Evaluating the effectiveness of restoration from an ecophysiological perspective

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INTRODUCTION: Anthropogenic degradation of ecosystems leads to loss of biodiversity and ecosystem services. The only terrestrial ecosystem services increasing in supply, crops and livestock, are increasing in association with human domination of the landscape (1). Ecological restoration has increasingly been used as a tool to attempt to reverse this damage, and reestablish key ecosystem functions (2). There are diverse approaches to implementing restoration but uniform criteria for evaluating restoration effectiveness have not been developed (3). This is a recognized area of need, and there is greater emphasis on evaluating restoration against goals such as recovery of ecosystem services or resilience (3). Additionally, the inclusion of ecophysiological traits in evaluations of ecosystem recovery has largely been absent in the restoration practice (4). By assessing the physiological response of plant communities to disturbance and recovery-induced stress, and therefore tracking the recovery of plant physiological parameters to pre-disturbed levels, it could be possible to evaluate restoration techniques. Using instantaneously obtainable ecophysiological metrics of plant performance for rapid assessment of long-term recovery is a promising strategy (5).

BACKGROUND: The rate of recovery of key ecosystem services, such as whole-ecosystem carbon storage and nutrient-cycling processes, generally have positive relationships with the recovery of plant community performance over time. Increases in individual plant performance can be determined by changes in functional traits, such as nutrient and water use efficiency, which can be directly measured using ecophysiological tools (6). The challenge with this approach is that physiological parameters can only easily be obtained for individuals, and restoration needs to function on an ecosystem scale (4). Grouping individual plants into functional groups based on common physiological parameters is therefore necessary to scale to and understand patterns on an ecosystem level (6). I propose to evaluate restoration techniques by relating temporal changes in plant functional traits to the overall rate of recovery of a whole ecosystem, which will be an important step towards the evaluation of restoration effectiveness.

I will conduct my research in a chronosequence of restored tallgrass prairie sites established at the National Environmental Research Park (NERP) at Fermilab (Batavia, IL). Annually since 1975, tracts of land at NERP have been restored, providing a unique opportunity to track ecosystem development following restoration (7). Studies at this site have quantified temporal changes in plant-species composition (8), soil microbial communities (9), soil nitrogen (N) and carbon (C) stocks (10,11) and above and belowground net primary production (NPP) (10). After 100 years, restored prairies at NERP will reach an estimated 50% of their potential to store soil organic carbon (SOC) (10), an important ecosystem service. The relationship of temporal changes in plant ecophysiology to the rate of this recovery remains largely unknown.

HYPOTHESIS 1: Rapidly obtainable measurements of plant ecophysiology can be used to efficiently track long-term patterns of change, due to restoration, in individual plant function.

HYPOTHESIS 2: The return of plant functional traits to pre-disturbance ranges, scaled to the ecosystem level using plant functional groups, can be used as a metric of ecosystem recovery.

TESTING H1: I will use the same chronosequence of restored sites used in previous studies of restoration at Fermilab (1975, ’77, ’78, ’81, ’84, ’92, ’93, ’97, remnant prairie control) for plant physiological measurements (10,11). During the 2013 growing season I will establish 10 3x3-m plots in each chronosequence site. I will measure plant-species composition and abundance in four 1x1-m sub-plots in each plot (40 sub-plots per site). Concurrently, I will use a LI-6400 portable photosynthesis system (Li-Cor, Lincoln, NE, USA) bi-weekly to obtain instantaneous ambient-condition net photosynthetic rate (A), stomatal conductance (g_s) and transpiration (T) for one individual of the five dominant species in each established plot (5 dominants x 10 plots = 50 plants per site). I will also obtain A/Ci curves for two individuals of each species to quantify light-saturated maximum photosynthetic rates (A_{max}). I will harvest, dry, weigh and scan each individual plant and compute dry leaf mass per area (LMA). I will also quantify C and N percentages by weight using elemental analysis. Using these data I will calculate N content per unit area (LMA/N), water-use efficiency (WUE = A/T) and photosynthetic nitrogen use efficiency (PNUE = A/N). I will use multiple regression analysis, with time since restoration as an independent variable, to find changes in physiological parameters and to test the effects of these parameters on previously obtained SOC storage and above and belowground NPP data.

TESTING H2: I will characterize plant traits using multivariate approaches, such as non-metric multidimensional scaling, that integrate across multiple ecophysiological and other functional traits. Shifts in multivariate trait space occupied by restored plant communities will be evaluated over time and against the benchmark of a reference remnant prairie. An index of temporal change in plant efficiency, defined by the degree of physiological parameter convergence towards pre-disturbed levels (remnant prairie), will be calculated.

INTELLECTUAL MERIT: I will use the results of this study to link temporal changes in plant physiological parameters to whole-ecosystem recovery during restoration. Many strategies are employed in ecological restoration but evaluation of outcomes using physiological tools has been minimal to date (4). This study has important implications for the evaluation of restoration techniques because individual ecophysiological parameters will be scaled to show recovery in ecosystem efficiency. *H2* addresses this by creating a recovery-to-benchmark-function index.

BROADER IMPACTS: Title IV of the Omnibus Public Land Management Act of 2009 established the Collaborative Forest Landscape Restoration Program, which includes restoration as a mandate in US Forest Service activities (12). The lack of scientific consensus on how to evaluate the effectiveness of restoration projects calls for better integration of scientific progress and management techniques. The results of my study will address how instantaneously obtainable plant physiological traits can be used to assess the effectiveness of long-term restoration techniques. This will be very valuable in the rapid evaluation of policy-mandated restoration.

I have a commitment to the mentorship of undergraduates, both through the NSF REU and other academic programs (*see 'Personal Statement'*). I also plan to mentor students and develop curriculum on the restoration of human-degraded ecosystems for the Junior Science Club, a collaboration between Northwestern and the Boys & Girls club of Chicago, which involves traditionally under-represented middle school students in hands-on science activities. Results from this study will be disseminated at the annual meeting of the Ecological Society of America, as well as in publications in peer-reviewed journals. The LI-6400 data will be submitted to Oak Ridge National Laboratory LeafWeb, a database of leaf gas-exchange and plant function.

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