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Protecting climate with forests

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Abstract

Policies for climate mitigation on land rarely acknowledge biophysical factors, such as reflectivity, evaporation, and surface roughness. Yet such factors can alter temperatures much more than carbon sequestration does, and often in a conflicting way. We outline a framework for examining biophysical factors in mitigation policies and provide some best-practice recommendations based on that framework. Tropical projects—avoided deforestation, forest restoration, and afforestation—provide the greatest climate value, because carbon storage and biophysics align to cool the Earth. In contrast, the climate benefits of carbon storage are often counteracted in boreal and other snow-covered regions, where darker trees trap more heat than snow does. Managers can increase the climate benefit of some forest projects by using more reflective and deciduous species and through urban forestry projects that reduce energy use. Ignoring biophysical interactions could result in millions of dollars being invested in some mitigation projects that provide little climate benefit or, worse, are counter-productive.

Keywords: afforestation, albedo, avoided deforestation, biophysics, carbon sequestration, climate change, climate policy, forest restoration, global warming, tropical, temperate and boreal forests

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Policies are being proposed and implemented to influence forestry and land-management practices for climate change mitigation [1, 2]. The proposed Lieberman–Warner bill, for example, establishes a US CO_2 market that allows corporations to offset up to 30% of their emissions through forestry and land-management activities. Many countries are already using forestry credits in voluntary carbon markets trading billions of dollars each year. Forest conservation will also likely play an important role in the second commitment of the Kyoto Protocol.

Planting forests and avoiding deforestation can help to slow increases in CO_2 concentrations and global temperatures. However, in addition to altering the carbon balance and emissions of other greenhouse gases, forest projects come with an additional suite of biophysical changes (figures 1(A) and (B)). They often darken the land surface compared to pastures, agricultural lands, and snow-covered surfaces (figures 1(A)–(C)). This effect leads to higher sunlight absorption that can warm the land regionally. Other biophysical changes alter the amount of water that evaporates from plants and the soil, the roughness or unevenness of the vegetation canopy, and the production of convective clouds and rainfall (figures 1(A) and (B)). Overall, such biophysical changes can affect local to regional climate much more than the accompanying carbon sequestration does—and sometimes in a conflicting way [3–7].

Unlike reducing fossil fuel combustion, where the effect on greenhouse gas emissions is dominant, the net climate impact of a forest has dimensions beyond carbon storage alone. For forests, which mitigation activities will have biophysical changes that reinforce or negate the benefits of carbon sequestration? What if a forest offset activity cools the Earth globally but warms it locally—or alters the regional hydrologic balance—exacerbating the regional impacts of climate change? This paper outlines a framework for examining such interactions and provides some recommendations based on that framework.

Biophysical influences on air temperature depend on where sequestration activities occur. In the tropics, forests cool regionally by increasing the evaporation of water from land to air (figures 1(A) and (B)). This added water vapor can help to form clouds that contribute to additional cooling by reflecting sunlight back to space [3, 8–11]. In this case the biophysics and carbon sequestration of forest cover change are usually aligned; the best science indicates that avoided deforestation and forest establishment in the tropics cools the climate through evapotranspiration, cloud feedbacks, and slowing the buildup of CO_2 in air.

Boreal forests provide a different extreme. Rates of carbon storage there are much slower than in the tropics because of colder temperatures, less sunlight, and other factors that limit tree growth. Boreal lands are also covered in snow and ice for extended periods each year. Replacing snow with a surface that absorbs more sunlight, such as an evergreen spruce or pine canopy, warms the area at spatial scales of hundreds or even thousands of kilometers [12, 13]. As a result, planting forests in northern countries will help to stabilize global atmospheric CO_2 but may accelerate climate warming regionally, further speeding the loss of snow and ice cover.

The greatest uncertainties lie in temperate forests [6, 14]. While their rates of carbon sequestration are well established, much less is known about how accompanying biophysical changes influence climate. A number of climate model studies suggest that replacing forests with agriculture or grasslands in temperate regions cools surface air temperatures [14–17]. Other studies show the opposite—that temperate forests cool the air compared with grasslands and croplands [18–20]. In warm-temperate areas, such as the southeastern US or northern Argentina, surface temperatures of forests are often 1–5 °C cooler than adjacent grasslands or croplands (figure 1(D)). This local cooling is caused by more evapotranspiration and a more efficient coupling between the land and the atmosphere in forests attributable to increased roughness. Paradoxically, these forests also deliver more heat to the atmosphere because they are darker and absorb more sunlight (figure 2). The fate of this added heat within the atmosphere—both in the form of air temperatures and water vapor—is poorly understood. In some temperate and tropical regions additional water vapor may form clouds that contribute to surface cooling and increased rainfall in nearby areas. In other regions where water availability is relatively scarce, such as the southwestern US, forest plantations may warm regional climate by absorbing more sunlight without substantially increasing evapotranspiration.

While the science of biophysical interactions is still emerging, some recommendations for best practices in climate protection are possible. Based on decades of research in carbon sequestration and biophysics, we suggest that avoided deforestation, forest restoration, and afforestation in the tropics provide the greatest value for slowing climate change. Tropical forests combine rapid rates of carbon storage with biophysical effects that are beneficial in many settings, including greater convective rainfall [8–11]. Forestry projects in warm-temperate regions, such as the southeastern US, can also help reduce warming, but large uncertainties remain for the net climate effects of forestry projects in temperate regions. Forestry projects in boreal systems are less likely to provide climate cooling at local to global scales because of the strong snow-cover feedback [5, 12, 13]. Thus, incentives for reforesting boreal systems should be preceded by thorough analyses of the true cooling potential before being included in climate policies.

Policies could also be crafted to provide incentives for beneficial management practices. For instance, urban forestry provides the opportunity to reduce energy use directly; in temperate regions deciduous trees block sunlight in summer, reducing the energy needed to cool buildings, but they allow sunlight to warm buildings in winter. In addition to choosing appropriate deciduous species, foresters could also select trees that are 'brighter', such as poplars, with albedos relatively close to those of the grasses or crops they replace (figure 2). Additionally, forest planting and restoration can be used to reclaim damaged lands, reducing erosion and stabilizing streambanks [23].

However, some trade-offs and unintended consequences are possible when forests are included in climate policies. Eucalypts, for instance, grow quickly and have a fairly bright

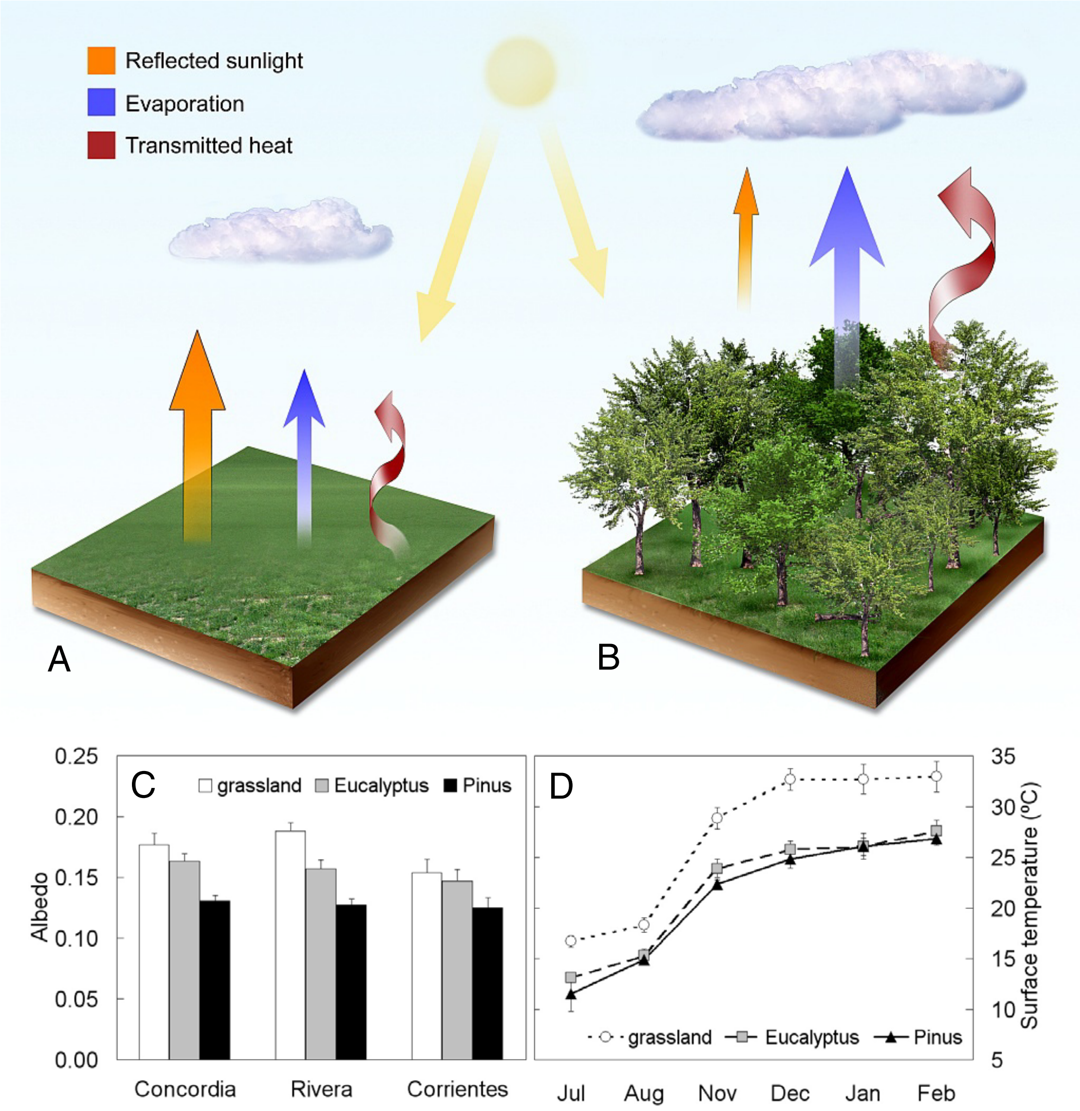

Figure 1. Examples of various biophysical factors in a grassland or cropland (A) and forest (B). Because of a grassland or cropland's higher reflectivity (albedo), it typically reflects more sunlight than the forest does, cooling surface air temperatures relatively more. In contrast, the forest often evaporates more water and transmits more heat to the atmosphere (latent and sensible heat, respectively), cooling it locally compared to the grassland or unirrigated cropland. More water vapor in the atmosphere can lead to a greater number and height of clouds as well as to increased convective rainfall. In addition, the forest has a more uneven canopy (surface roughness) that increases mixing and upwelling of air. ((C) and (D)) Comparison of shortwave albedo and surface skin temperature for 215 grassland and forest stands across Argentina and Uruguay. The satellite data were assessed using 180 km × 180 km Landsat images (2000–2005) on seven dates for the Corrientes and Concordia regions of Argentina and three dates for the Rivera region of Uruguay. The Landsat scenes were geometrically and atmospherically corrected and correspond to images 226/80 (path and row) for Corrientes, 225/82 for Concordia, and 223/82 for Rivera. In general, measurements at sites within a region compared adjacent grassland, pine, and eucalypt stands.

albedo, but they are fire-prone [24] and often use more water than native vegetation [19]. Because forestry projects can appropriate scarce water resources, they may be poor choices in semi-arid regions [19, 25]. Applying fertilizers in forest sequestration projects helps trees grow more quickly but also increases the emissions of nitrous oxide, a potent greenhouse gas [26]. Finally and perhaps most importantly, forests provide a wide range of important services, including preserving biodiversity, wildlife habitat, and freshwater supply. Policies focused solely on managing vegetation to cool local or global temperatures may jeopardize other key ecosystem services.

In the coming decades, policies for forest carbon sequestration and offset activities will create a multi-billion-dollar industry. The biophysical consequences of forest cover change and other co-effects of these activities can be large at regional scales [27, 28] and may sometimes reduce or even cancel the benefits of carbon sequestration. Biophysical interactions should therefore be factored into climate mitigation strategy in at least two ways—in designing carbon sequestration projects to achieve the greatest climate benefit and in comparing the costs and benefits of terrestrial carbon sequestration with those of other mitigation activities. Successful policy should account for the different ways that

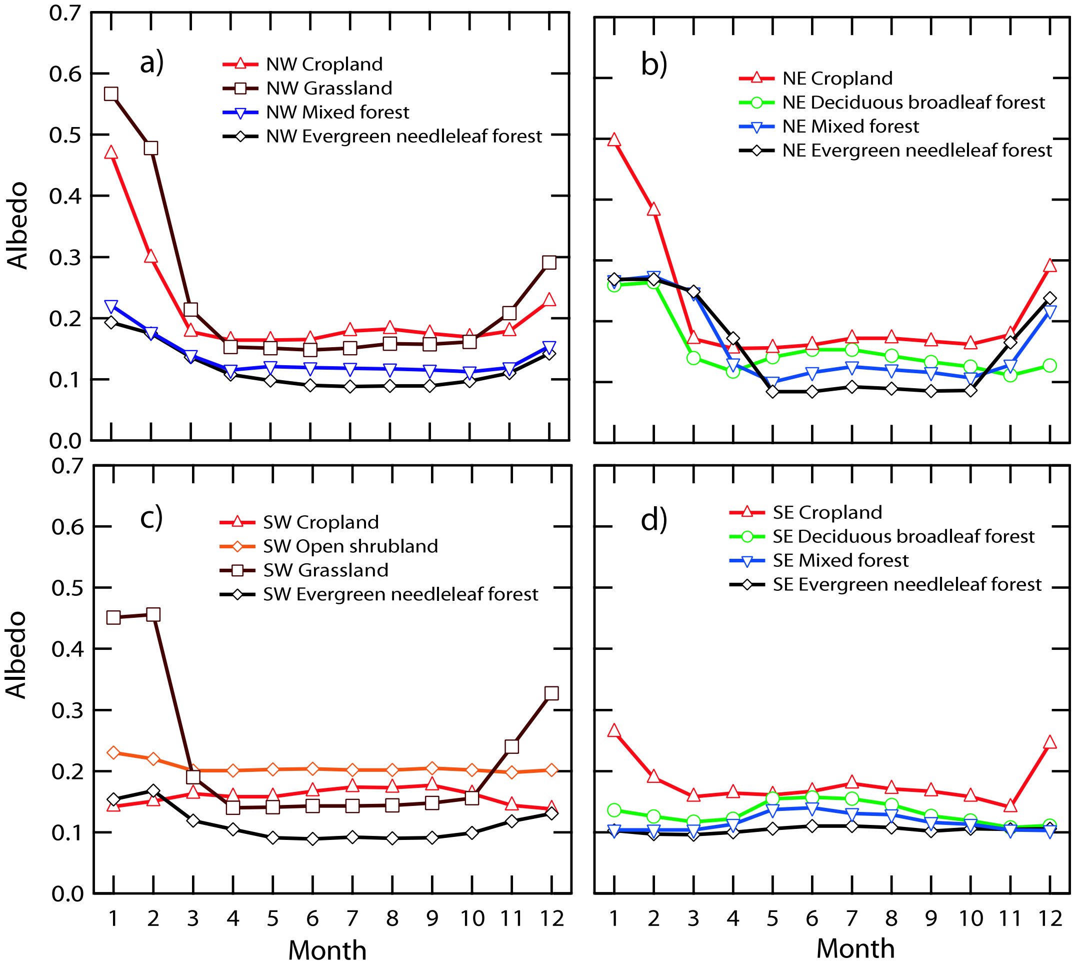

Figure 2. Satellite observations of monthly shortwave surface albedo for dominant US land cover types in the Northwest (a), Northeast (b), Southwest (c), and Southeast (d). In all regions, albedo in croplands is substantially higher than in nearby forests. In the Northeast and Southeast, deciduous broadleaf forests have higher albedo values than evergreen needleleaf forests during summer. The data from 2004 were obtained from MODerate resolution Imaging Spectroradiometer (MODIS) measurements of black sky albedo (MCD43C3 version 5) [21]. The albedo observations were averaged within International Geosphere-Biosphere Program (IGBP) land cover classes (MOD12C1 version 4) developed using concurrent MODIS surface reflectance observations [22]. All 0.05° × 0.05° grid cells comprised of >80% of a single IGBP land cover type were included in the analysis. The borders of the four regions were: 40°N to 50°N and west of 105°W for the Northwest, 40°N to 50°N and east of 90°W for the Northeast, 30°N to 40°N and west of 105°W for the Southwest, and 30°N to 40°N and east of 90°W for the Southeast.

forests interact with climate. It also needs to acknowledge factors beyond climate science, including trade-offs with other ecosystem services and the demand for and economics of land use.

Currently, no formal mechanism accounts for biophysics in climate policy. Adding biophysical effects into frameworks for evaluating carbon sequestration programs is a challenge, but simple rules (or mechanisms to adjust carbon prices) can be developed to encourage best practices. Ignoring this challenge could result in millions of dollars invested in some mitigation projects that provide little climate benefit or, worse, are counter-productive.

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