The Ecosystem Impacts of Severe Warming

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Popularized images of global warming portend previously lush ecosystems catastrophically turning to deserts, driving down biodiversity worldwide, and ruining human welfare and livelihoods. But, whether such catastrophic change should be linked to climate change is not clear. This paper evaluates the potential for climate change to cause catastrophic changes to ecosystems.

The paper uses well-established quantitative vegetation ecosystem models (Pan et al. 1998) to explore the long term dynamics of ecosystem change (Sitch et al. 2008). The results of earlier studies indicate that ecosystems would likely respond to warming by expanding more productive biomes, increasing productivity per hectare, and increasing biomass per hectare. Here we explore the ecosystem consequences of uncontrolled greenhouse gas emissions further into the future (to 2300). Multiple climate change scenarios are linked to a dynamic quantitative ecosystem model in order to trace how paths of warming up to 9°-12°C impact the geographic location of biomes, changes in their productivity (NPP), and changes in their standing biomass.

Our rational for examining far future scenarios is to understand the consequences of more severe warming scenarios. Even if greenhouse gas concentrations are stabilized this century, warming will continue for centuries due to the thermal inertia of the oceans. The thermal inertia can create lagged effects on vegetation dynamics that play-out on decadal to centennial time scales. This paper examines how such lags might play-out using a climate change scenario that follows a relatively rapid increase in emissions from (RCP8.5). Ecosystem impacts are assessed up to 2300. Our purpose is two-fold: to see whether ecosystems will collapse as global temperatures rise and to quantify what changes warming is likely to cause in ecosystems. In doing so, we aim to provide a scientific foundation upon to which to judge the magnitude of the nonmarket losses or gains that may be entailed by ecosystem changes globally. Losses (gains) will be measured in terms of wholesale reductions (increases) in productivity, falling (increasing) in situ biomass, global reductions (increases) in the spatial extent of valued ecosystems such as forests and especially tropical forests, and increases (reductions) in the global extent of low productivity ecosystems such as deserts, semi-arid grasslands, and tundra. We further seek to understand whether the changes in vegetation will trigger corresponding changes in the biodiversity of the animal kingdom and especially in global mammalian diversity.

I. Modeling

We explore the consequences of very high temperatures using the Representative Concentration Pathway (RCP) 8.5 scenario. This scenario involves a rapid increase in anthropogenic greenhouse gas emissions for more than a century followed by stabilization of climate forcing after 2250.

Using the RCP8.5 emission scenario throughout, we examine the climate change patterns (temperature, precipitation, cloudiness) predicted by four CMIP5 climate models: IPSL-CM5A-LR, MPI-ESM-LR, CCSM4, and HadGEM2 from 2005-2300. For the historical period, we use observational data from CRU TS 3.1 (Mitchell and Jones 2005). The four climate models predict dramatic warming by 2300 of between 9°C to 12°C.

We then examine the ecosystem impacts of each climate scenario using the LPX-Bern Dynamic Global Vegetation Model (Sitch et al. 2003). The model captures terrestrial processes, including vegetation dynamics, carbon and nitrogen cycling, fire, and prescribed exogenous anthropogenic land use changes. The land use changes predict that cropland in the tropics continues to expand but at a decreasing rate over time. The distribution of biomes is derived from the simulated vegetation composition and structure following Prentice et al. (2011). Preparation of model inputs and the simulation setups are identical to Stocker et al. (2013), except that the simulations are extended to 2300. The purpose of this paper is to isolate the effect of climate change on ecosystems, not predict what the world may be like in 2300.

Determining the attendant nonmarket value of all of these ecosystem changes is challenging because there are no observable "prices" of ecosystems, the changes are worldwide, and the changes unfold over a very long time horizon. We have two primary tools to measure nonmarket ecosystem values: the travel cost method and contingent valuation. The travel cost method measures the value of preserving natural sites by measuring the consumer surplus under a demand function for visits to each site. The contingent valuation method relies on people answering survey questions about their perceived values for different ecosystems states or types. In the United States, recreational visitation is three times higher in United States Forest Service forests compared to Bureau of Land Management grasslands (English 2014). A valuation study of global biomes suggests that tropical forests are the most highly valued terrestrial biome (DeGroot et al. 2012). Contingent valuation suggests that people have strong preferences for biodiversity. Specifically, people prefer to keep species of birds and mammals from going extinct (Loomis and White 1996). People also want wildlife near them. 71 million Americans participated in wildlife viewing in 2011 (United States Fish and Wildlife Service 2011).

There are important limitations to this modeling. We rely on only one ecosystem model. There may be factors that this model fails to account for that would limit the extent of some of the predicted changes. For example, maximum leaf temperatures may limit growth. There may be nutrient limitations (for example in phosphorous) that limit net productivity increases. There may be plant-animal interactions that limit biomass. Finally, it is not clear how to value all of these predicted ecosystem changes.

II. Results

An important predicted ecosystem change caused by warming is the shift of biomes over geographic space (Figures in Appendix). Warming is expected to cause tropical forests to expand into where temperate forests are now and temperate forests to expand into where boreal forests are now. As temperatures rise by 6°C, temperate forests start to give way to temperate parkland. As temperatures warm by about 9°C, tropical forests give way to tropical savannah. Across the four climate scenarios, forests change from 55 million km^2 today to 46-66 million km^2 by 2300. Specifically, tropical forests expand from 23 to 24-32 million km^2, deciduous temperate forests expand from 12 to 15-24 million km^2, and boreal forests decline from 16 to 0.7-4 million km^2. Savannah/woodlands expand from 32 million km^2 to 36-44 million km^2. Desert and dry grassland change from 32 million km^2 to 26-38 million km^2. Tundra and shrub tundra shrink from 11 million km^2 to 0.4 to 0.6 million km^2.

Global average NPP increases as a result of CO_2 fertilization and warming in an S-shaped pattern (see Appendix). Growth increases rapidly during the 21st century and then slows as the growth in CO_2 and temperature slows. Higher rates of NPP appear across all plant types. Biomass/ha accumulates in forests in an S-shaped fashion as well.

The consequence of these vegetative changes to animals and other biota are only partially understood. The increasing tropical and temperate forest habitat will provide increasing support to the many species dependent on this habitat. Increasing NPP, providing more food, will likely support larger populations worldwide. However, the declining extent of boreal forests will shrink endemic boreal species (such as grizzly bears, bald eagles, moose, and common loon) possibly at the risk of extinction. There are also likely to be many species threatened by being stranded on islands and mountain tops or who face natural and human barriers that prevent migration.

From a market perspective, the increasing NPP of cropland and pasture means more food. The increasing NPP of forestland means more wood. From a nonmarket perspective, the expanding temperate and tropical forests will be beneficial whereas the contracting boreal forest is harmful. The increases in NPP are likely to lead to desirable increases in wildlife populations. Increases (decreases) in biomass will generally be beneficial (harmful). There are also potential damages from the increased risk of extinction for specific species (especially boreal, polar, and island species). The movement of biomes across space will also create challenges for conservation strategies that are designed for stability.

III. Conclusion

The modeling undertaken provides a first glimpse of what may happen to ecosystems as global temperatures increase well beyond 4°C. The results suggest that ecosystems are surprisingly robust to a world that is warmer, wetter and CO_2 enriched. There is scant evidence of ecosystem collapse. Ecosystems will survive and maintain their productivity. But they will also change a great deal with severe warming. Tropical and temperate forests will expand and boreal forest and tundra will contract.

It is difficult to quantify the net value of this complex set of changes predicted by the analysis. The expansion of temperate and tropical forests is likely to be beneficial. The increase in overall NPP (growth) is likely to be beneficial. In contrast, the increased risks of extinction for select species are likely to be harmful. The net value of all these changes is not clear- more research is needed before any conclusions can be drawn. But what is clear is that there is no support for globally catastrophic consequences to ecosystems across a wide range of global warming scenarios.

This study shows that it is possible to marshal scientific evidence to study ecosystem change. The study reveals it is worthwhile to conduct further research into this area to quantify the value of important consequences. What are the impacts to birds and animals? What will happen to insects? Can including these changes affect vegetation outcomes? How do we trade off changes in the risk of extinction for one set of animals against increased safety for other species? What is the value of smaller or larger animal populations? What is the value of expanding tropical and temperate forests versus shrinking boreal forest and tundra? How can we adapt and manage global ecosystems in a warming world?

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