Progress report: Biomass energy: The climate-protective domain

Christopher Field, Rosamond Naylor, Gregory Asner, David Lobell

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This is a three-year project initiated in 2008 and scheduled for completion in 2011. During the project's second year, research focused on three main areas. These were (1) the comparative efficiency of transportation services from liquid biofuels versus electricity from biomass, (2) remote sensing of biomass energy deployments and related land-use changes, and (3) modeling the climate consequences of changes in land-surface properties related to biomass energy crops. This was a very successful year for the project. Several papers were published, including papers in *Science* (Campbell et al. 2009), *Nature* (Loarie et al. 2009), and *Geophysical Research Letters* (Georgescu et al. 2009). One GCEP post-doc (Eve Hinckley) moved to a new post-doctoral position at the University of Colorado, and two PhD students (Rachael Garratt and Lena Perkins) started working intensively with the project.

A brief summary of each of the main project areas follows.

1) The comparative efficiency of transportation services from liquid biofuels versus electricity from biomass

Greater transportation energy and GHG offsets from bioelectricity than ethanol

J. Elliott Campbell, David B. Lobell, and Christopher B. Field

The quantity of land available to grow biofuel crops without impacting food prices or greenhouse gas emissions from land conversion is limited. Therefore, bioenergy should maximize land use efficiency when addressing transportation and climate change goals. Biomass could power either internal combustion or electric vehicles, but the relative land use efficiency of these two energy pathways is not well quantified. Here we show that bioelectricity outperforms ethanol across a range of feedstocks, conversion technologies, and vehicle classes. Bioelectricity produces an average 81% more transportation kilometers and 108% more emissions offsets per unit area cropland than cellulosic ethanol (Figure 1). These results suggest that alternative bioenergy pathways have large differences in how efficiently they use the available land to achieve transportation and climate goals.

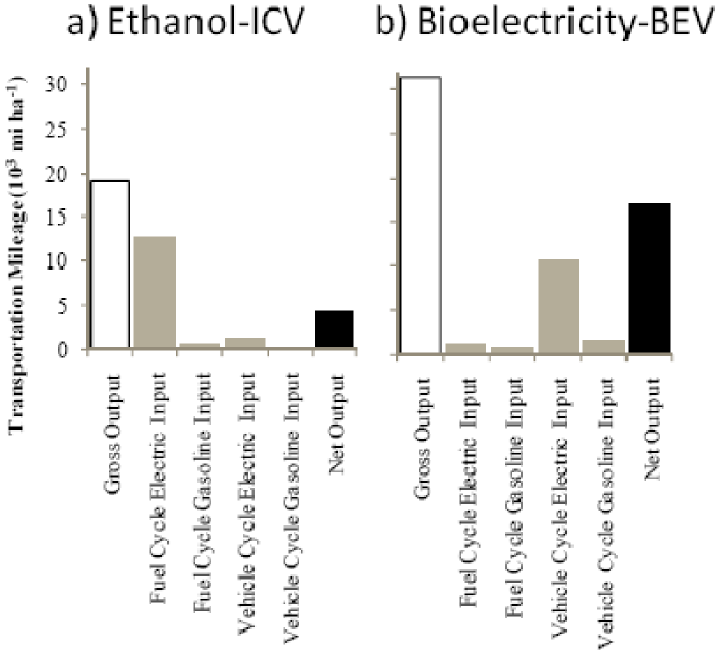

Figure 1. Transportation and GHG offsets from bioelectricity and ethanol based on a range of vehicle classes, agriculture systems, and energy conversion technologies. Net output accounts for co-products as well as input in the fuel cycle and vehicle cycle. Results are not plotted for cases when more kilometers could be traveled with input energy than with gross output energy.

2) Remote sensing of biomass energy deployments and related land-use changes

The velocity of climate change

Scott R. Loarie, Philip B. Duffy, Healy Hamilton, Gregory P. Asner, Christopher B. Field, David D. Ackerly

The ranges of plants and animals are moving in response to recent changes in climate. As temperatures rise, ecosystems with ‘nowhere to go’, such as mountains, are considered more threatened. However, species survival may depend as much on keeping pace with moving climates as the climate’s ultimate persistence. Here, we present a new index of the velocity of temperature change (km yr^{-1}), derived from spatial gradients ($^{\circ}C$ km^{-1}) and multimodel ensemble forecasts of rates of temperature increase ($^{\circ}C$ yr^{-1}) in the 21st century. This index represents the instantaneous local velocity along Earth’s surface needed to maintain constant temperatures, and has a global mean of 0.42 km yr^{-1} (A1B emission scenario). Due to topographic effects, the velocity of temperature change is lowest in mountainous biomes such as tropical and subtropical coniferous forests (0.08 km yr^{-1}), temperate coniferous forest, and montane grasslands. Velocities are highest in flooded grasslands (1.26 km yr^{-1}), mangroves, and deserts (Figure 2). High velocities suggest that the climates of only 8% of global protected areas have residence times exceeding 100 years (Figure 3). Small protected areas exacerbate the problem in mediterranean-type and temperate coniferous forest biomes. Large protected areas may mitigate the problem in desert biomes. These results suggest management strategies for minimizing biodiversity loss from climate change. Montane landscapes may effectively shelter many species into the next century. Elsewhere, reduced emissions, a much expanded network of protected areas, or efforts to increase species movement may be necessary. A manuscript reporting these results was published in *Nature* in December, 2009 (Loarie et al. 2009).

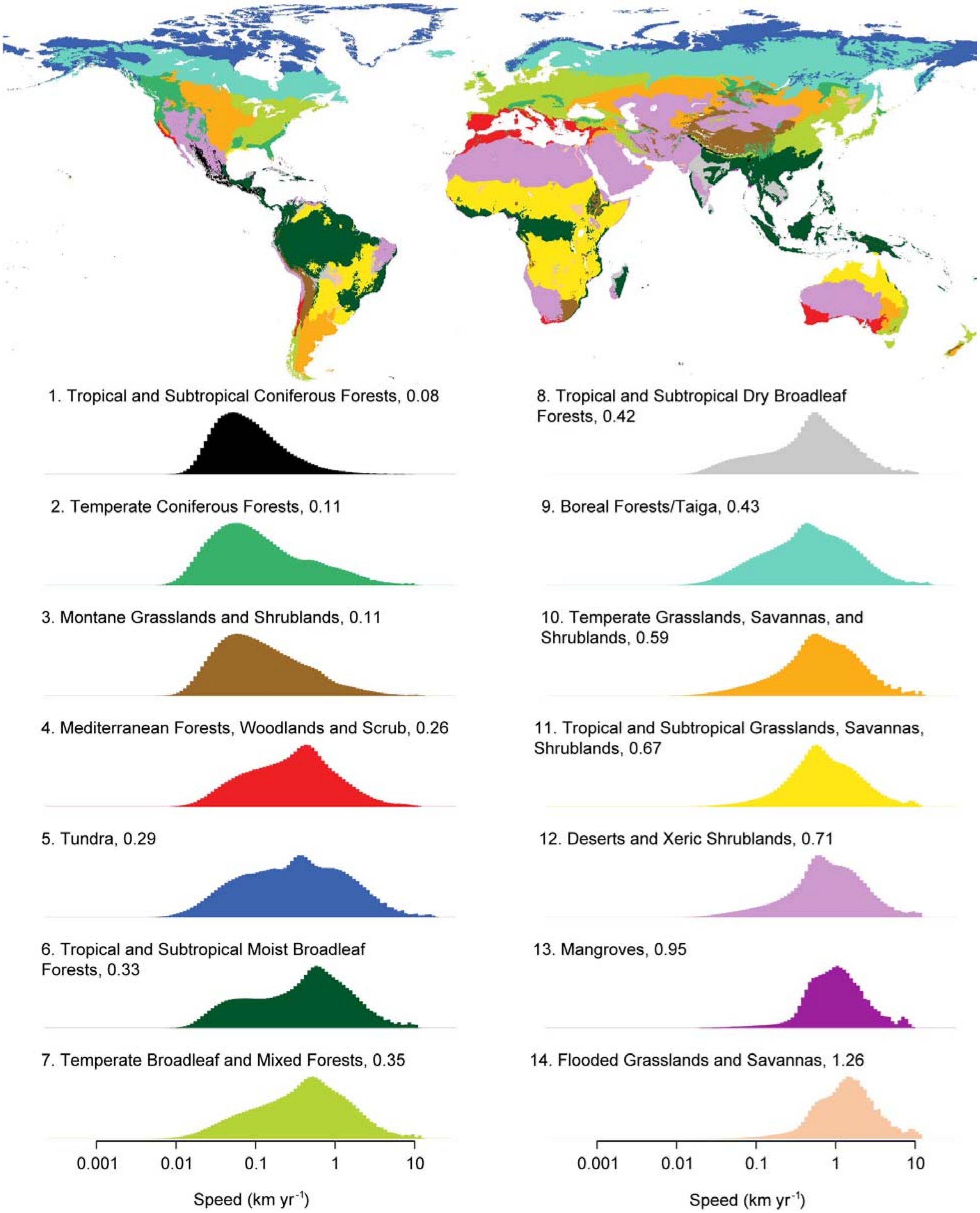

Figure 2. The velocity of temperature change by biome. A map of biomes and histograms of the speed of temperature change within each biome. Histograms are ordered by increasing velocity according to their geometric means.

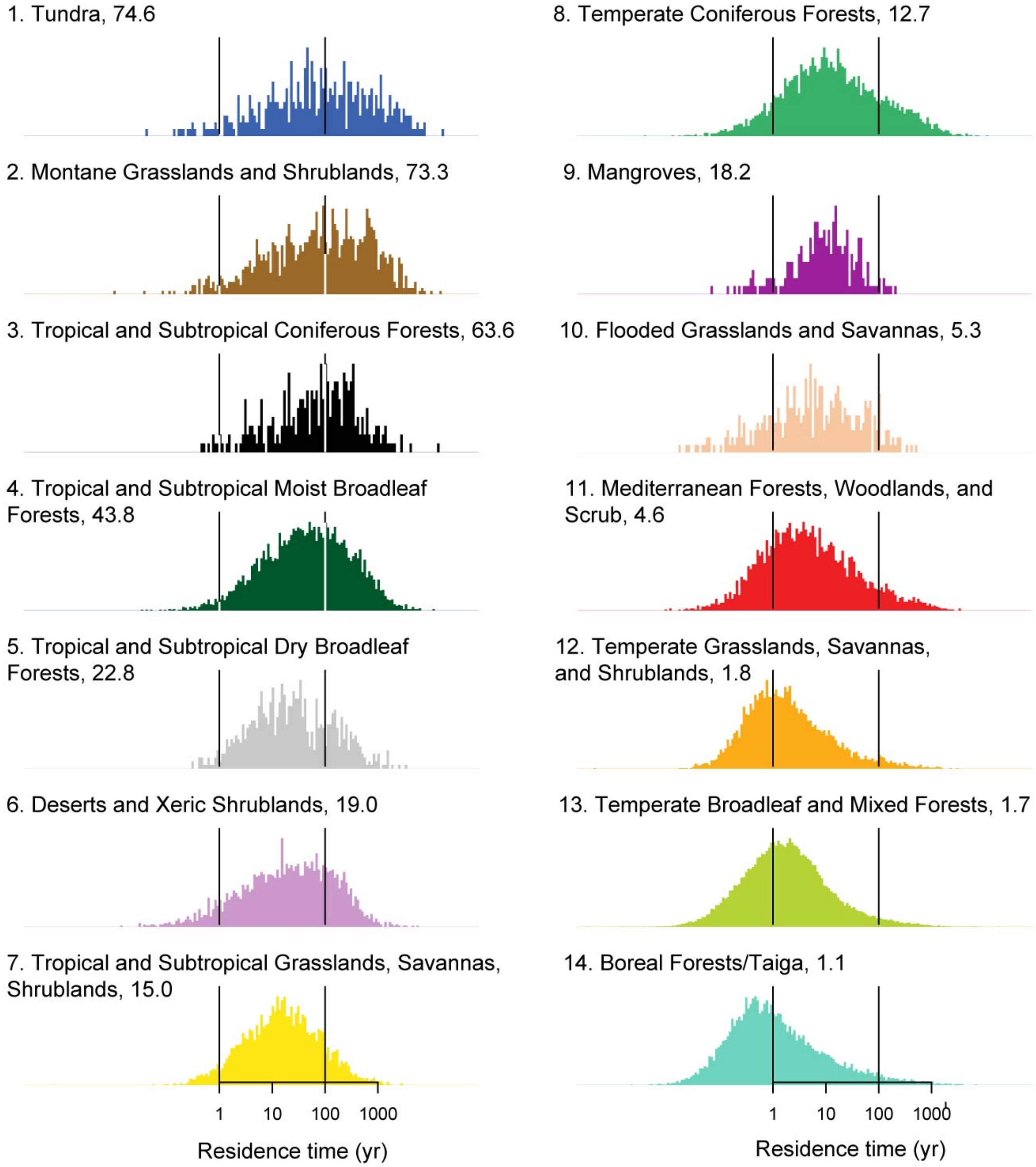

Figure 3. Climate residence time (yr) in protected areas. Histograms represent the ratio of protected area diameter (km) to climate velocity (km/hr), and are ordered by decreasing mean residence time across biomes. The vertical bar indicates 1 and 100 years.

Land-cover change and surface water drive large albedo increases in South America

Scott R. Loarie, David B. Lobell, Gregory P. Asner, Christopher B. Field

Albedo is an important factor affecting global climate, but uncertainty in the sources and magnitudes of albedo change has led to very simplistic treatment of albedo in climate models. Here we examine nine years of historical 1-km MODIS albedo estimates across South America to advance understanding of the magnitude and sources of large scale albedo changes. We use the magnitude of albedo change from the Brazilian Amazon arc-of-deforestation (+2.8%) as a benchmark for comparison (Figure 4). Large albedo increases (>+2.8%) are 2.2 times more prevalent than similar decreases throughout South America (Figure 5). Changes in surface water drive most large albedo changes that are not caused by vegetative cover change. Decreased surface water in the Santa Fe and Buenos Aires regions of Argentina is responsible for albedo increases exceeding that of the arc-of-deforestation in magnitude and extent. The mechanism driving changes in surface water is a combination of natural flooding and human manipulations through dams and other agriculture infrastructure. This study demonstrates the substantial role that land cover and surface water change can play in continental-scale albedo trends. A manuscript reporting these results is in review at *Earth Interactions*.

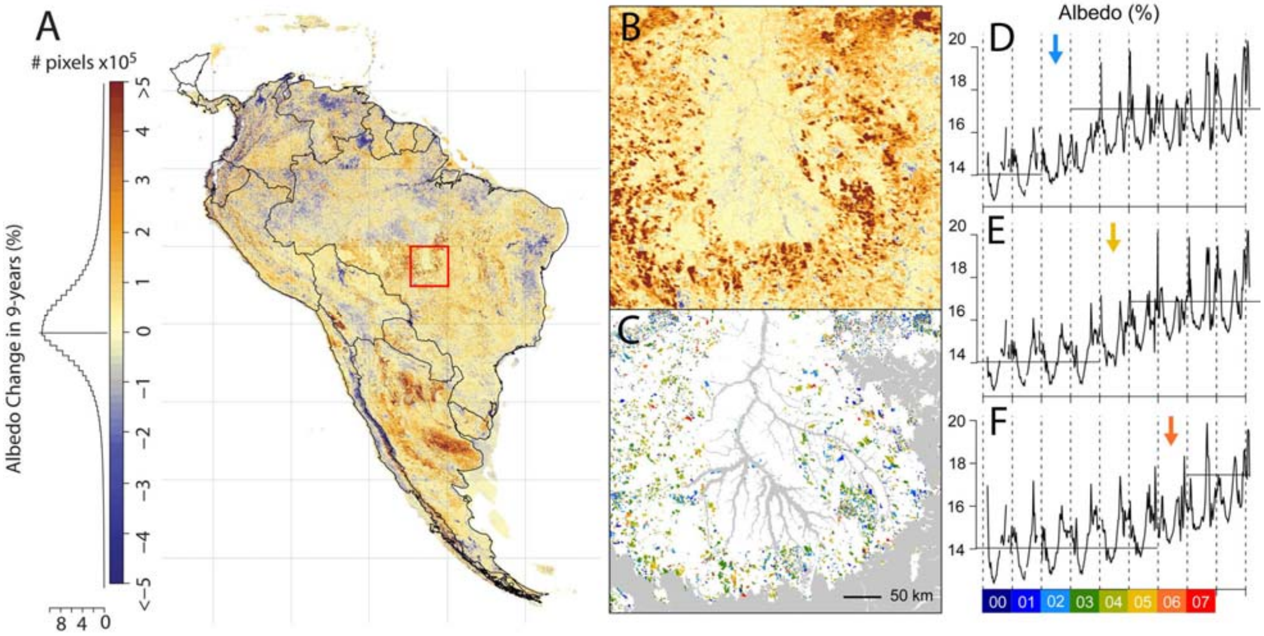

Figure 4. (A) Albedo change (%) over a 9 year period (2000-2008) across South America calculated from 1 km, 8-day MODIS albedo products. The histogram corresponds to the color bar. Black outlines are country boundaries. Red rectangle overlaps the state of Mato Grosso in the southern Brazilian Amazon (North East quarter of tile h12v10). A detail of this quarter tile showing (B) albedo change from 2000-2007 and (C) PRODES deforestation data colored by deforestation year. Areas not naturally forested are in gray. Graphs show albedo (%) for 1 km pixels deforested in (D) 2002, (E) 2004, and (F) 2006. Arrows indicate year deforested, horizontal lines show average albedo before and after deforestation.

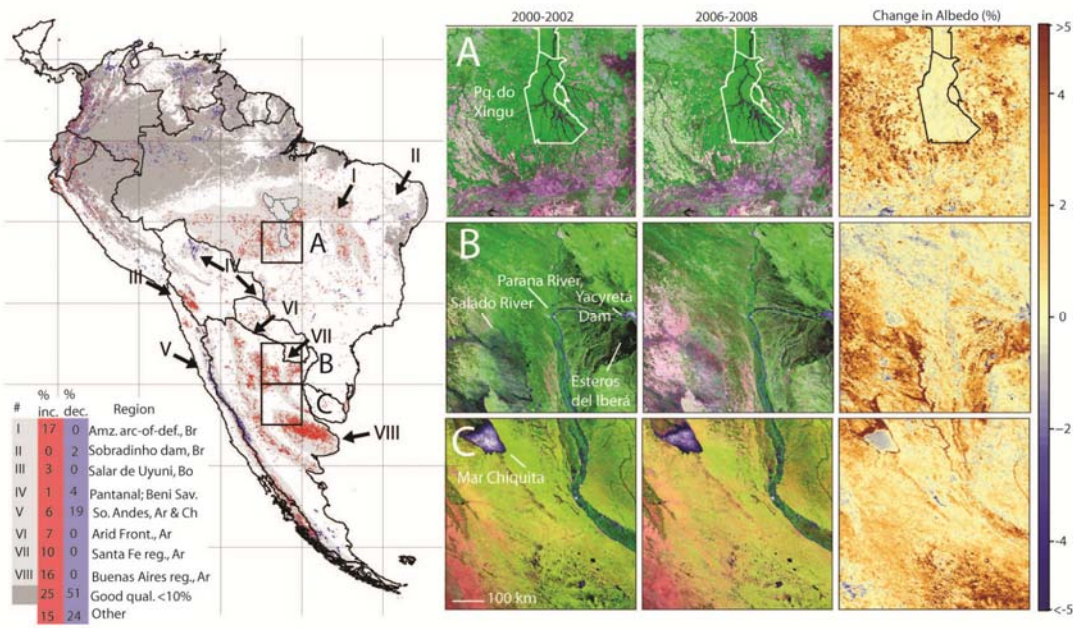

Figure 5. Large Increases (>+2.8%, red) and decreases (<-2.8%, blue) in albedo across South America. The legend shows the percentage of these large changes within regions of interest (light gray areas) labeled by roman numerals. Dark gray areas have scarce good quality data (<10%). Black outlines are country boundaries. Gray outlines indicate a sample of indigenous reserves in Brazil, including the Parque Nacional Indigena do Xingu. The gray grid shows 1200 x 1200 km MODIS tiles. A-C are quarter MODIS tiles that intersect three regions of interest. Columns represent composite false-color images of landcover averaged across 2000-2002, 2006-2008, and change in albedo over the 9-year period. False-color represents the MIR, NIR, and red with red, green, and blue colors respectively. Under this scheme vegetation appears green, water appears blue, and bare ground appears pink. The blue to red color scheme represents change in albedo. Outlines in the Amazon arc-of-deforestation image indicate the Parque Nacional Indigena do Xingu. Labels in the Argentina images indicate water bodies referred to in the text.

Combined effects of climate and land-use change on the future of humid tropical forests

Gregory P. Asner, Scott R. Loarie, Ursula Heyder

New deforestation and selective logging data and climate change projections suggest that biodiversity refugia in humid tropical forests may change more extensively than previously reported. However, the relative impacts from climate change and land use vary by region. In the Amazon, a combination of climate change and land use renders up to 81% of the region susceptible to rapid biodiversity change. In the Congo, logging and climate change could negatively affect the biodiversity in 35-74% of the basin. Climate-driven changes may play a smaller role in Asia-Oceania compared to that of Latin America or Africa, but land use renders 60-77% of Asia-Oceania susceptible to major biodiversity changes. By 2100, only 18-45% of the biome will remain intact (Figure 6). The results provide new input on the geography of projected climate change relative to ongoing land-use change to better determine where biological conservation might be most effective in this century. A manuscript reporting these results is in revision at *Conservation Letters*.

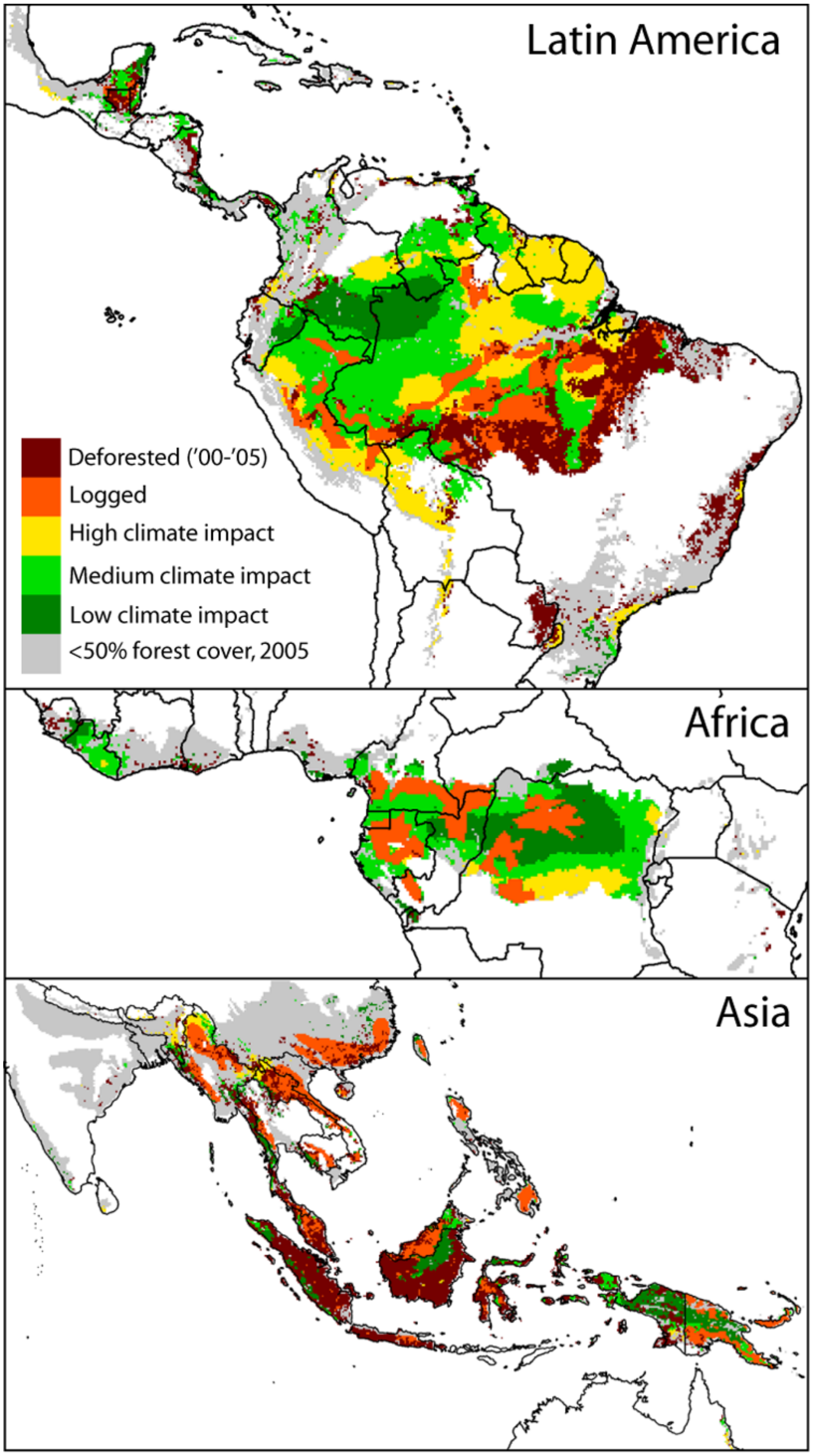

Figure 6. The footprint of deforestation, selective logging and climate change in the humid tropical forest biome.

Biofuel expansion does not promote increased local cattle density: evidence for indirect landuse effects?

Scott R. Loarie, David B. Lobell, Rachael Garrett, Chris B. Field

Over the last decade in Brazil, both the head of cattle and the land area utilized for sugarcane biofuel production has increased substantially. The expansion of biofuels into food crop and natural areas may have adverse effects on food security, biodiversity, and carbon emissions. Policy makers therefore advocate moving biofuels onto pasture despite concurrent, large increase in the number of Brazilian cattle. We ask whether meeting the demands of these two competing land uses increased local densities of cattle on pasture or pushed cattle elsewhere. We mapped changes in the distributions of in cattle, pasture, sugarcane, other crops across Brazil at the municipality level from 1996-2006. We found that increases in crops including sugarcane are significantly correlated with a decrease in local pasture indicating that these crops are at least partially expanding into former pastures. Importantly, increases in sugarcane are not significantly correlated with increases in cattle density, and the overall number of cattle decline in the presence of increasing biofuels. These results suggest that as biofuels expand cattle are moved elsewhere rather than accommodated on smaller pastures through increased density. The implications of increasing numbers of cattle elsewhere constitute an indirect landuse effect of biofuel expansion with uncertain implications. A manuscript reporting these reports is in preparation for publication.

3) Modeling the climate consequences of changes in land-surface properties related to biomass energy crops

Climate feedbacks from regional-scale biomass-energy cropping

Matei Georgescu, David B. Lobell, Christopher B Field

Our research has extended recent work assessing indirect impacts of landscape change associated with bioenergy expansion through a biogeochemical lens by focusing on the direct biogeophysical climate effects on local and regional climate.

Aided by the Weather Research and Forecasting Model (WRF), a coupled land-atmosphere modeling system, we conducted a suite of midsummer, continental-wide, sensitivity experiments by imposing realistic biophysical parameter limits appropriate for bio-energy crops in the Corn-Belt of the United States. Our intention was two-fold: first, to isolate the maximum regional climate impact due to land-use change resulting from bioenergy crops and second, to quantify the relative importance of biophysical parameters relative to one another. The full breadth of albedo and minimum canopy resistance specification resulted in the largest simulated local changes in 2 m temperature (order of 1°C). The tendency of greater leaf area index (LAI) and rooting depth for perennial rather than annual bioenergy crops highlight their local cooling contribution of 1-2°C, notwithstanding any changes in albedo and minimum canopy resistance. The paper reporting these results was published in *Geophysical Research Letters* in 2009.

An immediate extension focused on the biogeophysical effect associated with phenological differences resulting from conversion of annual to perennial bioenergy crops across the central U.S. These differences were parameterized in the WRF modeling system and a series of multi-season numerical experiments were conducted to show that annual to perennial bioenergy crop conversion imparts a significant local to regional cooling impact (primarily at the onset and conclusion of the growing season, with reduced effects during mid-summer). The simulated biogeophysical impact is compared to the carbon-saving effect and is found to be of considerably greater magnitude. Lastly, the conversion of annual to perennial bioenergy crops partially offsets projected warming due to increased greenhouse gases, though this impact diminishes rapidly with increasing spatial scale and is of reduced relative importance farther out in time. A manuscript reporting these results is in preparation for submission.

Our current focus of bioenergy driven landscape change and associated (direct) climatic consequences is centered on Brazil, where sugar cane expansion has been and is expected to continue to replace the natural landscape (savannah) of the region. Guided by actual field measurements that will be used to parameterize both sugarcane and savannah, we aim to conduct multi-season experiments centered over Sao Paulo state (central region of sugar cane expansion during the previous decade), in order to quantify the hydroclimatic impact of this rapidly changing land-use.

References

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