Rainfall variation impact above- and below-ground biota and soil biogeochemistry in the Eel River watershed

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ABSTRACT

Rainfall abundance and distribution are key watershed parameters that are likely to profoundly shape both aboveground biota and belowground biogeochemistry. The complex interplay of these factors will largely control water and nutrient fluxes into rivers. In addition to spatial variation, any watershed location experiences year-to-year variation in rainfall and long term changes in water inputs are anticipated as the result of global climate change (Figure 1). Study of the impact of water abundance and distribution on above and belowground processes across landscapes and over time is complicated by local heterogeneities, making direct causes and effects difficult to deduce. Consequently, we have studied the linkages among precipitation amount and timing, soil microbial communities, soil carbon and nitrogen concentrations, and above ground plant and invertebrate species richness in a well replicated experimental site in the Angelo Reserve, California.

Our research plots were established in a grassland meadow in 2000 in order to test the ecosystem consequences of climate change-induced modification of rainfall amount and seasonality (Figure 2 and Suttle et al. Science 2007). We have obtained detailed records of aboveground plant and animal responses over six years and soil bacterial and archaeal communities over two years. In addition, compounded soil biogeochemical responses have been documented. Strikingly, above and belowground communities respond differently to changes in precipitation. Increased spring rainfall dramatically altered plant and invertebrate communities, an effect that has been mainly attributed to the proliferation of legumes that host nitrogen-fixing bacteria (Figure 3). Conversely, soil microorganisms showed no compound effect over six years, yet responded strongly on a seasonal basis to both intensified winter and spring rainfall (Figure 4). These results suggest that soil microorganisms are more resilient than plant and animal communities. The enormous functional redundancy in microbial consortia appears to have prevented strong treatment-specific changes in soil physical properties and chemistry, at least over the six years of study. Consequently, although aboveground primary productivity and biodiversity may vary considerably in grasslands across the watershed as a function of rainfall inputs, relatively small changes in soil consortia activity are predicted. Moreover we, found that, after six years, the changes in the amount and stage of humification (as indicated by C:N ratio) of soil organic carbon in the top soil layer (0-5cm) are insignificant. However, at depth both amount and timing of rainfall had statistically significant effects on humification of soil organic carbon (Figure 5). Ongoing studies are essential to validate and explain seasonal patterns in soil responses and to determine their consequences for biogeochemical fluxes to the watershed.

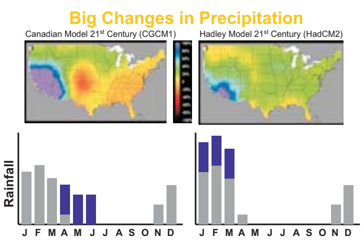
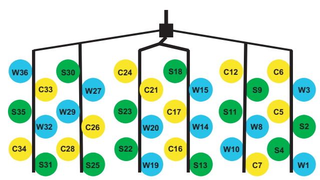


Figure 1. Changes in annual precipitation projected by leading climate models. Both predict substantially increased rainfall over most of California, but disagree as to the seasonal timing of those increases. The Canadian model forecasts extension of the rainy season into the summer, while the Hadley model calls for the entirety of the increase to fall during California's current winter rainy season.

EXPERIMENTAL DESIGN

We established thirty-six plots in a grassland on an abandoned terrace of the South Fork Eel River in Mendocino County, California. For the past six years, plots have been subjected to one of three watering regimes: (1) increased winter precipitation, (2) increased spring precipitation, and (3) ambient precipitation (Fig. 2). Winter- and spring-addition plots receive 14 to 16mm water over ambient ever third day from January through March and from April through June, respectively. Water is delivered to each plot through a sprinkler designed to distribute an even blanket of water over a circular area. The amendments amount to a 20% increase over average annual rainfall at the study site. We have monitored plant standing crop and species composition, soil and plant nutrient chemistry, and litter decomposition rates for the past six years, and are now undertaking a detailed characterization of soil biotic communities.



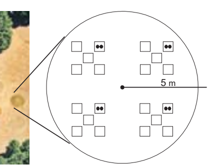


Figure 2. Experimental Approach

Plots are approximately 70m^2 and are arranged in a randomized block design. Winter-addition (W) plots receive 44cm of precipitation over ambient from January through March. Spring-addition (S) plots receive an identical amount from April through June. Control plots (C) receive only ambient precipitation.

Water is delivered to plots from sprinklers designed to distribute water evenly over a circular area. This has produced dramatic changes in the structure and composition of aboveground communities. We are now characterizing changes in underlying soil microbial communities sampled from multiple cores per plot.

RESULTS & DISCUSSIONS

Aboveground Response

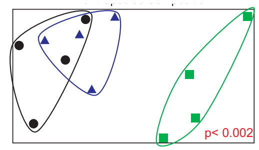


Figure 3. Non-metric Multidimensional Scaling (NMDS) of plant abundance. Control plots are BLACK; Winter rainfall addition plots are BLUE; and Spring rainfall addition plots are GREEN.

As has been described elsewhere (Suttle et al. 2007), aboveground communities have responded strongly to extension of the rainy season

- Addition of water during the winter rainy season has had little discernible effect on aboveground community structure and composition,
- However, extension of the rainy season via addition of water through spring and into summer has caused dramatic changes.

Changes above ground have strong legacy effects in subsequent years, so long-term effects of extended rainfall are difficult to predict based on initial response

Microbial Community Structure

Multivariate ordination techniques allow us to examine differences in composition across complex communities of microbial species based on patterns of treatment separation along ordination axes.

- DECEMBER 2005: Following five years of rainfall manipulation, we find no clear divergence of microbial communities among treatments. This is despite marked divergence in the structure and composition of aboveground communities
- APRIL 2006 - Yet after a sixth year of winter rainfall addition, we find strong seasonal responses to watering.
- MAY 2006 - Treatment differences are washed out in May, a time of peak diversity, activity, and production in plants and animals above ground.
- JULY 2006 - During summer drought, we again find strong responses to rainfall addition

Patterns point toward high levels of resilience within the soil microbial community, where any seasonal effects of increased rainfall fail to compound across years.

This contrasts sharply with how aboveground communities have responded, where seasonal effects of altered rainfall have a strong legacy in subsequent years.

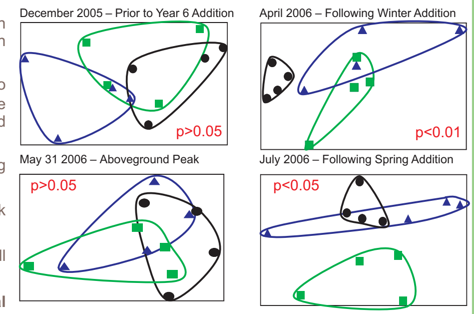


Figure 4. Non-metric Multidimensional Scaling (NMDS) of microbial abundance as derived from micro-array data analyzed at the sub-family level. Control plots are BLACK; Winter rainfall addition plots are BLUE; and Spring rainfall addition plots are GREEN.

Soil Carbon and Nitrogen Biogeochemistry

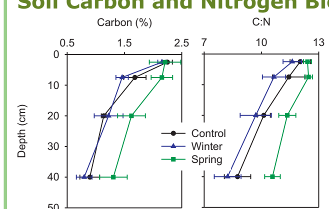


Figure 5. Concentration of soil organic carbon and carbon to nitrogen ratio.

After six years (DECEMBER 2006) we find that the concentration of soil carbon and nitrogen in surface soils (0-5cm) respond differently to the rainfall addition, compared to subsoils (5-50cm)

- %C - No significant differences in soil organic carbon concentration at most depths considered (except at the 5-10cm depth). Immediately below the soil surface significant organic carbon has accumulated in the spring addition plots.
- C:N - We find significant differences in nitrogen (N) concentrations and therefore carbon to nitrogen ratios (C:N) in the spring addition plots. The plots where the rainy season has been extended to the summer months appear to be undergoing lower rates of soil organic matter decomposition compared to the control plots and winter addition plots.

At depth, changing the amount and seasonal timing of rainfall resulted in statistically significant differences in humification (as indicated by C:N ratio) of soil organic matter. These patterns point towards accumulation of more, less decomposed soil organic matter in the soil profiles when the rainy season is extend to the summer months.

ACKNOWLEDGEMENT

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