

## ECOSYSTEM SERVICES

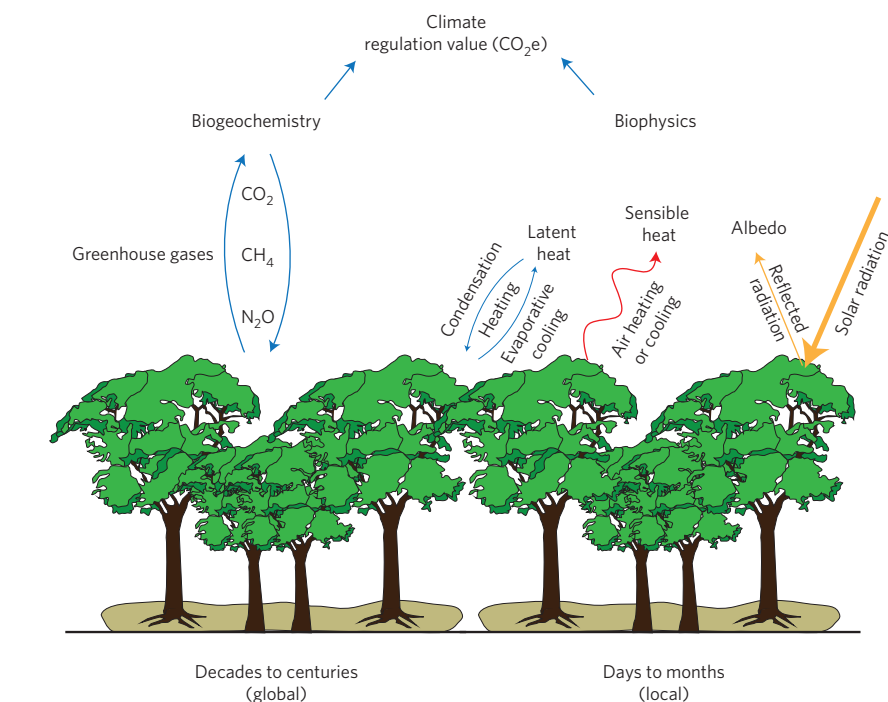
# Valuing ecosystems for climate

Ecosystems regulate climate through biogeochemistry and biophysics, but current policies only recognize biogeochemical influences. A new proposal to include biophysical effects changes the climate value of ecosystems, and sets the stage to expand the suite of climate regulation services considered in global policies and carbon markets.

Bruce A. Hungate and Haydee M. Hampton

Ecosystems are sensitive to climate, but the converse is also true: ecosystems strongly influence the climate system. Past ways of accounting for the effect of ecosystems on climate focused on their biogeochemical impacts, capturing the ways ecosystems affect the greenhouse-gas composition of the atmosphere. Ecosystems take up carbon dioxide from the atmosphere through photosynthesis and store it as organic carbon, primarily in wood and soil. They release carbon dioxide back to the atmosphere through respiration and fire. Ecosystems also take up and release methane and nitrous oxide. These effects are large enough to influence global climate. So, ecosystems that store more carbon, and emit less nitrous oxide and methane, could help reduce concentrations of these greenhouse gases in the atmosphere and thereby help counteract human-induced climate change. These biogeochemical influences of ecosystems on climate are tradable commodities in carbon markets, because of their contribution to reducing greenhouse-gas emissions (Fig. 1). Writing in *Nature Climate Change*, Anderson-Teixeira *et al.*<sup>1</sup> suggest that the climate regulation value (CRV) of ecosystems should not only include their biogeochemical influences, but also their biophysical ones.

Biophysical effects explain why you can escape the heat of the asphalt car park on a hot summer day by stepping onto the adjacent well-watered lawn. The lawn is more reflective (higher albedo) than the black asphalt, and part of the energy absorbed by the lawn evaporates water (latent heat), whereas more of that radiation just heats up the asphalt, which then heats the air around it (sensible heat). Such biophysical effects of differences in vegetation cover are large enough to influence global climate<sup>2</sup>. Anderson-Teixeira and colleagues suggest one way to convert the biophysical effects into the biogeochemical units, facilitating quantitative comparison. Their single metric expands on past efforts to quantify ecosystem effects on climate<sup>3,4</sup> by combining the biogeochemical and biophysical mechanisms through which ecosystems influence climate.



**Figure 1** | Ecosystem influences on climate over space and time. Global and long-term biogeochemical influences (left side) involve exchange of greenhouse gases between ecosystems and the atmosphere. Regional and shorter-term biophysical influences (right side) involve the balance between incoming solar radiation and reflection, and how absorbed radiation is partitioned between latent and sensible heat. Anderson-Teixeira and colleagues<sup>1</sup> calculate the climate regulation value, which combines biogeochemical and biophysical climate services of ecosystems into the common currency of carbon dioxide equivalents (CO<sub>2</sub>e) per hectare of the globe integrated over a 50-year period.

The researchers show how the climate regulation service varies between the different land types of the Americas, and also how the different forces that influence climate play relatively greater or lesser roles in different ecosystems, at different latitudes. They find that ecosystems that are intensively managed by humans, such as agricultural systems, generally have lower CRVs than ecosystems where management is less intense, such as tropical forests and tundra. They also confirm that including biophysical influences increases the value of tropical forests compared with forests at higher latitudes, especially in regions with snow<sup>3</sup>. Including biophysical influences increases the CRV of managed ecosystems, mainly because of

increased evaporation, a cooling mechanism relatively less important in the unmanaged ecosystems they replace.

The new CRV combines the radiative forcing caused by globally distributed greenhouse gases, the effects of albedo variation across the landscape, and local cooling caused by evaporating water that eventually releases heat when it condenses again, many miles away, into a common unit. The authors point out that CRV does not consider how evapotranspiration leads to cloud formation and increased reflectivity — effects that can be quite large for tropical forests<sup>2</sup> and croplands<sup>5</sup>. More research is needed to quantify and properly include these impacts, but this is one area for refinement.

The work by Anderson-Teixeira and colleagues has important implications for how we value efforts to slow global warming. Biogeochemical and biophysical influences on climate have long been recognized, but only biogeochemical ones have value in the carbon market. Greenhouse gases are well mixed, causing equal damage in terms of trapping heat in the atmosphere, regardless of the location from which they are emitted. The effects of ecosystems on reflectivity, evaporation, and heat exchange, are more local, and operate on shorter time scales — challenges that could motivate policy instruments that keep biophysical and biogeochemical influences separate<sup>6</sup>. The researchers propose a novel way to combine them: expressing the local biophysical influences on the global scale, integrating them over time and converting them into the common unit of carbon markets — carbon dioxide equivalents.

The research sets the stage for policies that value ecosystems for their biogeochemical and biophysical influences — arguably a more complete quantification of the way

ecosystems affect climate. Yet, the work also raises new questions for policy, because the consequences of valuing the biophysical influences are different from valuing the biogeochemical ones. As the authors note, we could err by emphasizing biophysical mitigation strategies, failing to address both the root cause of carbon dioxide emissions and other direct effects of increased atmospheric carbon dioxide, such as ocean acidification, and increased release of other greenhouse gases from terrestrial ecosystems<sup>7</sup>. Adopting CRV could reward land conversion, for example, from natural prairies to crops for biofuels — the biogeochemical value of the prairies is much higher than that of biofuels, but including the biophysical influences tips the balance the other way. Should we award higher market value to crop conversion to biofuels, based largely on biophysical effects? To take it even further, one could calculate the CRV of geoengineering schemes and the equivalent CRV of adopting energy-efficiency projects, or of other activities that actually reduce carbon dioxide emissions. For developing a more complete view of

the climate value of ecosystems, however, Anderson-Teixeira *et al.* provide a useful starting point by quantifying with a common metric the multiple ways that ecosystems influence climate. The stage is set to redefine the suite of ecosystem influences on the climate system that warrant value in the efforts to combat global warming. □

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## AGRICULTURE

# Wheat crops feel the heat

Extreme heat can accelerate wheat aging — an effect that reduces crop yields and is underestimated in most crop models. Climate warming may, therefore, present even greater challenges to wheat production than current models predict.

Tim Wheeler

A recent Intergovernmental Panel on Climate Change special report on climate extremes warns that it is “virtually certain” that hot day temperatures will become more frequent, and increase in magnitude, through this century<sup>1</sup>. There is therefore an urgent need to understand the impacts of such hot temperatures on crops. Knowledge that would aid in the development and adaptation of crops to a warmer future with more hot days. Writing in *Nature Climate Change*, David Lobell and co-workers address just this question. Investigating wheat crops in the Indo-Gangetic Plain, they show that day temperatures greater than 34°C accelerate the death of the leaf canopy, and hence lower grain yields<sup>2</sup>.

The study by Lobell and co-workers provides evidence that the duration of the leaf canopy of wheat is sensitive to day temperatures greater than 34°C, in addition to any effects of warmer average temperatures. Crop simulation models used to project the impacts of climate change on crops yields do

not include this particular response, so, are we underestimating how climate change will affect the world’s major annual crops?

Crop scientists have long known that the yield of annual crops such as wheat and maize will decline as average seasonal temperatures warm<sup>3</sup>. This response is underpinned by simple relationships between the duration of the crop growing season, average seasonal temperature and daylength<sup>4</sup>. As temperature warms, crop duration shortens, at least until an optimum temperature — which is usually somewhere between 25 and 35°C — is exceeded<sup>5</sup>. A shorter duration for crop growth reduces the amount of radiation that is intercepted by the leaf canopy, and hence the biomass and yield decline.

The effect of ‘extreme’ hot temperatures on crops is less well understood. Sensitivity of crops to hot temperatures does vary within the crop life-cycle. For example, a particularly sensitive stage for annual crops is the time of flowering, when only a single day hotter than 32–35°C can disrupt pollination, reducing

the number of grains that are formed, and so drastically lowering final yield (Fig. 1). Such a response is occasionally found in the current climate and could have contributed to the decline in the wheat harvests across central Europe in the exceptionally hot summer of 2003 (ref. 6).

At other stages of crop growth, however, any effect of hot day temperatures, short of those that are lethal to plants, are difficult to isolate from other effects, such as differences in average temperature, or drought. Disentangling these effects was the central challenge that Lobell and co-workers faced in their study. They defined two measures of the temperature regime — temperature accumulated over ‘normal’ (0 to 30°C) and ‘extreme’ (greater than 34°C) ranges. Warming in both normal and extreme temperature ranges reduced the green season length estimated from satellite observations, and hence accelerated the rate of leaf-canopy death (senescence). However, the shortening of green-season length was more