Effects of Urbanization-Induced Environmental Changes on Ecosystem Functioning

- A Case Study in Metropolitan Phoenix

Integrating Pattern, Process, Scale and Hierarchy

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ABSTRACT

Urban ecosystems are profoundly modified by human activities and thereby provide a unique "natural laboratory" to study potential ecosystem responses to anthropogenic environmental changes. Indeed, because large cities and their environs are now affected by urban heat islands, carbon domes, and high-level nitrogen deposition, to some extent they portend the future of the global ecosystem. Urbanization in the metropolitan region of Phoenix, Arizona (USA) has resulted in pronounced changes in air temperature (maximum and minimum), atmospheric CO_2 concentration, and nitrogen (N) deposition. We used a physiologically based ecosystem model to investigate how the native Sonoran Desert ecosystem dominated by creosotebush (*Larrea tridentata*) responds to urbanization-induced environmental changes. We found that, at the ecosystem level, aboveground net primary productivity (ANPP) and soil organic matter (SOM) both increased with increasing CO_2 and N deposition individually, and with all combinations of changes in air temperature, CO_2, and N deposition. Soil N responded positively to increased N deposition, but negatively to elevated CO_2 concentration and air temperature. Effects on ANPP and SOM were significantly greater in wet years, whereas changes in soil N were larger in dry years. At the plant functional type (PFT) level, ANPP generally responded positively to elevated CO_2 and N deposition, but negatively to increased air temperature. Significant changes in ANPP at the PFT level were observed, primarily in wet years. C_3 winter annuals showed a greater ANPP response to higher CO_2 levels (>420 ppm) than shrubs, perhaps because competition for soil water and nutrients was stimulated by increased CO_2. Overall, effects of the three environmental factors were interactive and non-additive, and largely dependent upon variability in rainfall. Our simulation results have intriguing implications for assessing ecological consequences of urbanization, both in this region and in arid ecosystems globally.

RESEARCH HYPOTHESES

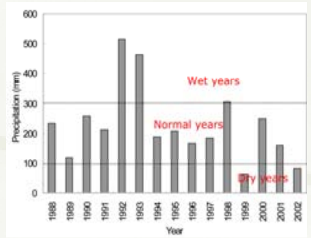
- **Hypothesis 1:** While the response of three ecosystem variables to increasing T_{air}, CO_2, and N_{dep} differs in detail, the general response pattern is nonlinear for all three. This nonlinearity may manifest itself in two ways: nonlinear responses without clearly identifiable thresholds, and responses exhibiting threshold behaviors.

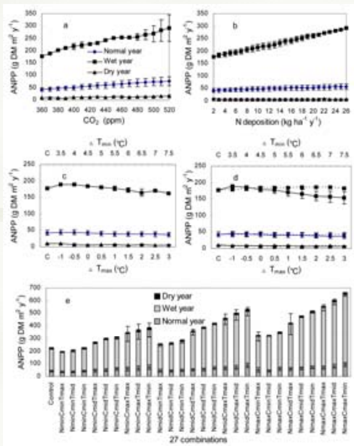
Hypothesis 2: Different plant functional types respond differently to increasing T_{air}, CO_2, and N_{dep} and, in particular, grasses have greater responses than shrubs in the same plant community.

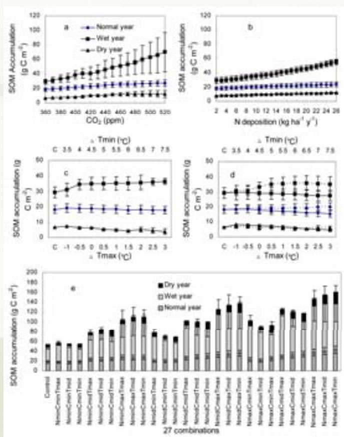
Hypothesis 3: When increasing T_{air}, CO_2 and N_{dep} simultaneously, "magnification" and "compensation" effects occur as a result of nonlinear interactions among the three factors plus precipitation.

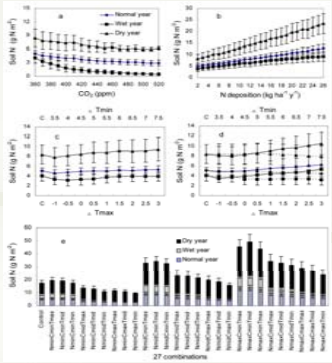
METHODS

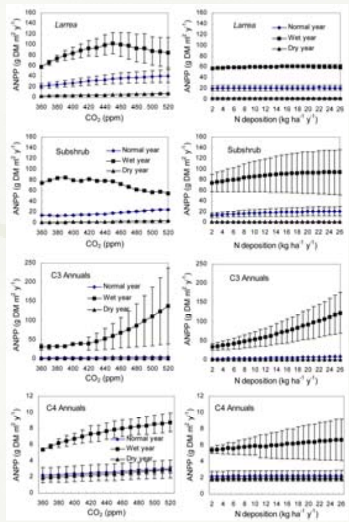
- Simulation experiments using a process-based ecosystem model
- Factorial design with 3 factors: CO2, N deposition, & air temperature

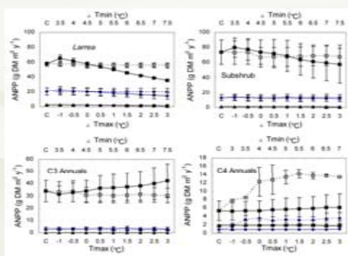


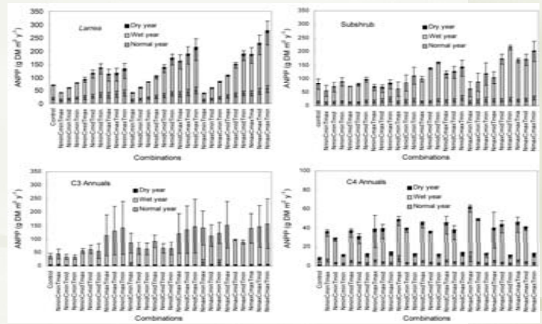












CONCLUSIONS

The hypotheses we proposed were partially supported by our simulation modeling results. The response behavior of the *Larrea* ecosystem to urbanization-induced environmental changes can be linear or nonlinear, with nonlinear response patterns occurring more often in wet years,and linear patterns typifying dry years. At the ecosystem level, simultaneous increases in atmospheric CO_2, N deposition, and air temperature in the Phoenix metropolitan area had positive impacts on ANPP and SOM, but negative impacts on soil N, especially during wet years. At the plant functional level, strong between-FT competition (for resources: soil water and nutrients) was observed. C_3 winter annuals were more responsive at higher CO_2 levels when water was available. This could result in top-down regulation of shrub ANPP. Clearly, ecosystem and plant-FT responses to urban environmental changes were largely mediated by water— not only the amount of precipitation but also other characteristics of the precipitation regime like seasonality, intensity, and timing. Therefore, future precipitation patterns may ultimately control how desert ecosystems respond to changes in other environmental factors.

Ecosystem responses to urbanization-induced environmental changes involve multiple biotic and abiotic factors, between-factor interactions, feedback loops, and several spatial and temporal scales. Although in this study we demonstrate that simulation experiments can bring insights to help understand this complex issue, combining this approach with manipulative experiments and urban-rural gradient analyses may provide the greatest potential for understanding urbanization effects on natural ecosystems, managed ecosystems, and human societies embodied in the heterogeneous urban landscape (Grimm *et al.*, 2000; Dunne *et al.*, 2004). Because many anticipated global changes are already occurring in urban ecosystems, thorough exploration of urban–rural environmental gradients, exemplified here by Phoenix, in combination with carefully designed manipulative field experiments (Cook *et al.*, 2004) and model-simulation experiments, could play very important role in understanding ecosystem response to global environmental change in general.