LTER Cross-Site Synthesis Post-doctoral Project Final Report
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Title

Response of ecosystem productivity to Critical Climate Periods: understanding the role of fine-scale temporal climate patterns on ecosystem productivity.

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Summary

Across broad spatial scales mean annual precipitation and temperature explain much of the variability in ecosystem productivity, but the inter-annual variability in productivity does not always correlate well with annual climate statistics. The sensitivity of ecosystems to the timing of drought and heat waves may provide a better understanding of the inter-annual variability in productivity. We are beginning to understand how both the magnitude and variability of growing season precipitation affects ecosystem function, but less is known about the role of heat waves across a range of systems. The response of ecosystems to heat waves likely depends on the time of year that they occur; spring heat waves could increase productivity through increased growing season length, and summer heat waves may reduce productivity through direct heat stress or reductions in soil moisture due to higher evaporative demand. A better understanding of the impact the timing of drought and heat waves has on a range of ecosystems is needed to better predict the impacts of our changing climate on ecosystem function.

Long-term data sets represent an important resource for assessing how the timing of heat waves may affect a range of ecosystems. Long-term data sets capture variability in the climate/productivity relationship that can be used to assess the sensitivity of ecosystem productivity to both heat waves and drought. Manipulative experiments have not found consistent responses of ecosystems to heat waves, but these experiments rely on *a priori* knowledge of when ecosystems are most

sensitive to heat waves, and this knowledge does not exist for many, if any, ecosystems.

The purpose of this project was to identify the Critical Climate Periods (CCPs) of precipitation and temperature that have the biggest impact on ecosystem productivity. We analyzed data from 10 LTER sites (and 3 non-LTER sites) that had >10 years of continuous Aboveground Net Primary Productivity (ANPP) and climate data collected at the same site. We found that using <10 years of data gave unreliable results. We used non-woody biomass to compare sites as long-term data sets of woody biomass from forested ecosystems is not readily available for many sites and relies on many scaling relationships that are not as accurate as direct measurements of herbaceous biomass. Therefore, non-woody ANPP was the most accurate measurement to use in order to capture the inter-annual variability in productivity among sites. We did analyze wood production for one LTER site (Hubbard Brook) where detailed, spatially distributed measurements of basal area were available.

We found that hot/dry sites responded more strongly to droughts late in the growing season, where cool/wet season responded to drought in the winter and spring. Three cold/wet sites even had increased productivity when winter/spring precipitation was below average. Among all sites, the CCP for precipitation explained 45% of the inter-annual variability in precipitation, and increased the our ability to predict ANPP based on this single variable. The CCP for temperature was significant in predicting ecosystem productivity for 12 of the 13 sites, on average, explained another 19% of the variability in ANPP. Grasslands tended to respond negatively to heat waves during the growing season, but deciduous forests responded positively to heat waves in the spring and fall. Wood production at Hubbard Brook was consistent with the results for leaf production. Forests are generally considered to be less sensitive to drought, but we found that all ecosystems were equally sensitive to drought and heat waves, but it is the direction of the response that varies among sites.

The primary product from this project is a manuscript entitled "The Importance of the Timing of Heat Waves on North American Ecosystems". This manuscript describes the results highlighted above and will be submitted to *Science* in the next month. The manuscript is currently awaiting final comments from co-authors before final revisions and submission.

A secondary product from this project is a statistics package written in R (R Core Development Team, 2008) to identify the CCPs for a variety of variables. This package will summarize climate data appropriately for this analysis, identify the 'best' CCPs, and provide figures and summary statistics to estimate the uncertainty of the selected CCPs. The initial test of this package generated the data for an LTER funded working group (Award Year 2013, PI: Laura Ladwig). During this working group (to take place in March 2013) the R-code will go through its final beta-testing and will be introduced to participants at the workshop.

Finally, a second manuscript related to this project is also being prepared that compares the Critical Climate Periods from three sources; ANPP, eddy-covariance carbon flux, and modeled productivity (using Agro-BGC). This analysis shows that, in general, the CCPs identified by these sources agree, but the modeled output identifies CCPs at much coarser scales than direct measurements, which suggests that models still cannot accurately predict the response of ecosystems to drought and heat waves. This manuscript is currently in preparation to be submitted to *Proceedings of the National Academy of Science* and should be submitted by the end of March 2013.

The results from this project highlight the importance of the long-term monitoring of ecosystems in order to understand a range of processes. It would be difficult to manipulate heat waves in mature forested ecosystems, and the timing that heat waves are applied may influence the results from these types of experiments. Using long-term data has allowed us to identify when a range of ecosystems are most sensitive to drought and heat waves. Continuing to monitor ecosystem productivity to further lengthen these time-series will allow us to better understand how ecosystem sensitivity may change over time, and can inform future research to more effectively test the questions facing ecologists today.