy planted in Mato Grosso is projected for the 2007/2008 crop and prices for beef are also climbing again (Zafalon 2007). This trend may strengthen in the future, as growing demands for biofuel and animal ration will likely maintain pressure on Amazon forests for many years to come.

In this study, we examined the Xingu River headwater region, in northeastern Mato Grosso, where highly profitable expansion of soy and cattle ranching has taken place around an indigenous park that is home to 14 tribes. The Xingu region is representative of many areas along the Amazon's agricultural frontier, but faces a more acute and immediate threat because it lies between two major federal highways (BR-158, BR-163) that have been slated for paving, and lies in the immediate pathway of the northward expansion of Brazil's grain belt. The central question of our research is: how much would it cost to the soy and cattle industries, per ton of reduced carbon emission, to slow deforestation in this region? We estimate the opportunity cost of foregone profits from soy and cattle production of lowering deforestation rates, the implications of legal compliance with the private land "forest code" for these costs, and the potential for building benefits for the indigenous populations of this region into the price of carbon.

Study Area

The study landscape is the headwater region of the Xingu River (Fig. 1). This 177,780 km^2 region is located in the northeastern corner of Mato Grosso state, in central Brazil. The region's soils (latosols, regosols, and red yellow podzolic soils in the Brazilian system) (Askew *et al*., 1970a), topography (100-300 m altitude, with flat interfluvial expanses) and climate (Ratter *et al*., 1973) are well-suited for soybean production and cattle ranching. The region is characterized by distinct dry (May to October) and wet (November to April) seasons, with 1350 to 1700 mm annual rainfall and a mean annual temperature of 23.5°C to 24.9°C (range: 17.0-32.7C) (Askew *et al*., 1970a; Furley *et al*., 1988; Ivanauskas *et al*., 1997). Native vegetation types in the region are comprised of forests (tall evergreen (25-45 m) transitional semi-deciduous (10-30 m), and riparian) and savannas (cerrado woodland, mosaics of grassland, thickets, gallery forests) (Askew *et al*., 1970b; Furley *et al*., 1988; Ivanauskas *et al*., 1997).

Ten indigenous territories are completely contained within the boundaries of the Xingu watershed in Mato Grosso (Fig. 1). Indigenous territories cover approximately 42,200 km^2 within the basin, representing 24% of the total area of the headwaters region. The population of indigenous peoples in the region is approximately 10,000, representing 20 different distinct ethnic groups, and representing approximately 2% of the total population of the region. Of these territories, the Parque Indigena do Xingu (PIX) is the largest, with an area of 28,000 km^2 (16% of the total headwaters area) (for comparison, the nation of Costa Rica has an area of 51,100 km^2). The territory is inhabited by approximately 4700 people (ca. 940 families), distributed among 14 different tribes (ISA 2007). However, the streams and rivers of these indigenous lands are under growing threats from sedimentation, agrochemical run-off, and associated fish die-off from the unprotected headwaters regions outside of the park boundaries, among the effects of the region's major economic activities (Sanches 2002).

At the turn of this century, global demand for soy and currency devalution also began to push soy prices up (Nepstad et al. 2006). Whereas in 1976, Mato Grosso planted no soy, by 2005 it planted one quarter of Brazil's national crop (Jepson 2006). Mechanized soy cultivation became extremely lucrative, making agrarian reform and forest protection difficult. Adding to this, Brazilian beef exports were growing in step with the growth in soy. Between 1994 and 2003, nearly 20,000 km^2 of transitional and tall evergreen forest were cleared in the Xingu region (Stickler *et al*., in prep). Since 2005, when soy prices dramatically dropped due to a rise in the value of the *real* against the dollar and the U.S. produced a bumper crop, many soy farmers have abandoned newly cleared lands and restricted their planting. However, soy prices are on the rise again (nearing the peak price of 2004), and although the area to planted in 2007/2008 was projected to be smaller than it was at the peak in 2004, farmers are rapidly reclaiming area that was soy three years ago (Zafalon 2007). Cattle ranching also continues to be an important economic activity in the region. During the brief soy crisis, ranching has served as a fall-back activity for many property owners. Moreover, the beef industry continues to grow in its own right. Finally, for some parts of the headwaters region, timber harvesting has been the dominant activity until recently. In the northwest and west of the basin, logging far outweighed ranching or agriculture until 2005, when federal and state authorities began to clamp down on the distribution of logging permits. Since 2006, the industry has been virtually at a standstill.

Methods

2007 Land Cover

To evaluate the current extent of deforestation in the region as a starting point for analyses of future policy options, we developed a land cover classification map for the year 2007 using image segmentation and object-oriented classification techniques on a 25m-resolution ALOS PALSAR image mosaic (composed of images from June and July 2007) (J. Kellndorfer et al., unpublished data), a 30m-resolution (oversampled to 25 m) Landsat 5 ETM image mosaic (composed of images from June to August 2007) (C. Stickler et al., unpublished data), and a 90m-resolution NASA Shuttle Radar Topography Mission (SRTM) digital elevation model (oversampled to 25 m). We distinguished cleared areas from more vegetated forest or *cerrado* woodland areas, as well as an aggregated "non-forest" class including such land cover types as wetlands and open water. In addition to tallying the total area of each class for the entire watershed to determine the total amount and location of forest and *cerrado* remaining in the region, we evaluated the extent to which the region as a whole meets legal requirements set forth by the Brazilian Forest Code for forest and/or *cerrado* reserves on private rural landholdings. To do so, we removed areas falling within protected areas (either indigenous territories or conservation units) and areas falling within legally mandated riparian buffer zones around streams, lakes, and springs from the analysis. The resulting map provides an indication of compliance with the legislation at a landscape-level, although it does not provide information regarding individual landholder compliance without additional property maps. We further refined the landscape-level analysis by determining the extent to which the major tributary watersheds to the Xingu River met legislative requirements. By calculating the amount of forest in excess of the legal requirement within each watershed, this analysis allowed us to determine the amount of compensation that private rural landholders as a group might be eligible for under a reduced carbon emissions compensation program.

Annual Deforestation, Carbon Emissions, and Historical Baseline, 2000-2007

We estimated annual deforestation in the Xingu headwaters region from 2000 to 2007 primarily using maps developed by the Brazilian National Space Research Institute (INPE) under the auspices of its PRODES annual deforestation monitoring program for the Brazilian Amazon (INPE 2008). Because spatially explicit data from PRODES were only available through 2006, we applied a mask derived from the INPE PRODES data to screen out areas classified as non-forest (including wetlands, *cerrado* woodlands, and other features and formations not considered to be part of the semi-deciduous and evergreen forest biomes of the region) and as previously deforested (through 2006) to our 2007 ALOS/Landsat-based classification. We identified those areas cleared in each year of the time series and tallied the total area.

To estimate the annual deforestation-driven carbon emissions from 2000 to 2007, we used a map of aboveground forest biomass developed for the region using remotely sensed and field-based data from or before 2000 (Saatchi et al. 2007). We estimated carbon stocks as one half of biomass and assigned carbon values to each pixel of deforestation. For each year, we summed the tons of carbon emitted from the cleared areas using published estimates of the carbon content of the pastures and farm plots that replace forests following clearing (Houghton et al. 2000).

We estimated the historical baseline for deforestation and for carbon emissions by averaging the annual deforestation and emissions, respectively, over the eight years from 2000 to 2007. Although current UNFCCC negotiations are considering deriving a baseline that includes deforestation and/or carbon emissions through 2005 (the year in which the reduced emissions from deforestation proposal was formally accepted as a point of discussion for the post-Kyoto period), since both deforestation and carbon emissions were lower in 2006 and 2007 in the Xingu region, our baseline is more conservative, in that it allows fewer credits to be earned (a baseline calculated from data through 2005 would have allowed nearly 3 million more carbon credits to be earned per year).

Opportunity Cost of Avoided Deforestation

The opportunity cost of avoided deforestation was calculated using spatially-explicit rent models for soy production (Vera Diaz et al. 2007, Nepstad et al. 2007), cattle ranching (Merry et al., unpublished data), and sustainable timber harvest (Merry et al., submitted)—the three major economic activities in the region. These models estimate the potential rent of each economic activity based upon analyses of the costs of production (several of which are spatially-dependent, such as transportation costs), yields, and prices. For each of the three economic activities, the net present value was estimated for 30 years into the future assuming a 5% annual discount rate and a plausible schedule of highway paving (Soares et al.2006). The layers derived from the models were combined such that, for any given pixel, the net present value of timber harvests was subtracted from the highest value from either cattle or soy activities. Negative values resulting from this calculation were set equivalent to zero opportunity cost. The area of interest was defined by the area classified as forest in 2007. We used the resulting map of opportunity cost to derive a map of price per ton of carbon, by dividing each pixel's estimated net present value by its carbon content.

We developed carbon supply curves to describe both the change in area of forest and the change in tons of carbon currently held by forested lands in the region as a function of the price per ton of carbon.

Results

Forest Cover in Xingu in 2007

In 2007, the Xingu headwaters region had 107,181 km^2 (78% of historical forest cover) of forest and 24,904 km^2 (66% of historical *cerrado* cover) of cerrado remaining over the entire area, including protected areas and riparian zones. Whereas the region's *cerrado* cover at the landscape level exceeds the legally mandated minimum of 35% of the historical vegetation by 11,611 km^2, total forest cover is already below the legally mandated 80% by 3,079 km^2. When indigenous territories, protected areas, and riparian areas are removed from the analysis, forest cover decreases to 69% (96,308 km2) of the original and cerrado cover to 58% (29,705 km2). For the forest biome, this represents a deficit of 10,702 km2 compared to the legally required amount. No sub-basin in the region had 80% or more of its forest vegetation, whereas the majority of tributaries had enough cerrado to meet the legal requirements (Figure 2).

Annual Deforestation and Historical Baseline, 2000-2007

Annual deforestation in the region from 2000 to 2007 ranged between 64,855 ha and 317,011 ha, peaking in 2003 and declining to its lowest level in 2006 (Figure 3a). Average annual deforestation over the seven-year period was 195,144 ha. Carbon emissions in the region followed a similar trend, ranging from ca. 2.5 million tC to ca. 18.5 million tC, peaking in 2004 and declining to the lowest level in 2007 (Figure 3b). Average annual carbon emissions were estimated to be 10.9 million tC.

Estimate of opportunity cost

The net present value of deforestation-dependent economic activities (soy production, cattle) for forested lands in the region ranged from $0 per ha to $2762 per ha (Figure 4). This translated to a price per ton of C of $0 to $180 (Figure 5). We estimate that approximately 71% of the forests in the region could be maintained for an opportunity cost of less than $20 per ton of carbon.

Cost of Reducing Emissions from Deforestation

This analysis suggests that the reduction of approximately eleven million tons of carbon emissions per year could be achieved through opportunity costs of $230M, or $23 per ton of carbon. However, Brazilian law imposes restrictions on the economic activities that can be carried out in the Amazon region. Private landholders cannot clear more than 20% of their forests for agricultural activities, although compliance with this law is very low. Hence, the opportunity costs associated with the reduction of carbon emissions may be only partially eligible for compensation, or not at all. The compensation of deforestation reduction that is already mandated by the law is an important topic of negotiation within the REDD regime of the UN Framework Convention on Climate Change.

Other costs, however, might be added to the cost of reducing carbon emissions from the Xingu region. For example, the 28,000 km^2 Xingu Indigenous Park at the core of the region has had virtually no deforestation, in part because of the successful efforts of the indigenous residents of this park in protecting these forests from incursions from ranchers and soy farmers. To provide each indigenous family in the Xingu Park with a forest subsidy of $USD 2400 per family per year—the minimum federally determined minimum salary in Brazil—would cost $2,300,000 annually, which translates to $0.06 per ton of carbon emission reductions. Hence, a very substantial level of compensation of indigenous communities is only a small fraction of the opportunity costs to soy growers and cattle ranchers.

Discussion and Conclusion

A carbon market mechanism for compensating Reductions in Emissions from Deforestation and Forest Degradation (REDD) could potentially slow deforestation and provide substantial flows of benefits to forest peoples even where the profitability of deforestation is extremely high. The average cost of taking the Xingu region deforestation down to nearly zero is about $20 per ton of carbon, well within the range of prices being paid in other markets (e.g., CCX: $15.73/tC; EU ETS: $41.81; Marketwatch 2008). The volume of these reductions is probably too great to be absorbed by the current volunteer market, however, where a total of approximately one million tons of carbon credits were traded in 2007 (P. Moura, Ecosecurities, pers comm.). But when an international regulatory framework is negotiated within the UNFCCC, our analysis demonstrates that substantial volumes of carbon credits from REDD could be developed at a reasonable place.

The payment of landholders to comply with forest legislation could potentially be disqualified since it does not satisfy the additionality requirements of carbon programs. However, in the Brazilian Amazon, the Forest Code is regularly attacked by agroindustrial interests in the federal Congress, and is virtually ignored by landholders. The provision of positive economic incentives for those countries that establish ambitious environmental legislation could go a long way in expanding support for REDD among tropical nations without making the price of these carbon credits beyond the reach of the market.

This analysis does not include transaction costs, including the development and implementation of institutional structures to channel carbon credit payments to beneficiaries, and to audit and verify emissions reductions. Future analyses will address transaction costs. However, our analysis does demonstrate that it is possible for a REDD payment scheme to provide substantial benefits to forest people while compensating the opportunity costs of forest maintenance for a highly-profitable agroindustrial sector. This is critical because not only do these groups sometimes have a dramatic impact on forested landscapes (as in Central and East Africa), but they are also the people who may best be able to protect forests and their ecosystem service functions. One concern that has been raised regarding avoided deforestation is that it will simply be one more top-down policy scheme that marginalizes these groups. Thus, any compensated reduction scheme must ensure equitable and effective distribution of benefits to all actors.

Finally, this our study indicates that science may have a critical role to play in policy-making for tropical forests by providing technical assistance in investigating the possible outcomes of different policy alternatives. In this case, in addition to identifying possible streams of revenues and incentives for different actors, our analysis makes it possible to determine where the cost of compliance is likely to the lowest and the conservation opportunities may be maximized. A next step in this research will be integrate the calculation of opportunity costs within a dynamic landscape simulation model that projects land cover change and corresponding changes in carbon stocks into the future in response to different carbon credit schemes.

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Figure 1: (a) The Amazon Basin region, showing areas of deforestation (red) within the Legal Amazon (composed of nine Brazilian states). The Xingu River basin is outlined in yellow; (b) The state of Mato Grosso (light brown), with federal and state conservation areas (light green) and indigenous areas (yellow) and major federal and state roads (red) shown. The Xingu River headwaters region is highlighted in dark green; (c) The Xingu River headwaters region, with indigenous lands and protected areas shown (red hatching). Land cover is shown for a Landsat 5 TM mosaic from 2007; greener areas indicate presence of more native vegetation or higher biomass regeneration, pinker areas indicate cleared areas or areas of low native biomass.

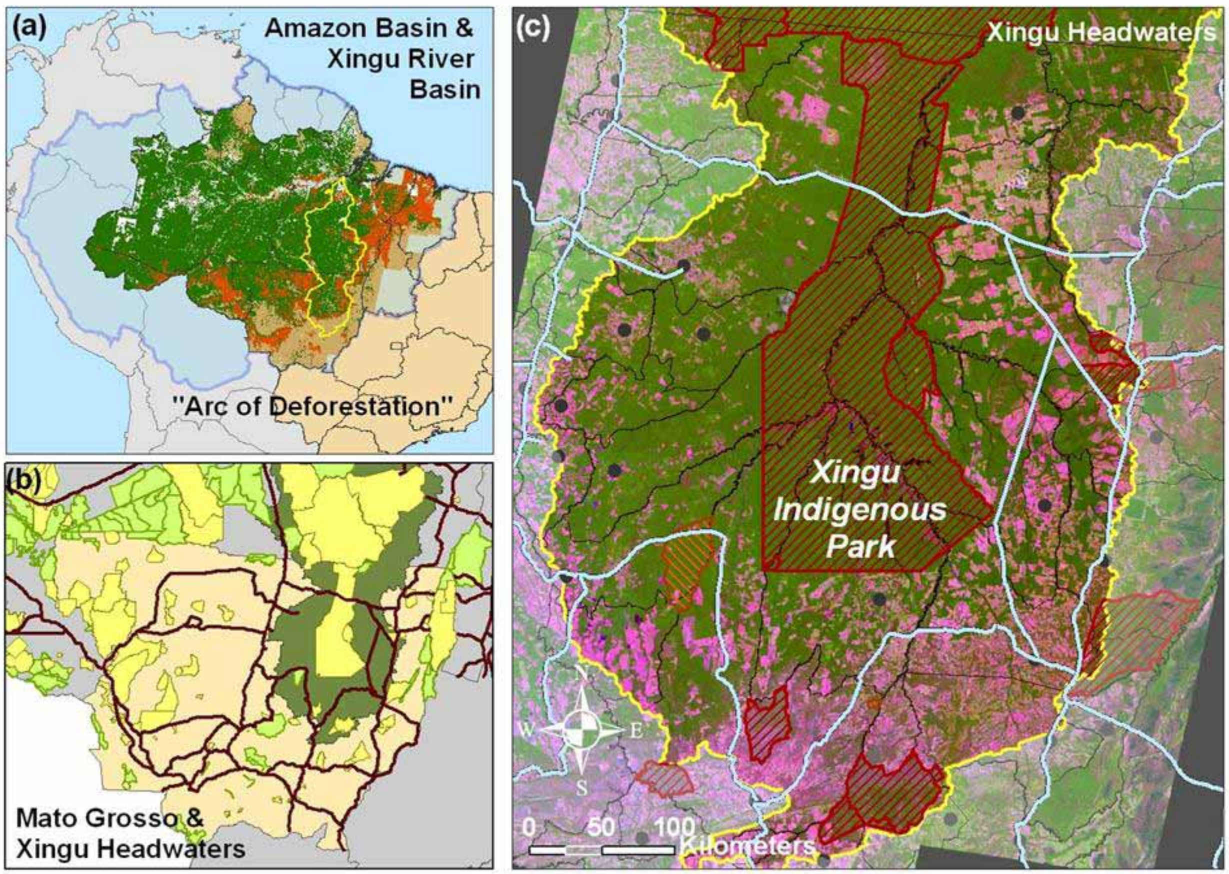

Figure 2: Percent of original forest (green bars) and *cerrado* (brown bars) vegetation remaining in 6 major tributaries to the Xingu River, as well as for the entire headwaters region (Total). Amount of vegetation is calculated as a percent of the total historical area for each vegetation type. Dashed lines indicate the legal minimum percent of original vegetation for each biome (green line = forest; brown line = cerrado) that private rural landholders must maintain on their properties according to the Brazilian Forest Code. Area of forest and *cerrado* vegetation was calculated following exclusion of indigenous territories, protected areas, and riparian zones, as these regulated separately from the "legal reserve."

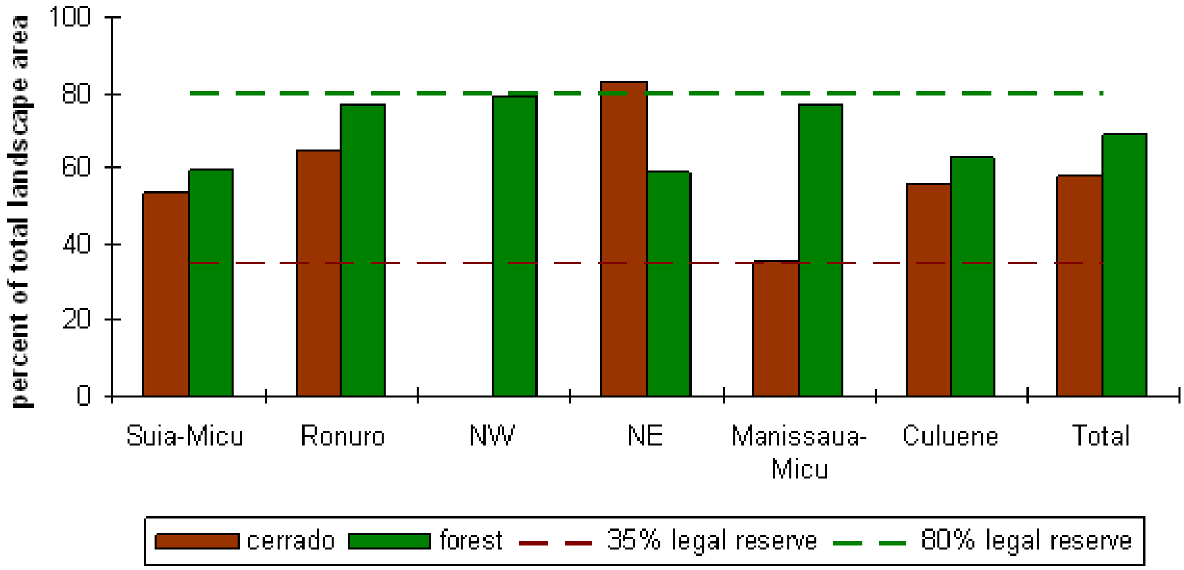

Figure 3: (a) Change in annual deforestation between 2000 and 2007, in thousands of hectares (black line). The historical baseline for annual deforestation (red dashed line) was calculated as the mean of the annual rates for each year from 2000 to 2007. (b) Change in annual deforestation-driven carbon emissions over the same time period, in millions of tons of carbon emitted (black line). The historical baseline for annual carbon emissions (red dashed line) was calculated as the mean of the annual rates for each year from 2000 to 2007.

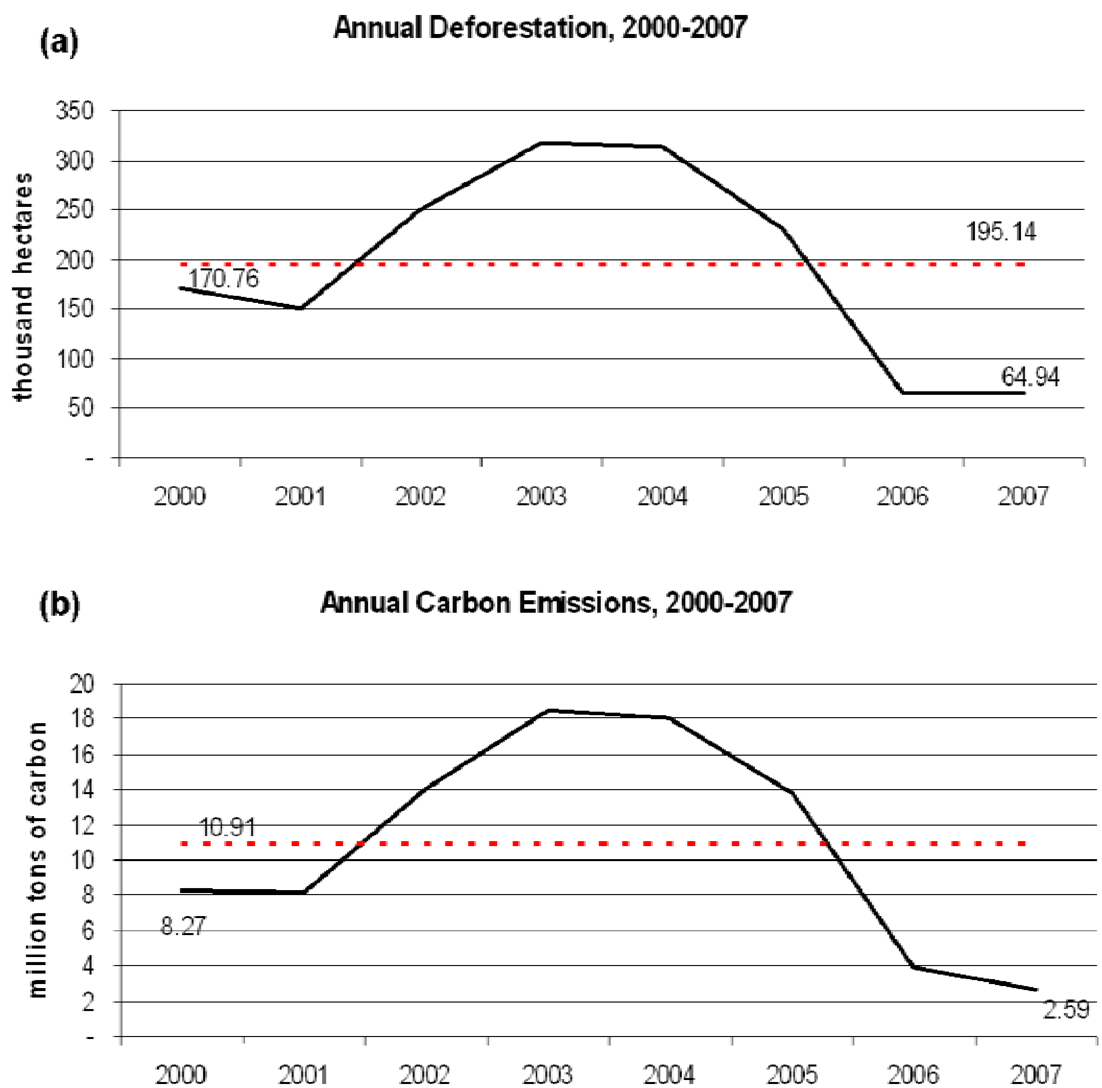

Figure 4: Map of opportunity costs within areas still forested in 2007. Opportunity costs were calculated from rent models for the three major economic activities in the region, soy farming, ranching, and timber harvesting. Opportunity cost for each pixel calculated based on subtracting the net present value of logging from the higher net present value of either soy or cattle. Zero was set as the lower limit for opportunity costs.

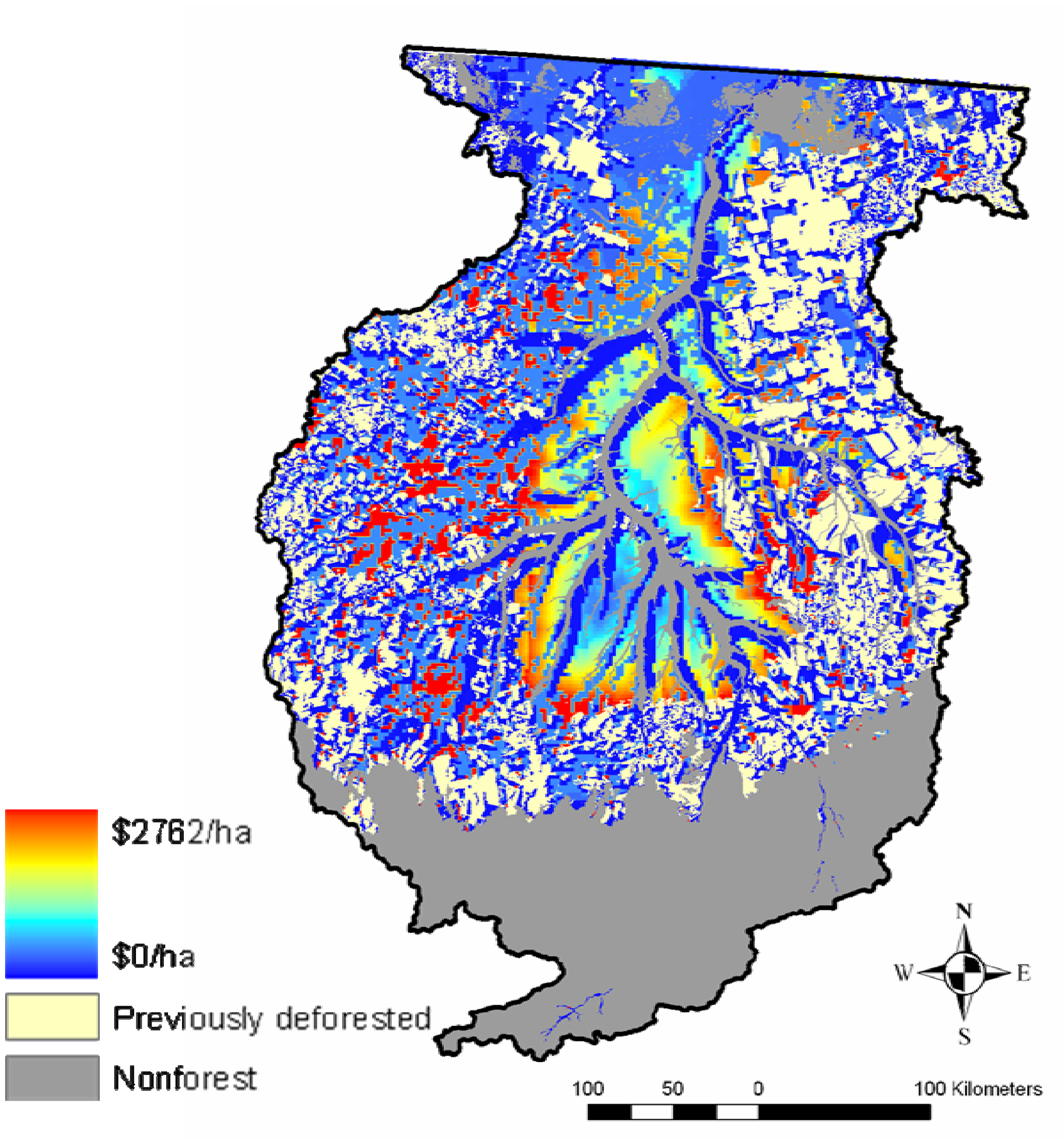

Figure 5: Marginal opportunity cost of reductions in carbon emissions for the Xingu River headwaters region. This graph plots the opportunity cost per ton of carbon, from the least to the most expensive possible reductions in emissions, in terms of (a) hectares of forest, and (b) tons of carbon.