

Literature Review: Changes and Feedbacks of Land-use and Land-cover under Global Change

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Abstract

Land-use and land-cover change induced by both human activities and natural feedbacks have converted large proportion of the planet's land surface. Variations promoted by anthropogenic activities include substituting forests and grassland for agriculture use, intensifying farmland production and urbanization. Albedo, roughness length and leaf-area index, etc. changes induced by these variations above, as well as global warming will give both positive and negative feedbacks on surface energy and water balance. Climate models (eg. combine general circulation modeling (GCM)), , remote sensing and field results are always combined together to identify the positive feedback loops or the negative ones.

Key words: Global change, vegetation variation, feedback

1 Introduction

Humans have been altering land cover since pre-history through the clearance of patches of land for agriculture and livestock. In the past two centuries the impact of human activities on the land has grown significantly, altering entire landscapes, and ultimately impacting the earth's nutrient and hydrological cycles as well as climate. Land-use and land-cover changes are local and place specific, and they currently become one of the most important facets of global environmental change. Land-use and land-cover changes mainly refer to replacing forests and grassland for agricultural use, intensifying farmland production and urbanization (fig 1). The variations of tropical forests, temperate forests, boreal forests and tropical savanna, and their feedbacks under current climate change are generalized in this review. In addition, the roles of carbon cycle feedback in global climate change are considered.

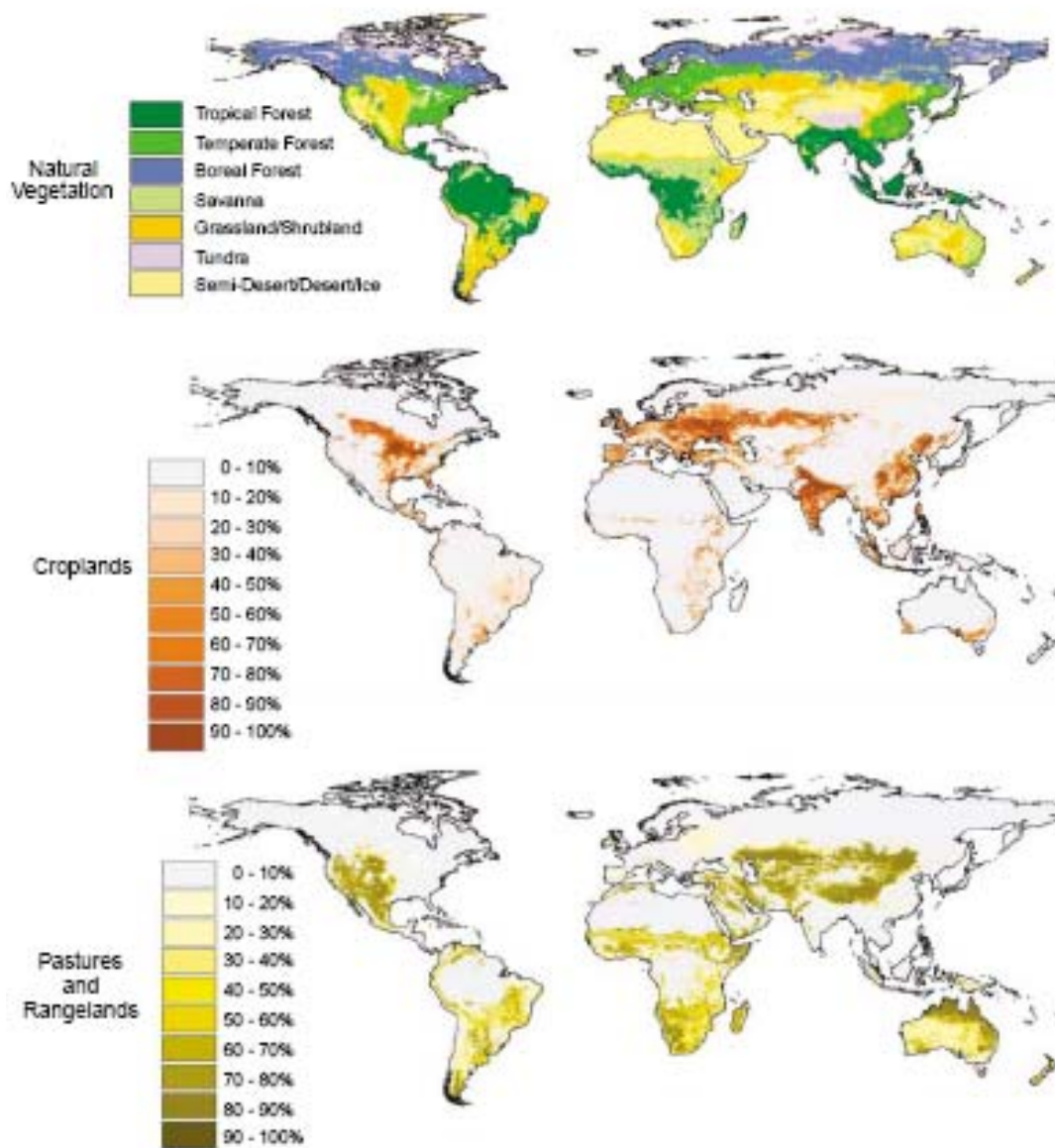


Fig. 1. Worldwide extent of human land-use and land-cover change. These maps illustrate the geographic distribution of “potential vegetation” (top), vegetation that would most likely exist in the absence of human land use, and the extent of agricultural land cover (including croplands and pastures) (middle and bottom) across the world during the 1990s. (Foley et al., 2005)

2 Changes of forests and their feedbacks

The world’s forests cover 42 million km² in tropical, temperate, and boreal lands, 30% of

the land surface. These forests influence climate through physical, chemical, and biological processes that affect planetary energetics, the hydrologic cycle, and atmospheric composition (Bonan et al., 2008). World's forests have been converted by human activities significantly. These activities, primarily for agricultural expansion and timber extraction, have caused a net loss of 7 to 11 million km² of forest in the past 300 years (Foley et al., 2005). Highly managed forests, such as timber plantations in North America and oil-palm plantations in Southeast Asia, have also replaced many natural forests and now cover 1.9 million km² worldwide area (Williams, 1990). Many land-use practices, such as fuel-wood collection, forest grazing, and road expansion, can degrade forest ecosystem conditions even without changing forest area. Land-use can also degrade forest conditions indirectly by introducing pests and pathogens, changing fire-fuel loads, changing patterns and frequency of ignition sources, and changing local meteorological conditions (Nepstad et al., 1999). In addition, forests are also under the threatening of global change.

2.1 Tropical forest

Agricultural use has resulted in a large area of tropical deforestation in the last several decades; further uncontrolled fire is another principal factor contributing to the degradation of deforested and selectively logged tropical forests.

Climate model simulations show that tropical forests maintain high rates of evapotranspiration, decrease surface air temperature, and increase precipitation compared with pastureland. The most studied region is Amazonia, where large-scale

conversion of forest to pasture creates a warmer, drier climate ([Bonan et al., 2008](#)). Flux tower measurements in the Brazilian Amazon indicates that forests have lower albedo compared with pasture, but greater net radiation and evapotranspiration, especially at the dry season ([Bonan et al., 2008](#)), producing a shallow, cool, and moist boundary layer.

Thinning or removal of the forest canopy permits greater insolation at the soil surface, which increases the air temperature and decreases relative humidity near the soil surface. Therefore, even the undisturbed tropical forest is not flammable, selectively logged forest and areas cleared for pasture are easily to be burnt. This burning, if happens, will further reduces tree cover and prevents tree regeneration; and this whole process will lead to a positive feedback at the local scale ([Hoffmann et al., 2002](#)).

Simulations with general circulation models (GCMs) demonstrated that changes in albedo, roughness length, leaf-area index and rooting depth caused by tropical deforestation reduce precipitation and relative humidity and increase surface temperature and wind speed. Thus, all of these changes above will increase fire risk ([Hoffmann et al., 2002, 2003](#)). Based on model research, both the local microclimatic change and the regional climate change are likely to contribute to a positive feedback loop in which deforestation results in increased fire frequency and further reductions in tree cover ([Hoffmann et al., 2003](#)).

2.2 Temperate forest

Temperate forests are forests in the temperate climate zones. They include temperate deciduous forest, temperate broadleaf and mixed forests, temperate coniferous forests and temperate rain forests. Temperate forests hold 20% of the world's plant biomass and 10% of terrestrial carbon. Much of the temperate forests of the eastern United States, Europe, and eastern China have been cleared for model agriculture.

Comparing with forests, croplands have a higher albedo, and many climate model simulations find that trees have greater potential to warm up the surface relative to crops. Studies of eastern United States forests find that trees also maintain a warmer summer climate compared with crops because of their lower albedo, augmented by evaporative cooling from crops and feedbacks with the atmosphere that affect clouds and precipitation ([Bonan et al., 2008](#)) The influence of crops on evapotranspiration is seen in flux tower measurements. Growing season evaporative cooling is greater over watered crops compared with forests, and these plants exert less evaporative resistance.

Researches based on global climate models find that temperate forests in the eastern United States warm summer temperature; mesoscale model simulations in the United States in July, however, indicated that trees increase evapotranspiration and decrease surface air temperature compared with crops ([Bonan et al., 2008](#)). Moreover, atmospheric feedbacks that alter cloudiness affect the magnitude of the temperature response in these simulations. Flux tower analyses show that conifer and deciduous broadleaf forests in North Carolina have lower surface radiative temperature than grass fields because of greater aerodynamic conductance and evaporative cooling of trees

compared with grasses, but the same may not pertain to cropland. In western Europe, forest and agricultural land have comparable surface radiative temperature when soil is moist but respond differently to drought ([Bonan et al., 2008](#)).

It can be seen that the net climate forcing of temperate forests is highly uncertain. Higher albedo results from the loss of forest cover could offset carbon emission so that the net climatic effect of temperate deforestation is negligible, or reduced evapotranspiration with loss of trees could amplify biogeochemical warming. Besides, the future of temperate forests and their climate services has high uncertainty. Conversion between deciduous and evergreen trees is likely in the future. Temperate forests are particularly vulnerable to human land use. The trend over the past several decades has been toward farm abandonment, reforestation, and woody encroachment from fire suppression, but meeting the needs of a growing global population could place greater pressures on these forests ([Bonan et al., 2008](#)).

2.3 Boreal forests

Though mature forests have low annual carbon gain, boreal forests store a large amount of carbon in soil, permafrost, and wetland and contribute to the Northern Hemisphere terrestrial carbon sink. Boreal forests are different in energy balance, which usually based on the types of forest. Conifer forests, for example, have low summertime evaporative fraction (defined as the ratio of latent heat flux to available energy), while the deciduous broadleaf forests always produce high rates of sensible heat exchange and deep atmospheric boundary layers ([Bonan et al., 2008](#)).

Climate forcing raises the fire frequency, which will increase surface albedo; the increased albedo may offset the forcing from carbon emission so that boreal deforestation cools climate. A long-term forcing is a balance between post-fire increase in surface albedo and the radiative forcing from greenhouse gases emitted during combustion. Averaged over an 80-year fire cycle, the negative forcing from surface albedo exceeds the smaller positive biogeochemical forcing. Yet in the first year after fire, positive annual biogeochemical forcing from greenhouse gas emission, ozone, black carbon deposited on snow and ice, and aerosols exceeds the negative albedo forcing. Flux tower measurements illustrate the potential for changes in species composition, arising from change in the fire regime, to affect climate. Based on the observation, annual net radiation declined at postburn site and annual sensible heat flux also decreased, mostly in spring and summer ([Bonan et al., 2008](#)).

Boreal forests are vulnerable to global warming ([Fischlin et al., 2007](#)). Trees may be converted into tundra, but die back along southern prairie ecotones. In the main boreal forest, there may be loss of evergreen trees and a shift toward deciduous trees. Siberian forests may collapse in some areas and become more evergreen in the north. Increased disturbance from fire or insect outbreaks will shift the forest to a younger age class. Climate forcing arising from younger stand age may be comparable to that arising from biome shifts ([Bonan et al., 2008](#)).

Owing to the different tree species and the different distribution, tropical forests, temperate forests and the boreal forests response differently to species variation and

global climate change (Table 1). Though some of the differences have been verified by field study and model simulations, some other characteristics of the variation and feedbacks are still uncertain, which should be promoted by advanced research.

Table 1. Climate services in tropical, temperate and boreal forest, and their possible feedbacks on climate change.

	Carbon storage	Evaporative cooling	Albedo decrease	If is replaced by grassland or farmland	Feedback
Tropical forests	Strong	Strong	moderate	Trend to warmer and drier the air	Positive
Temperate forest	Strong	Moderate	Moderate	Uncertain	Positive and negative (Uncertain)
Boreal forest	Moderate	Weak	strong	Trend to cool down the surface.	Negative

3 Changes of tropical savanna and their feedbacks

Savannas, another ecosystem which are currently subject to intense human pressure, and nearly one fifth of the global population living in tropical savanna regions (Solbrig et al., 1996). The ensuing expansion of agriculture and grazing lands is driving conversion of the original mixture of trees and grasses to predominantly herbaceous vegetation, with frequent anthropogenic burning disturbing many sites not yet cleared. Besides anthropogenic activities, fire frequency and intensity, which are highly sensitive to meteorological conditions, will likely respond quickly to climate change. At the global scale, greenhouse warming is predicted to increase fire risk (Williams et al., 2001) and, in consequence, emissions of greenhouse gases (Hoffmann et al., 2002).

GCM simulations promoted by Hoffmann ([Hoffmann et al., 2002](#)) indicate that ongoing clearing of tropical savannas increases temperatures and wind speeds and decreases precipitation and relative humidity, which will substantially raise fire frequency. By employing NOAA-12 satellite images and meteorological data, Hoffmann's research ([Hoffmann et al., 2002](#)) estimates that complete savanna clearing will increase fire frequency by 42%. By combining these data with long-term fire studies, the research demonstrates that fire-mediated feedback may already be contributing to declining tree densities in the world's savannas and will become increasingly important as vegetation change continues in the coming century.

Totally speaking, conversion of savanna to grassland significantly altered the four climatic variables—precipitation, dry season max temperature, dry season maximum wind speed, and dry season minimums relative humidity--most relevant to fire risk (Table 2). Daily maximum surface temperatures and wind speeds increased significantly in all savanna regions included in this research, while precipitation declined significantly in northern and southern Africa, as did relative humidity in the cerrado, the llanos, and southern Africa (Table 2). Each of these changes increases fire risk ([Noble et al., 1980](#)).

Humans play an important role in this vegetation-climate feedback by igniting the majority of fires in tropical savannas. Understanding vegetation-climate feedbacks is essential for predicting the consequences of land-use change and other forcings ([Hoffmann et al., 2002](#)) on future vegetation and climates. As demonstrate above, fire plays an important role in these feedbacks, a result that emphasizes the need to represent fire processes in global-scale modeling. The rapid response of vegetation to

fire suggests that fire-driven feedbacks could have important consequences within the scale of human life-spans.

Table 2. Simulated Effects of vegetation Change on Mean Annual Values of the Four Meteorological Variables Used to Calculate the Forest Fire Danger Index (FFDI).

	Precipitation (mm yr ⁻¹)		Dry season max. Temperature (°C)		Dry season max. wind speed (m s ⁻¹)		Dry season min. Relative humidity (%)	
	Control	Change	Control	Change	Control	Change	Control	Change
Cerrado	1530	-30 ^{ns}	30.8	1.5 ^c	5.51	0.77 ^c	36.6	-2.4 ^a
Llanos	1718	0 ^{ns}	32.5	2.0 ^c	5.10	0.46 ^c	40.0	-2.6 ^a
Southern Africa	1104	-119 ^c	27.5	1.4 ^c	5.58	0.99 ^c	37.3	-1.8 ^b
Northern Africa	1108	-93 ^c	33.7	1.4 ^c	5.52	1.07 ^c	21.0	-0.4 ^{ns}
Australia	872	-12 ^{ns}	29.3	1.2 ^c	6.16	1.05 ^c	38.5	0.0 ^{ns}

Dry season values were averaged over periods with mean precipitation less than 2 mm d⁻¹ in the savanna scenario. The t-test was used to compare scenarios by first taking daily means over all grid cells in a region, then accounting for temporal autocorrelation using the approach of Zwiers and von Storch (1995). aP < 0.05. bP < 0.01. cP < 0.005. ns Not Significant. (Hoffmann et al., 2002)

4 Carbon Cycle

Research on carbon cycle is also important for understanding climate change. Based on the comparison of 11 models of a variety of complexity, carbon cycle–climate feedbacks increase atmospheric CO₂ at the end of the 21st century by 4 to 44% (multimodel mean, 18%), equivalent to an additional 20 to 224 (ppm) (multimodel mean, 87 ppm) (Denman K L et al., 2007). Analyses of observed atmospheric CO₂ concentrations figure that the efficiency of the carbon cycle to store anthropogenic CO₂ in ocean and land will decline, and the extent to which could even be larger than models simulations (Bonan et al., 2008).

It has been well known that plants respond to rising atmospheric CO₂ through photosynthetic enhancement, and this “CO₂ fertilization” is a negative feedback to higher atmospheric CO₂ concentration. In accordance with model comparison, land carbon storage increases with higher atmospheric CO₂ in all models, driven by a 12 to 76%

increase in NPP with CO₂ doubling (multimodel mean, 48%), offset slightly by increased heterotrophic respiration ([Denman K L et al., 2007](#)).

Ecological responses to climate change alter the biogeophysical function of forests and also provide climate feedback. These “indirect” carbon cycle feedbacks include changes in stomatal conductance, leaf area index (LAI), and species composition. Decreased stomatal conductance with higher atmospheric CO₂ concentration reduces evapotranspiration and reinforces warming. It is possible that more extensive tree cover may promote the warming trend in boreal forests by decreasing surface albedo. Reduced evapotranspiration in a drier climate may initiate a positive climate feedback which will result in the shrinking tropical forests ([Bonan et al., 2008](#)).

5 Discussion

Climate trends over the 21st century should be driven by interactions among CO₂ emission, land use, and forest-atmosphere feedbacks. Considering the land-use and land-cover aspect, a large amount of areas of forests have been replaced by farmland, and climate warming over the industrial era may be smaller than that expected from rising atmospheric CO₂ alone, primarily from increased spring albedo with loss of extratropical forests. The biogeophysical land-use forcing of climate may in some regions be of similar magnitude to greenhouse gas climate change ([Bonan et al., 2008](#)).

Fundamentally, even if the short-term supplies of material goods are increased by modern land-use practices, many ecosystem will be undermined by these practices in the long run, on both regional and global scales. Confronting the global environmental

challenges of land use will require assessing and managing inherent trade-offs between meeting immediate human needs and maintaining the capacity of ecosystems to provide goods and services in the future (Foley et al., 2005). Therefore, effective policy should be promoted to keep the balance between the current requirements of human society and the capacity of ecosystems.

Through albedo, evapotranspiration, the carbon cycle, and other processes, forests can amplify or dampen climate change arising from anthropogenic greenhouse gas emission and land-use and land cover changes. The interactions between all these factories are complex, therefore when comes to the research in climate change, extrapolation of process-level understanding of ecosystem functioning gained from laboratory experiments or site-specific field studies to large-scale climate models remains a daunting challenge.

For advanced research, synthesis of flux tower data from a variety of boreal, temperate, and tropical regions in various stages of ecosystem development is essential to understand the functioning of forests across wide gradients of climate, soils, disturbance history, and plant functional types (Bonan et al., 2008). Further, some of the process, such as the effect of nitrogen on carbon uptake, physiological effects of high ozone concentration, photosynthetic enhancement by diffuse radiation, and disturbance should be made clear; and the realistic depictions of vegetation dynamics, especially the time scales of vegetation response to disturbance, and fires, aerosols, as well as reactive chemistry should be taken into account or even well represented in current generation of

models.

In addition, remote sensing data are intertwined in many ways with other environmental issues, such as climate change and carbon cycle, loss of biodiversity, sustainability of agriculture, and provision of safe drinking water. Moreover, the international scientific community has created new interdisciplinary research programs to understand the multiple causes and consequences of land-cover and land-use change (LEPERS E et al., 2005). Therefore, it can be true that better employment of synthesized remote sensing data would help to access the instantaneous surface variations on global scale.

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