

PLOS Science Wednesday: Hi! We're Camilo Mora and Iain Caldwell, here to talk about our paper in PLOS Biology that investigates how plant growth is impacted by climate change — AUA!

PLOSScienceWednesday¹ and r/Science AMAs¹

¹Affiliation not available

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Abstract

My name is Dr. Camilo Mora and I am an assistant professor at the University of Hawaii Manoa. My research focuses on understanding the feedback loops between people and biodiversity. My earlier career was on basic ecology, but then I realized that the effects of people on various species were massive and already evident. Quantifying such impacts and their feedbacks on people represent the main topic of my latest research. And my name is Dr. Iain Caldwell and I am a post-doctoral researcher at the University of Hawaii Manoa. I am an ecologist with broad interests in how organisms can respond to changes in their environment, including the potential consequences of projected climate changes for such organisms. Along with several colleagues from the University of Hawaii and the University of Montana, we recently published a study in PLOS Biology titled Suitable Days for Plant Growth Disappear under Projected Climate Change: Potential Human and Biotic Vulnerability. In this paper, we explored the potential consequences of projected climate changes on future plant growth worldwide, and what that could mean for various ecosystems and the people that depend on those ecosystems. Our findings indicate that, if climate change continues as it has in the past, there could be significant global declines in the number of suitable plant growing days by 2100; with the most drastic changes affecting people in the poorest countries of the world. There is hope though; as our results also indicate that if we can curb our global carbon emissions, these changes in plant-growing conditions should be far less severe. We will be answering your questions at 1pm ET. Ask Us Anything! Don't forget to follow Iain on Twitter [[@ircaldwell](http://www.twitter.com/ircaldwell)](<http://www.twitter.com/ircaldwell>).

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PLOSSCIENCEWEDNESDAY [R/SCIENCE](#)

ABSTRACT

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Our findings indicate that, if climate change continues as it has in the past, there could be significant global declines in the number of suitable plant growing days by 2100; with the most drastic changes affecting people in the poorest countries of the world. There is hope though; as our results also indicate that if we can curb our global carbon emissions, these changes in plant-growing conditions should be far less severe.

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Wednesday: Hi! We're Camilo
Mora and Iain Caldwell, here to

Double-counting of climate impacts

Posted by RichardBetts on 11 Jun 2015 at 15:27 GMT --on PLOS Biology.

One of the other very odd things about this paper is how the authors have decided that it is legitimate to "adjust" the net primary productivity (NPP) projections from the CMIP5 models on the basis of the so-called "unsuitable plant growth days" which have been diagnosed from the CMIP5 climate. Irrespective of Colin Prentice's and Trevor Keenan's concerns (which I share) about the validity of these "unsuitable days", this seems like double-counting of climate change impacts.

The CMIP5 NPP simulations *already* take account of meteorological factors, often on a much finer timescale than Mora et al, and certainly in a way which is process-based as opposed to correlations. The HadGEM2-ES model, for example, uses meteorological and hydrological

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quantities on time steps of less than one hour to drive the NPP calculations. This means that the model is already not allowing plants to grow when it's too hot, dry etc. This is already factored in to the CMIP5 NPP projections. For these projections to then be adjusted further on the basis of a second (and less sophisticated) interpretation of the meteorology is giving undue weight to the unfavourable conditions.

I also find it strange that the authors pick and choose which components of the CMIP5 models they will use, without realising that all the components interact. They are somewhat dismissive of CO2 effects on plants when it comes to their effects on growth, but overlook the fact that these effects also contribute to the climate change itself through the surface energy and moisture budget. Warming over land is projected to be larger because of CO2 effects on vegetation, and this also affects evaporation and precipitation. By discarding the CO2 effects in one part of the system but not the other, the authors are introducing an inconsistency.

[PLOSReddit](#)

Camilo:

1) Double counting climate unsuitability We found remarkably complicated to identify the climatic conditions when plants stop growing from the data on NPP from CMIP5 models. In your words, what are the levels that are too hot or too dry for a plant to grow? The complication arises because NPP data are available mostly at monthly scales, which prevents to see what are the daily climates when plants stop growing. The second reason is due to the intricate nature of Global (process –base) Vegetation Models, which prevents separating factors. In the words of a paper by Cramer and colleagues, GVM differ considerably in their prediction of carbon storage, for reasons that are not completely understood, and are often “obscured by model complexity”. Ideally, we would have like to see if there were “thresholds” being used by the CMIP5 models and even if they were, how extreme were they. But that was not feasible with available data. However, the purpose of that one figure, which was cited in one line at the end of our paper, and was done mostly in response to a reviewer comment, was to show that even under very extreme climate conditions, even beyond those conditions we know surpass plant survival today, NPP is still projected to increase according to CMIP5 models. One purpose of that figure was to highlight this discrepancy, which is not new to our paper as it has been previously mentioned by papers like that by Anav and Colleagues, Reichstein and Running to name a few. We do not mean to use this to dismiss the value of modeling NPP, quite the opposite; we need more of such studies.

2) Picking parts of the CMIP5 models. You find strange that we choose some components of the CMIP5 but not others. I presume you are talking about the fact that we use climatic variables (temperature, water, solar radiation) while being critical and omitting the use of NPP, which as you suggest is modeled to the full extent of its complexity. We agree with your comment and this is entirely based on the fact that the CMIP5 models are good at modeling some variables but not others. For the case at point, there is a very nice paper by Anav and colleagues, who found that while Earth System Models are relatively good at modeling actual climate variables (e.g., temperature, and to a lesser degree water), they do not so good at modeling NPP.

Another question/comment from the PLOS Biology article page:

How (not?) to estimate changes in the suitability of days for plant growth

Posted by colinprentice on 11 Jun 2015 at 10:47 GMT

Implications of global environmental change for the growth of plants (whether as natural ecosystems, managed forests, or crops) are a hot topic. Key aspects, such as the control of leaf canopy temperatures, the ability of plants to acclimate to high temperatures, and the effectiveness of CO2 "fertilization" and water saving by plants at high CO2 under different

environmental conditions, are incompletely understood. There are obvious concerns, for example, for regions that are undergoing increasing drought and where this trend is projected to continue, and about the major geographic changes in global agriculture that will be necessary if "high-end" climate change projections come about.

This paper attempts to cut through these complexities by means of an empirical analysis of net primary production (NPP) derived from satellite observations. The results are dramatically more pessimistic than previously published analyses obtained with Earth System models, which have many of their own uncertainties and problems. However, there are good reasons to suspect that these new results are strongly biased towards a "glass half empty" interpretation of the evidence. In summary:

1. The specific method adopted implicitly assumes that climate combinations that are rare today are unsuitable for plant growth. So for example, projected future increases in temperature and rainfall together might create novel environments that would be suitable for plant growth, but the method assumes they are not suitable. This approach produces some strange but presumably significant side-effects, such as an upper temperature threshold that is below the optimum for photosynthesis as observed in many species.
2. The quantity analysed, called MODIS NPP, is not a measurement of NPP. It is a model of NPP, that has previously been criticized for the way in which it treats plant respiration, which tends to exacerbate the modelled effects of warming on NPP.
3. The approach assumes that any positive effects of CO₂ concentration on growth or water use by plants do not exist. This is one extreme position on a continuing controversy. The authors refer to an "over-emphasis" on CO₂ fertilization in current Earth System models, but they do not present evidence for their view which is, as far as I know, impossible to reconcile with the continuing and strong uptake of anthropogenic CO₂ by the land.

Colin Prentice

[PLOSReddit](#)

Camilo/Iain: Thank you for your comments.

1) In regards to your comment about the assumption that climate combinations that are rare today are unsuitable, we actually had a similar comment from one of the PLoS reviewers that we addressed by re-running our thresholds weighted by their occurrence (i.e. weighted by area, Fig S1). This analysis basically calculates the average NPP produced for a given set of climatic variables instead of the cumulative NPP, giving less weight to conditions that are common. If the best conditions for growth currently occur in these rare conditions we would have expected to see much different thresholds than we did. However, the differences among the thresholds (weighted by area vs. not) were minimal (Fig S1).

We were also intrigued by the seemingly low upper thermal threshold but there are several things to consider:

- We used mean temperatures in our analysis and maximum temperatures could have been significantly higher. As mentioned in the response to Ed Hawkins comment, future models could include maximums and minimums to test their effects, although testing the interactions among so many additional (and correlated) variables could prove challenging.
- When we analyzed the interactions among variables (Fig 1D-G) it was clear that the upper temperature threshold is higher at different levels of soil moisture and solar radiation.
- The upper thermal threshold we used is actually similar to that found for corn in the U.S., in which their production declines sharply at temperatures of 29 degrees Celsius, although it is less than for

corn at 30 degrees Celsius and for cotton at 32 degrees Celsius (Schlenker and Roberts 2009). It should be noted that these and other crop species could potentially have higher resilience than other unaided species through intensive breeding efforts and other adaptive measures meant to increase their production.

2) We fully acknowledge that MODIS NPP is a model and state this in the paper itself: "MODIS NPP data are modelled using remotely sensed satellite data..." While there have been criticisms on the use of MODIS NPP (for example, the paper mentioned by Belinda Medlyn in the comments section of the PLoS Biology article), an analysis by Zhao and Running (Fig. 2) indicates that MODIS NPP is quite similar to observations of NPP from the Global Primary Production Data Initiative.

3) Our paper also acknowledges the possibility of (and uncertainties around) elevated CO₂ influencing our thresholds in the "Caveats and Considerations" section. Specifically, we say the following:

"Interactions among CO₂ and climatic variables could also broaden or narrow modern thresholds. For instance, elevated CO₂ is known to increase resistance to drought by plants closing their stoma [48,49]. However, under warming conditions the closing of the stoma may induce overheating (by preventing transpiration) and/or if sustained could decrease carbon fixation [50,51]. Likewise, the temperature ranges over which elevated CO₂ enhances plant growth are strongly mediated by water availability [49]."

Thank you for doing this AMA!

Overall, scientific evidence points to the widespread negative consequences of global climate change. In addition, it seems like some degree of climate change is, at this point, unavoidable.

Given all of this, can you talk a little bit about how in some areas and for some crops, climate change effects (such as increased atmospheric CO₂, warmer temperatures, or altered precipitation) can potentially increase crop yield? What is your perspective on research efforts that try to capitalize on this phenomenon to try to maintain global food supply, alongside measures to attenuate climate change?

[neurobeegirl](#)

Camilo: I guess it depends on how we take this piece of evidence.

Indeed even our paper shows that some areas of the world would benefit from ongoing climate change. I would agree this could be a good thing if we use it to buy us time to mitigate and adapt to climate change. However, it would be very disappointing if this piece of evidence is used to justify our ongoing emission of greenhouse gases.

Also worth noting that there are numerous studies (David Lobell's, Michael Roberts's work comes to mind but there are several others) showing that even in the very recent past, crops has failed when it gets too hot and too dry. This has been true even for developed countries in Europe and the USA. Using the argument that CO₂ can help, even if true, would be too much of a gamble for the massive loss anticipated from ongoing climate change, not only on crop systems but for nature and humanity overall.

With respect to the US and Canada, which states and provinces will likely be hit the hardest with climate change with respect to agriculture and which area's might benefit (if any)?

[kofclubs](#)

Iain: While we did not run our analysis for individual states or provinces, our results suggest that Canada will fare better than the U.S., with Canada actually gaining growing days in the future, and that the northern U.S. states will fare better than southern states.

Our analysis could easily be re-run to compare states and provinces and could be done, at least as a first run, using our webpage if you are interested (<http://128.171.126.15/growingdays/index.html>).

The paper mentions the possibility of amending thresholds in the model to deal with biological adaptation or ecological community restructuring, or perhaps even ecological plasticity. Have you done any of this and can you say how much this will affect your estimates of the negative impacts?

G Mace

Camilo: The extent to which our results would change would largely depend on whether plants would adapt. Unfortunately, despite some attempts to assess plant adaptation, I feel our field does not have a good answer to this question of plant adaptation, especially on how it will shift climate tolerance thresholds, which are a key element of our metric. Ideally, we will run long-term trans-generational experiments to look at potential adaptation and/or use current conditions as natural experiments. These data could then be used to re-calculate our metric of suitable plant growing days. Alternately, one could re-run our analysis under different adaptation scenarios; however, we have not yet done such an analysis, mostly because it would remain largely guess work.

Welcome to [/r/science](#)

I have a few questions for ye.

What crops in particular do anticipate will be hardest hit first? Assuming little is done to reduce carbon emissions, what role could ye see technology, such as GMOs, having in mitigating the deterioration in plant growing conditions?

With the extra growing days in Russia, Canada and China, will the suitability of the soils and the lack of strong sunlight further north reduce the potential quality and quantities of yields in these regions?

Finally, could ye elaborate on what climate feedbacks ye anticipate all this could trigger?

Cheers.

IceBean

Camilo:

What species will be hit hardest? The most vulnerable species would likely be the ones with the narrowest climate thresholds or those whose thresholds are close to current climate conditions. Based on some data we found, corn may have an upper temperature threshold as low as 29°C, soy 30°C and cotton 32°C (data from a paper in PNAS authored by Schlenker). The problem, however, is our limited knowledge of climatic thresholds under multiple interacting variables, for most species. There is a big possibility that the effects of one variable could be entirely reversed, for good or bad, when variables interact. This sensitivity of plants remains a large uncertainty of current climate knowledge.

Role of technology. Technology can indeed be our way out of this potential hardship, in addition, of course, to consuming less. In addition to GMOs, there are things that can help such as traditional breeding methods, better irrigation and water use efficiency, etc. Most of these technologies are already available, but what we lack is unselfishness to share it free or at a low cost to the poorest parts of the world. What is concerning, based in the results of our study, is that the countries that would need the most adaptation are the ones that have the least capacity to do it.

Role of nutrients in areas with future suitable climate. There is indeed a need to explore many climatic variables in interaction, especially nutrients. E.g. While CO₂ can increase the capacity of plants to grow; nutrients alone can render many of these effects neutral, as could ozone, drought, etc.

Feedbacks. Our paper describe the potential for permafrost-feedbacks, in which there is the potential for warming to release CO₂ that could not be sequestered by plants as they lack light and water for growth. Another feedback we describe is the possibility of turning forest from carbon sinks to sources, as photosynthesis switches to respiration when plants are stressed beyond their tolerance thresholds.

This is really cool work!

My question is about the climate thresholds. It looks like for this analysis that thresholds were broadly defined using climate conditions under which 95% of global MODIS NPP occurs. Could you instead define these thresholds using information from plant physiology studies? It occurs to me that just because 95% of the productivity falls within that threshold doesn't mean that it can't occur outside of the threshold. Further, by using this global MODIS NPP dataset, you are mixing productivity of many different kinds of vegetation. For example, the climate thresholds for a cornfield in Iowa are probably different than those of a patch of Amazon forest.

It seems like you could do a similar analysis (possibly more informative) using thresholds for specific regions and vegetation types. Could you could rerun the analysis by dominant vegetation type (using vegetation-type specific thresholds) and show that say corn productivity will likely rise in the Midwest but soy productivity will decline in Brazil? I'm sure you've thought of this, but I just wonder if it's feasible.

[thigmotroph](#)

Iain: Thank you for your question. We agree that this is really cool work and are glad that you liked it so much.

Yes, instead of using the conditions under which 95% of the world's productivity (MODIS NPP) occurs to define our thresholds we could have used species specific thresholds. This was, in fact, our original idea. However, this approach has its own limitations. While there are some thresholds available from physiological studies, particularly in crop species, such studies are not available for the vast majority of plants. Furthermore, even amongst those studies which test thresholds for individual species, we found few physiological studies that tested simultaneous thresholds resulting from interactions among more than one variable (e.g. temperature and soil moisture). We certainly could have limited our study to individual crop species but wanted to get a more holistic picture of the conditions under which most of the world's productivity occurs.

Our analysis could certainly be re-run on individual species for which information is available on temperature, soil moisture, and/or solar radiation thresholds. In fact, with help from staff at ESRI we have created a website (<http://128.171.126.15/growingdays/index.html>) where anyone with internet access could enter their own plant growth thresholds and see how that would affect future projections of plant growing days. I should caution, though, that the algorithm we used for that web page was an earlier version of our analysis that does not include changes in thresholds resulting from the interactions among the three climate variables (i.e. on the webpage if conditions on any day are outside any of the three thresholds then that day is considered unsuitable).

I wonder what the effect of climate change will be on tea production. I love using teas to balance out my moods and energy, but I could see climate change causing chaos in the tea industries. If not that, resource conflicts may keep tea from being produced and sent across seas.

I think it would be a shame if tea became too expensive and rare due to climate change. The compounds teas have could be very useful.

[barrano247](#)

Iain: I too enjoy tea and am enjoying some right now. Your comment actually brings up an important

point, though, about the potential consequences of the high degree of spatial variability we found in changes in growing days among countries. In some cases, highly vulnerable countries are found beside less vulnerable countries and this could potentially lead to border conflicts and/or issues with migration between neighboring countries in the future.

It would indeed be a shame if tea were to become prohibitively expensive in the future for developed countries like the U.S. but an even greater concern is whether people in developing countries will be able to afford food, as some of the most extreme changes we found in plant growing days were found in some of the poorest countries.