An Empirical Analysis of the Role of Ecological Filters in Grassland Restoration

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Introduction: Degradation has reduced ecosystem services over nearly half of the Earth's land area, making an understanding of ecological restoration a critical issue for ecology [1]. However, restoration has historically been practiced on an *ad hoc* basis, without adequate planning or proper application of the scientific method. As a result, most restoration projects fail to achieve lasting change and seldom provide insights that may be broadly applicable and advance restoration theory.

Experts in the field of restoration ecology are now calling for studies that apply ecological principles to empirically test basic ecological theories that are pertinent to restoration, such as community assembly and succession and, specifically, the role of trophic interactions [2]. My research attempts to respond to this call by answering questions regarding the interactions of herbivory, seed-predation and biotic soil disturbance in the restoration of a grassland ecosystem in California. Through my efforts, I hope to advance the science and practice of large-scale grassland restoration.

Background: The ultimate goal of restoration ecologists is to manipulate assembly and succession in ways that produce the most desirable stable state, either by speeding up natural processes or by overcoming thresholds that might be insurmountable without human intervention. Ecological filters are biotic or abiotic variables that favor the assembly of certain species over others. If well-understood, these filters can be used to favor desirable species while inhibiting the establishment of undesirable ones, thereby directing community assembly towards the most desired state. In grasslands that have been invaded by exotic annual grasses, managers could use ecological filters to promote the re-assembly of native bunchgrasses to improve habitat quality for native plants and animals and improve forage quality for livestock [3].

The role of plant-herbivore interactions such as herbivory, seed-predation, and biotic soil disturbance as potential ecological filters is poorly understood. Evidence suggests that physical soil disturbance caused by burrowing rodents, such as the endangered Giant Kangaroo Rat (*Dipodomys ingens*) in my study system, promotes the invasion of exotic annual grasses [4]. However, recent work has shown that kangaroo rats also preferentially eat the large seeds of exotics and thus the net effect of their presence on plant recruitment is currently unknown [5]. Another study found that the exotics responded to defoliation with more vigorous regrowth than natives did, and the authors therefore concluded that grazing by large herbivores promotes dominance by exotics [6]. However, the effects of grazing are not limited to defoliation; animals also exhibit preferential selection and alter soil characteristics through compaction and nutrient addition [7]. Thus, the net or synergistic effects of these interactions on native plant restoration remain unclear.

Hypotheses: (1) Soil disturbance by kangaroo rats will favor the assembly of exotic grasses while compaction caused by cattle will favor native bunchgrasses. (2) Nutrient addition by both animal species will favor the assembly of exotics and have a greater impact on the re-assembly process than physical soil disturbance. (3) Cattle with help export excess nutrients by selectively grazing nutrient rich vegetation and kangaroo rats will control the abundance of exotics by preferentially consuming their seeds. (4) A combination of cattle and kangaroo rats will be most successful in directing re-assembly towards a state dominated by native bunchgrasses.

Research Plan: To test the effects of herbivory, seed-predation, and soil disturbance on re-seeding efforts I will establish 1-m^2 restoration plots within an existing framework of nested cattle and kangaroo rat exclosures—allowing for the quantification of both the individual and

combined effects of cattle and rodents. Two plots will be established in each of the three test areas, one on rodent disturbed soil and one on undisturbed soil (n = 10 exclosures). Additionally, soil samples will be taken on and off disturbed soil in each test area and will be analyzed for bulk density and chemical composition. These data will allow for the artificial decoupling of physical soil disturbance from nutrient addition. Additional plots will be established in the kangaroo rat exclosures—one to simulate physical soil disturbance, one to simulate nutrient addition, and one to simulate both types of disturbance (for comparison with genuinely disturbed plots) for both animal species. Differences in bulk density will be simulated using a soil corer (to reduce density) or a rammer (to increase density). To simulate nutrient addition, fertilizer will be added to plots in an amount necessary to achieve the observed soil chemical composition where kangaroo rats or cattle have been active.

All plots will first be surveyed in the spring using a pinframe method, then sprayed with herbicide and sown with four rows of seeds in the following winter. Each row will be randomly assigned to one of four native species of varying forage quality—two were preferred and two were avoided in kangaroo rat feeding trials [5]. Plots will be monitored weekly through the growing season. Soil disturbance, seed germination, and herbivory on seedlings will be recorded. Plant cover will be monitored annually each spring. Data will be analyzed using mixed-model ANOVAs.

Logistics and Support: The nested cattle and kangaroo rat exclosures were constructed two years ago as part of a concurrent project. The effectiveness of this experimental framework has already been demonstrated [5], and the kangaroo rat exclosures are checked on a regular basis for evidence of rodent activity. Our partners at the Bureau of Land Management (BLM) are in full support of this project and have generously agreed to provide the required seed and equipment. As a graduate student at UC Berkeley, I will also have access to the resources provided by the Graduate Group in Range Management—including the support of expert faculty who specialize in grassland ecology and restoration.

Broader Impacts: The results of my research will advance ecological theory by helping to elucidate the roles of herbivory, seed predation, and biotic soil disturbance on plant community assembly. Since many of the issues addressed in my research are ubiquitous throughout grassland ecosystems, my findings could be broadly applied in restoration all over the world. These results will also be useful to land managers and ranchers who hope to reduce the damage caused by invasive plants—currently estimated at $2 billion annually in US grasslands [8]. Besides preparing the results for peer-reviewed publication, I will also collaborate with various stakeholders to determine how my findings can best be applied to large-scale management and restoration. At a local level, the joint managing partners of Carrizo Plains National Monument (the BLM and the Nature Conservancy) have already demonstrated a keen interest in applying the results of my research in future restoration projects at the Carrizo Plains—California's largest remnant grassland and home to 13 endangered species.

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