ENVIRONMENT

Tropical Forests and Climate Policy

New science underscores the value of a climate policy initiative to reduce emissions from tropical deforestation.

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Tropical deforestation released ~1.5 billion metric tons of carbon (GtC) to the atmosphere annually throughout the 1990s, accounting for almost 20% of anthropogenic greenhouse gas emissions (1). Without implementation of effective policies and measures to slow deforestation, clearing of tropical forests will likely release an additional 87 to 130 GtC by 2100 (2), corresponding to the carbon release of more than a decade of global fossil fuel combustion at current rates. Drought-induced tree mortality, logging, and fire may double these emissions (3), and loss of carbon uptake (i.e., sink capacity) as forest area decreases may further amplify atmospheric CO_2 levels (4).

A combination of sovereignty and methodological concerns led climate policy-makers to exclude "avoided deforestation" projects from the 2008–12 first commitment period of the Kyoto Protocol's Clean Development Mechanism (CDM) (5). The United Nations Framework Convention on Climate Change (UNFCCC) recently launched a 2-year initiative (6) to assess technical and scientific issues and new "policy approaches and positive incentives" for Reducing Emissions from Deforestation (RED) in developing countries. This process was initiated at the request of several forest-rich developing nations, an indication of willingness to explore approaches to reduce deforestation that do not intrude upon national sovereignty. Recent technical progress in estimating and monitoring carbon emissions from deforestation (7) and diverse climate policy and financing proposals to help developing countries reduce their deforestation emissions (8) are currently being reviewed by the UNFCCC Subsidiary Body on Scientific and Technical Advice.

Whether a successful RED policy process can make an important contribution to global efforts to avoid dangerous climate change depends on two issues. First, are the potential carbon savings from slowing tropical deforestation sufficient to contribute substantially to overall emissions reductions? Second, is it likely that tropical forests (and the forest carbon) protected from deforestation will persist over coming decades and centuries in the face of some unavoidable climate change? The available evidence indicates that the answer to both questions is yes, especially in a future with aggressive efforts to limit atmospheric CO_2.

Potential savings for a range of deforestation levels are shown in the figure (above). Reducing deforestation rates 50% by 2050 and then maintaining them at this level until 2100 would avoid the direct release of up to 50 GtC this century (equivalent to nearly 6 years of recent annual fossil fuel emissions, and up to 12% of the total reductions that must be achieved from all sources through 2100 to be consistent with stabilizing atmospheric concentrations of CO_2 at 450 ppm (1) (figs. S1 to S5). Emissions reductions from reduced deforestation may be among the least-expensive mitigation options available (9). The IPCC estimates that reductions equal to or greater than the scale suggested here could be achieved at ≤U.S.\$20 per ton CO_2 (1, 10).

Reducing deforestation not only avoids the release of the carbon stored in the conserved forests, but by reducing atmospheric carbon, it also helps to reduce the impacts of climate change on remaining forests. The experience of the 1997–98 El Niño Southern Oscillation Event (ENSO) demonstrates how climate change can interact with land-use change to put large areas of tropical forests and their carbon at risk. The extended dry conditions triggered by the ENSO across much of the
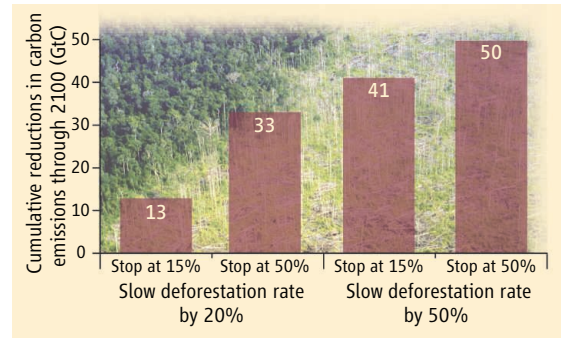
Estimated cumulative reductions in carbon emissions achievable by 2100 through reducing tropical deforestation. Calculations assume (i), deforestation rates observed in the 1990s decline linearly from 2010–50 by either 20 or 50%, and (ii) that deforestation stops altogether when either 15 or 50% of the area remains in each country that was originally forested in 2000 (1).

Amazon and Southeast Asia increased tree mortality and forest flammability, particularly in logged or fragmented forests. Globally, increased forest fires during the 1997–98 ENSO released an extra 2.1 ± 0.8 GtC to the atmosphere (11).

Even in non-ENSO years, global warming may be putting tropical forest regions at risk of more frequent and severe droughts. Over the last 5 years, a number of Amazon Basin and Southeast Asian droughts have been uncoupled from ENSO events but have coincided with some of the warmest global average temperatures on record.

In recent decades, carbon losses from tropical deforestation have been partly or largely offset by a tropical sink (12). Forest sinks are, however, unlikely to continue indefinitely, and continued warming will likely diminish and potentially even override any fertilization effects of increasing CO_2. Climate change might also adversely impact tropical forests by reducing precipitation and evapotranspiration, making them drier, more susceptible to fires, and more prone to replacement by shrublands, grasslands, or savanna ecosystems (13), which store much less carbon. In the Amazon Basin, continued deforestation may disrupt forest water cycling, amplifying the negative impacts of climate change (1).

A new generation of coupled climate-carbon models is being used to explore the prospects for the persistence of tropical forests in a changing climate. A widely discussed early

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study projected that business-as-usual increases in CO_2 and temperature could lead to dramatic dieback and carbon release from Amazon forests (14), raising concerns that high sensitivity of tropical forests to climate change might compromise the long-term value of reduced deforestation, with dieback releasing much of the carbon originally conserved. However, of 11 coupled climate-carbon cycle models using the IPCC's mid-to-high range A2 emissions scenario, 10 project that tropical forests continue to act as carbon sinks, albeit declining sinks, throughout the century (fig. S6). The moderate sensitivity indicated by the new results suggests that reducing deforestation can result in long-term carbon storage, even with substantial climate change. Aggressive efforts to reduce industrial and deforestation emissions would likely further reduce the rate of decline and risk of reversal of the tropical sink (1) (fig. S6).

While no single climate policy approach is likely to address the diverse national circumstances faced by forest-rich developing countries seeking to reduce their emissions, there

Most deforestation for cattle production in Amazonia yields unproductive pasture but releases hundreds of tons of CO_2 per hectare. Compensating landowners to keep their land in forests instead of creating pastures could be done at relatively low carbon prices (16).

are promising examples of countries with adequate resources and political will that have been able to reduce forest clearing (10, 15). In some countries, it may be possible at relatively low cost to reduce emissions from deforestation and forest degradation that provide little or no benefit to local and regional economies. For example, reducing accidental fire and eliminating forest clearing on lands that are inappropriate for agriculture are two promising low-cost options for reducing greenhouse gas emissions in Brazil and Indonesia.

Other measures are unlikely to be implemented at large scales without financial incentives that may be feasible only within the framework of comprehensive environmental

service payments, such as through carbon-market financing (16, 17). In forests slated for timber production, for example, moderate carbon prices could support widespread adoption of sustainable forestry practices that both directly reduce emissions and reduce the vulnerability of logged forests to further emissions from fire and drought exacerbated by global warming. On forested lands threatened by agricultural expansion, financing could provide significant incentives for forest retention and enable, for example, more effective implementation of land-use regulations on private property and protected area networks (18).

Parties to the UNFCCC should consider adopting a range of options, from capacity building supported by traditional development assistance to carbon-market financing to help developing countries meet voluntary national commitments for reductions in forest-sector emissions below historic baselines (7). Voluntary commitments, which were put forward by several tropical forest nations (19), would substantially address a concern associated with the project-based approach of the CDM that emissions reductions from a site-specific project might simply be offset by increased deforestation elsewhere (10).

Key requirements for effective carbon-market approaches to reduce tropical deforestation include strengthened technical and institutional capacity in many developing countries, agreement on a robust system for measuring and monitoring emissions reductions, and commitments to deeper reductions by industrialized countries to create demand for RED carbon credits and to ensure that these reductions are not simply traded off against less emission reductions from fossil fuels.

Beyond protecting the climate, reducing tropical deforestation has the potential to eliminate many negative impacts that may compromise the ability of tropical countries to develop sustainably, including reduction in rainfall, loss of biodiversity, degraded human health from biomass burning pollution, and the unintentional loss of productive forests (16). Providing economic incentives for the maintenance of forest cover can help tropical countries avoid these negative impacts and meet development goals, while also complementing aggressive efforts to reduce fossil fuel emissions. Industrialized and developing countries urgently need to support the RED policy process and develop effective and equitable compensation schemes to help

tropical countries protect their forests, reducing the risk of dangerous climate change and protecting the many other goods and services that these forests contribute to sustainable development.

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20. We thank S. Brown, S. Schwartzman, B. Schlamadinger, and T. Johns for comments. C.D.J. was supported by the U.K. Department for Environment, Food and Rural Affairs Climate Prediction Program, under contract PECD 7/12/37. This paper contributes to the Global Carbon Project of the Earth System Science Partnership.

Supporting Online Material for

Tropical Forests and Climate Policy

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This PDF file includes

SOM Text
Figs. S1 to S6
References

Supporting Online Material

SOM Text

Carbon emissions from tropical deforestation

Tropical deforestation released c. 1.4 GtC yr^{-1} (range: 0.9–2.2) (calculated as the average and range of *S1–S3*) throughout the 1990's, accounting for 17.3% (range: 12.0–28.0) (*S4*, *S5*) of total annual anthropogenic greenhouse gas emissions during this period.

Cumulative carbon emissions reductions required to stabilize at 450 ppm CO_2

Cumulative carbon emissions from 2010–2100 allowed under the WRE-450 stabilization scenario were calculated as follows. First, the IPCC allowable emissions from 2001 to 2100 for this scenario range from 365 to 735 GtC, based on uncertainty in rates of carbon uptake by the ocean and terrestrial biosphere (*S6*). The mid-range estimate of emissions from 1991 to 2000 under the "S" concentration profiles is 630 GtC (*S7*). Subtracting estimated global emissions of 57.6 GtC (*S8*) for 1990–1999 from 630 GtC gives a mid-range estimate of 572 GtC from 2000 to 2100. The next step is to adjust the range and mid-point from 2000 to 2010. Global emissions from 2000 to 2003 total 27.8 GtC. SRES-projected emissions in 2010 are 8.4 GtC (*S9*). Filling in estimated global annual carbon emissions between 2004 and 2010 by linearly interpolating between 2003 values and SRES-projected 2010 emissions gives total cumulative emissions from 2000 to 2009 of 74.9 GtC. Subtracting this value from the cumulative emissions allowed from 2000 to 2100 gives a mid-point of allowable carbon emissions from 2010 to 2100 of 498 GtC, with a range of 297 to 667 GtC. For comparison, total cumulative carbon dioxide emissions for the A2 and B2 SRES emission scenarios over the period 2010 to 2100 are 1785 and 1090 GtC respectively (Fig. S1).

Note that limiting global average temperature increases to 2°C above pre-industrial levels, the target adopted by the European Union (*S10*), could require more ambitious reductions (Fig. S2) (*S11*).

Emissions reductions from slowing deforestation

Houghton (2005) (*S12*) estimates projected emissions from tropical deforestation as follows. First, deforestation rates and emissions during the 1990s have been estimated based on satellite imagery (*S13*) and based on sampled country inventory data (*S14*, *S15*). For simplicity, Houghton (2005) assumes deforestation rates and associated emissions stay constant for each country until remaining forested area in that country reaches 15% of the forest area in 2000. At that point, deforestation is assumed to halt as the remaining forested area is already protected or is located in a region that is not cost-effective to clear (Fig. S3).

To assess the potential reductions in projected carbon emissions that could be obtained through substantial measures to reduce tropical deforestation, we re-calculated the carbon emissions that would result from (a) a linear reduction in deforestation rates to 20% and 50% below 1990s rates by 2050, and (b) stopping deforestation when 50% of forested

area relative to 2000 was still remaining, rather than just 15% as in the Houghton (2005) estimates. Figure S4 compares the baseline emissions, taken as the average of 1990's emissions based on satellite and sampled country inventory data, with the emissions based on slowing deforestation rates and increasing the remaining forest area at which deforestation halts. Slowing rates to 50% below 1990's rates by 2050 results in more than 50% of the forested area still remaining by 2100 for most tropical countries.

How much of a contribution to global carbon emissions reductions could the reductions in deforestation examined here make? In 2003, annual global emissions slightly exceeded 8.9 GtC yr^{-1} ($S5$, $S8$). Deforestation reductions from 2010 to 2100 under these scenarios have the potential to reduce emissions by 13–50 GtC, which is equivalent of up to 5.6 years of global emissions at present-day levels (Fig. 1). The potential contribution of these reductions towards the total emission reductions required to stabilize atmospheric CO_2 levels at 450 ppm through 2100 is up to 12%, depending on total industrial emissions over this period and the uptake of CO_2 by the biosphere (Fig. S4).

Are emissions reductions of the magnitude discussed here feasible? Drawing on several recent global forest sector economic models estimating the cost of achieving emission reductions through reduced deforestation, the IPCC (table 9.3 in $S16$) estimates that the mitigation potential of reduced tropical deforestation is 1.04 GtC/yr in 2030, of which 55% (0.57 GtC/y) could be accomplished at prices up to U.S.$20 per tCO_2. By contrast, the most aggressive emission reduction scenario considered here (reducing deforestation rates by 50%, and stopping deforestation altogether when 50% of original forest area remains) would require annual emission reductions of c. 0.41 GtC/y in 2030. Hence, emission reductions from reduced deforestation equal to or greater than the scale considered here appear feasible at moderate carbon prices.

Using a price of U.S.$20 per tCO_2, the *average annual cost* of emission reductions over the period 2010–2100 would be (in billions of dollars) U.S.$10.5, $26.9, $33.4, or $40.8, for the 13, 33, 41, and 50 GtC scenarios, respectively. Actual costs could be considerably lower, as the IPCC identifies U.S.$20 per tCO_2 as an upper threshold for price.

**The impact of deforestation on Amazon rainfall**
When global climate models simulate Amazon deforestation, they typically find that precipitation decreases approximately linearly with increasing amounts of deforestation. Maximum precipitation reductions of 5–30 % are seen at complete deforestation ($S17$, $S18$). However, meso-scale models, with finer spatial resolution, fail to find the same pattern ($S19$). Instead of a uniform decrease in precipitation, they show complex patterns of change, with some areas increasing and others decreasing, but not necessarily a marked decrease in overall precipitation.

Supporting Figures
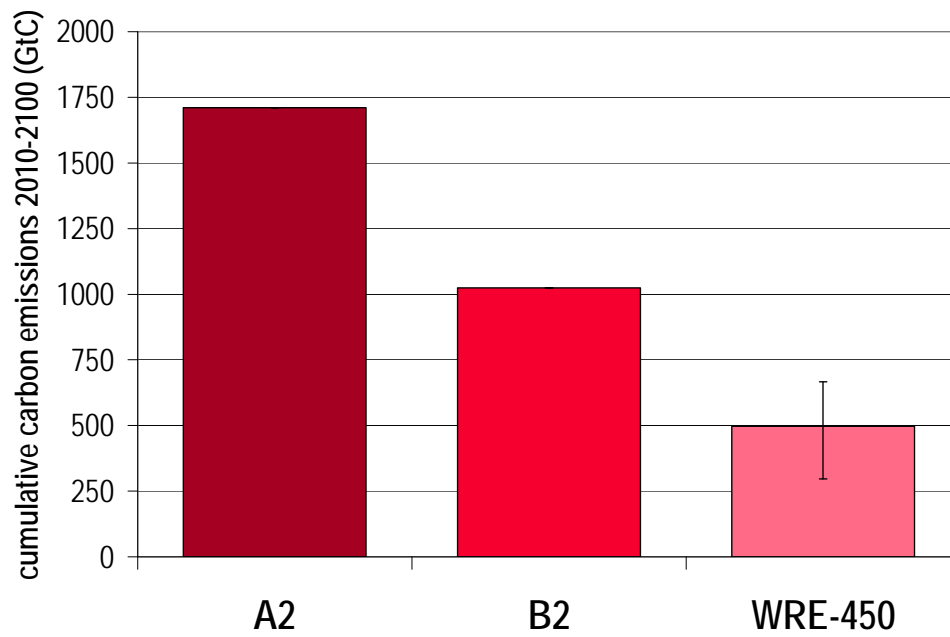
Figure S1. Cumulative carbon emissions for the SRES mid-range A2 and B2 marker scenarios, as compared with emissions under the WRE-450 stabilization pathway. The range in cumulative emissions under the WRE scenario represents uncertainty in carbon uptake by the marine and terrestrial biosphere.
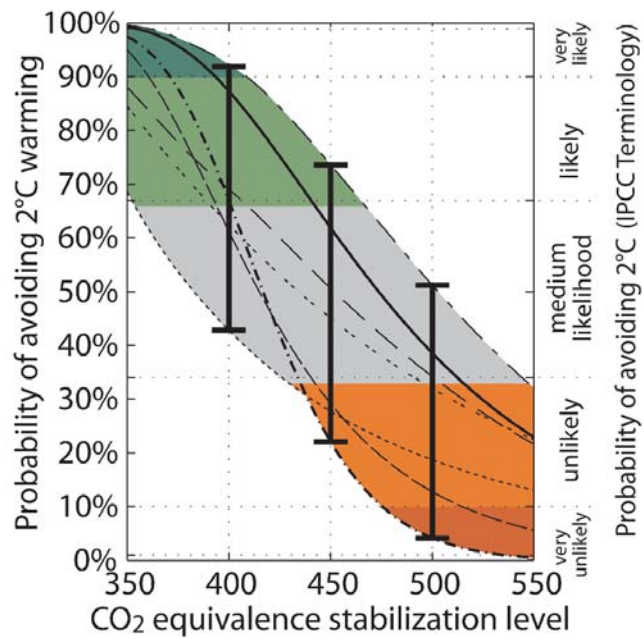
Figure S2. Probability of avoiding (i.e., remaining below) a global 2°C warming target as a function of CO_2-equivalent stabilization levels. Uncertainty range is determined by current estimates of climate sensitivity [redrawn from (*S11*)]. CO_2 concentrations are currently at approximately 385 ppm, while CO_2-equivalent concentrations, which include other gases such as CH_4, N_2O, SF_6 and CFCs, are approximately 425 ppm.
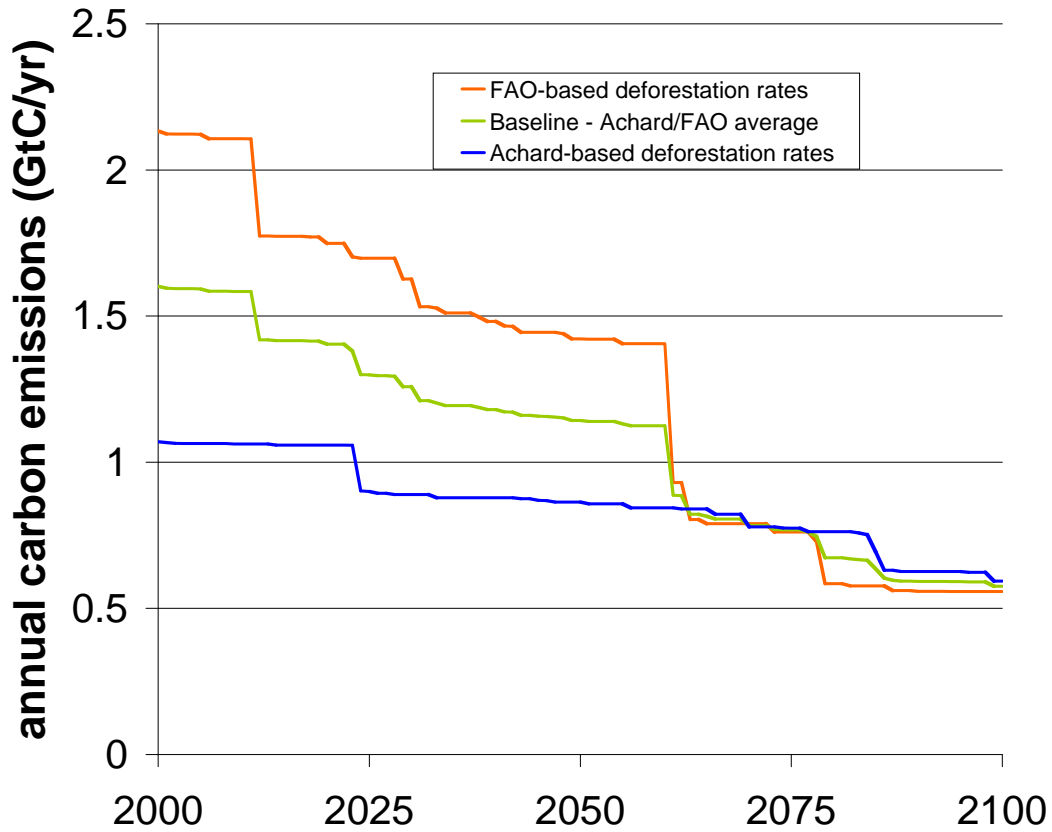
Figure S3. Annual emissions of carbon from tropical deforestation summed over Africa, Asia & Latin America, based on FAO (*S14*) (orange), Achard *et al*., 2004 (*S13*) (blue) and the average of the two estimates (green), which we use as the baseline for this analysis. Emissions assume that rates of deforestation for the 1990s continue in the future, after Houghton (2005) (*S12*). Deforestation is estimated to halt when each country's forest area reaches 15% of its forested area in 2000.
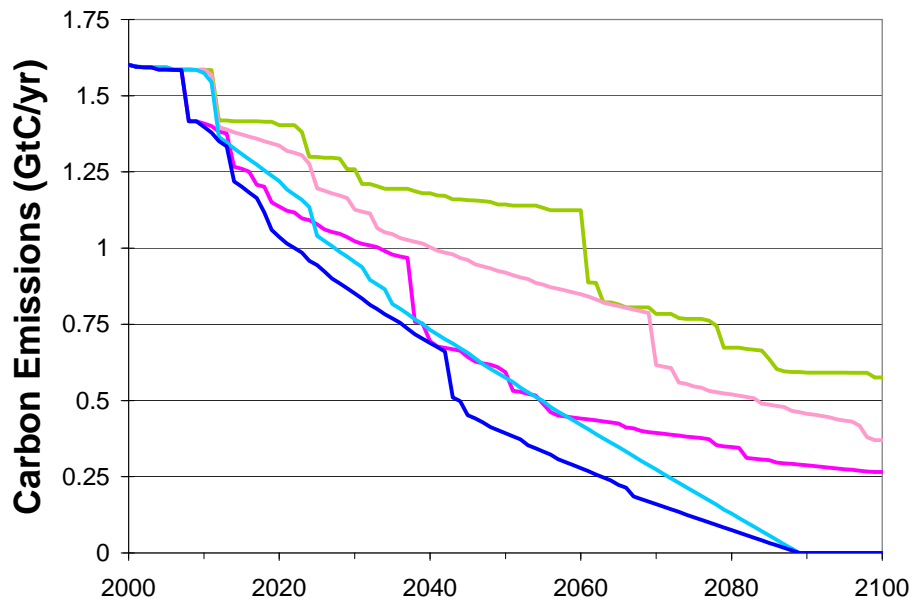
Figure S4. Baseline global emissions from deforestation as estimated by Houghton, 2005 (*S12*) (green). The pink lines show the emissions based on a 20% slowing in deforestation rates by 2050 relative to 1990s average, stopping at 15% of remaining forest area by individual country (light pink) or 50% of remaining area (dark pink). Similarly, the blue lines show emissions corresponding to a 50% slowing in deforestation rates by 2050 stopping at 15% (light blue) or 50% (dark blue) of remaining forest area by individual country.

A
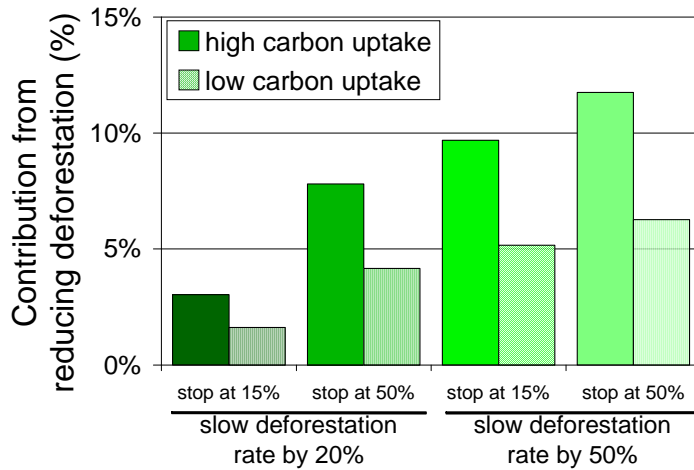
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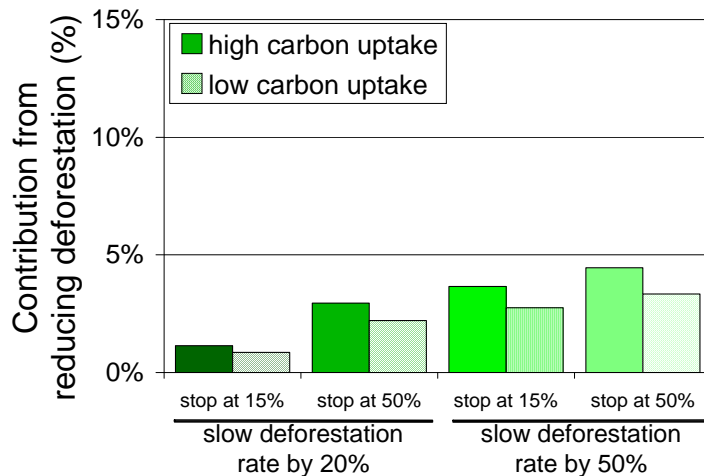
Figure S5. The contribution of reduced tropical deforestation towards achieving a 450 ppm stabilization pathway. The deforestation scenarios are defined by two variables. First, current day deforestation rates are reduced by either 20% or 50% by 2050, and then maintained at these levels until 2100. Second, deforestation stops entirely once forest cover has been depleted to either 15% or 50% of forest area in 2000. The analysis considers both low- and high future carbon uptake scenarios by the marine and terrestrial biosphere (*S6*). (**A**) The contribution of reduced deforestation under the SRES A2 medium-high emissions scenario, which projects cumulative carbon emissions of 1785 GtC from 2010 to 2100. Allowable emissions for the WRE-450 stabilization pathway range from 297 to 667 GtC over the same period, meaning that the cumulative emission reductions required are 1118–1488 GtC. (**B**) The same as (A), but using the SRES B2 mid-range emissions scenario, which predicts cumulative carbon emissions of 1090 GtC between 2010–2100, and would require emission reductions of between 423 and 793 GtC to be consistent with a 450 ppm stabilization pathway.
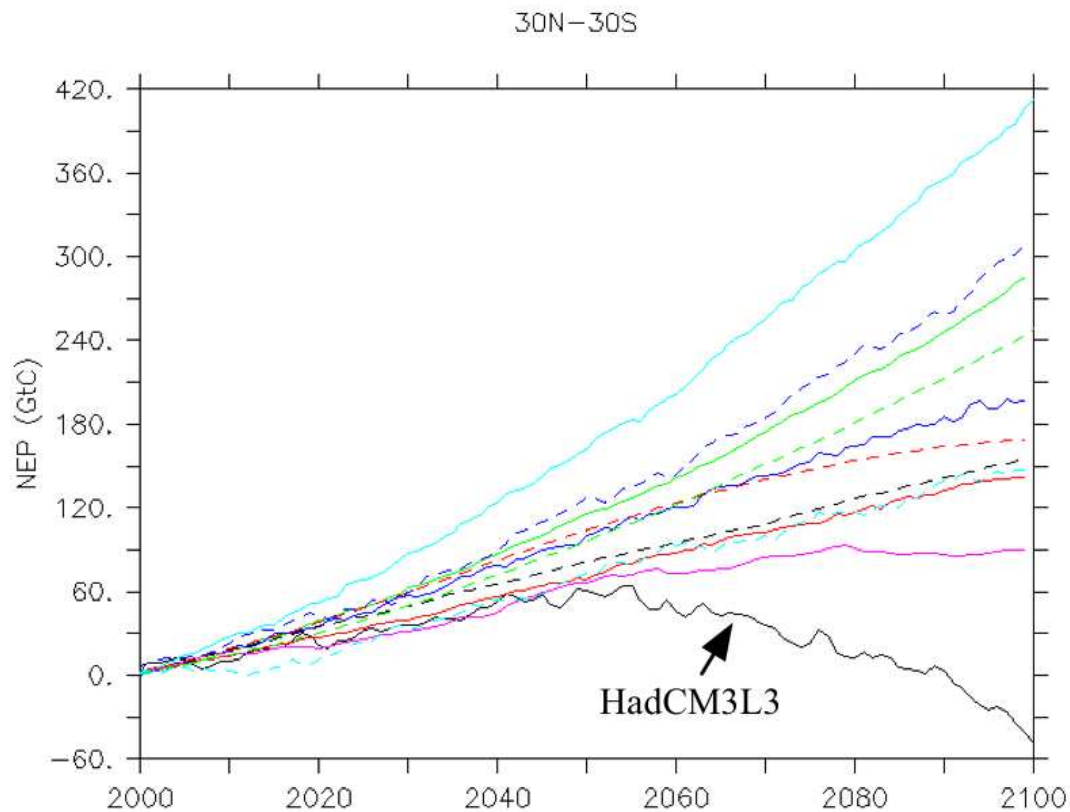
Figure S6. Cumulative change in Net Ecosystem Productivity (NEP) in the tropics from 2000 to 2100 for the eleven models participating in the Coupled Climate-Carbon Cycle Model Intercomparison Project. Models use the medium-high SRES A2 emission scenario, which assumes that atmospheric CO_2 concentration will exceed 550 ppm by mid-century, and reach 850 ppm by 2100. Results show the combined effects of climate change and CO_2 fertilization. Projected land-use emissions are included in the simulations, but land use *per se* is not modeled, and does not influence the distribution of natural vegetation. Most models show that sink strength declines over time, with one model (HadCM3LC) projecting that tropical forests become net sources of carbon. [Key to models: HadCM3LC (solid black), IPSL-CM2C (solid red), IPSL-CM4-LOOP (solid yellow), CSM-1 (solid green), MPI (solid dark blue), LLNL (solid light blue), FRCGC (solid purple), UMD (dash black), UVic-2.7 (dash red) and CLIMBER (dash green), BERN-CC (dash blue). See (*S20*) for full description.] Aggressive efforts to reduce industrial and deforestation emissions would likely further reduce the rate of decline and risk of reversal of the tropical sink. Under a 450 ppm CO_2 stabilization scenario, for example, Amazon dieback-associated emissions for the HadCM3L3 model are reduced 43 GtC, or 45%, through 2100 (S*21*).

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