Landscape-scale Relationships between
Oak Recruitment and Livestock Management

I. Lead and Support Personnel.

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II. Qualifications.

Katharine Suding is an assistant professor at the University of California Irvine (UCI). She is a plant community ecologist, with expertise in interactions among species and ecosystem processes. **Mitch McClaran** is a professor of range management at the University of Arizona, with broad expertise in vegetation change and rangeland management practices, including hardwood rangeland in California. **Stanley Harpole** is a postdoctoral fellow at UCI. Stan recently completed his dissertation at Sedgwick Ranch, focusing on the interactions between annual non-native grasses, native bunchgrasses, seed limitation, and resource availability. **Loralee Larios**, a technician in the Suding lab, has experience with small mammal trapping and plant ecology in California. *CV*s for Suding, McClaran, and Harpole are included in the Appendix.

III. Brief Summary of the Proposed Project.

Oak woodland and savanna habitats have suffered significant losses over the last century, primarily due to urban expansion and agricultural development. Oak woodlands play important ecosystem roles by supporting high wildlife-diversity and controlling water and nutrient cycling (Huntsinger and Fortmann 1990, State of California 2001). In the remaining 3 million ha of oak habitat, there is a concern that natural oak recruitment is not sufficient to maintain current populations (Griffin 1971, Swiecki and Bernhardt 1998, McCreary 2004). In particular, the inability of oak seedlings to transition to sapling and larger stages may often constrain recruitment (Allen-Diaz and Bartolome 1992, Swiecki and Bernhardt 1998).

The influences of livestock and non-native annual grasses are generally implicated as the major causes of this failure to recruit (Swiecki and Bernhardt 1998). Alternative livestock grazing regimes that reduce the duration and intensity of herbivory pressure on woody vegetation relative to herbaceous vegetation may enhance the success of oak saplings while maintaining an important source of forage production in California.

Grazing impacts may vary seasonally and spatially as a function of livestock type, stocking density, and duration. Hall and co-workers (1992) found evidence suggesting that only winter grazing by cattle, when grasses were actively growing but planted oaks seedlings were leafless, was associated with greater oak survival than grazing in either spring or summer. In addition, they found that oak seedlings in pastures not grazed by cattle, but used by deer and small mammals, had lower survival than pastures grazed only in the winter by cattle. Allen-Diaz and Bartolome (1992) found that sheep grazing in both winter and summer did not affect recruitment of naturally-occurring blue oak seedlings: mortality rates were similar in grazed and ungrazed areas. In summary, these studies suggest the importance of season of grazing, particularly positive results in winter-only grazing and negative results in all other seasons (including no grazing yearlong). **Thus, we hypothesize that appropriately timed grazing may play a necessary role in the recruitment of oaks in this system.**

There are several pathways by which the timing of grazing on the landscape can influence oak recruitment (Fig. 1). Direct herbivory effects may be more frequent and severe when other green forage options are reduced. In addition, the timing and duration of grazing could influence residual dry matter present in fall when acorns are dispersed and germinate, and the vigor of herbaceous neighbors in spring when oak seedlings begin growth. Differences in herbaceous species composition resulting from grazing practices may influence the success of seedling survival due to changes in competitive intensity and nutrient and water use. Residual dry matter and herbaceous species composition could also influence damage from other herbivores such as deer, small mammals or insects.

We propose to investigate the landscape-scale relationship between the timing of grazing and blue oak (*Quercus douglasii*) recruitment, particularly with regard to the release of seedlings into the sapling stage. Our approach incorporates multiple factors and casual pathways (Fig. 1) at the landscape scale. The project has three components: **A) Landscape-scale surveys**, including monitoring naturally regenerating seedlings and saplings, in multiple pastures with different histories of seasonal livestock grazing management; **B) Experimental planting of oak seeds (acorns)** combined with manipulating defoliation and herbaceous structure; **C) A greenhouse experiment** to further isolate the importance of timing of defoliation relative to the phenology of herbaceous neighborhood. Results from this multi-level approach will inform management regarding the timing and duration of grazing, suggesting ways to optimize forage production, while simultaneously improving the native representation of the herbaceous community and oak recruitment.

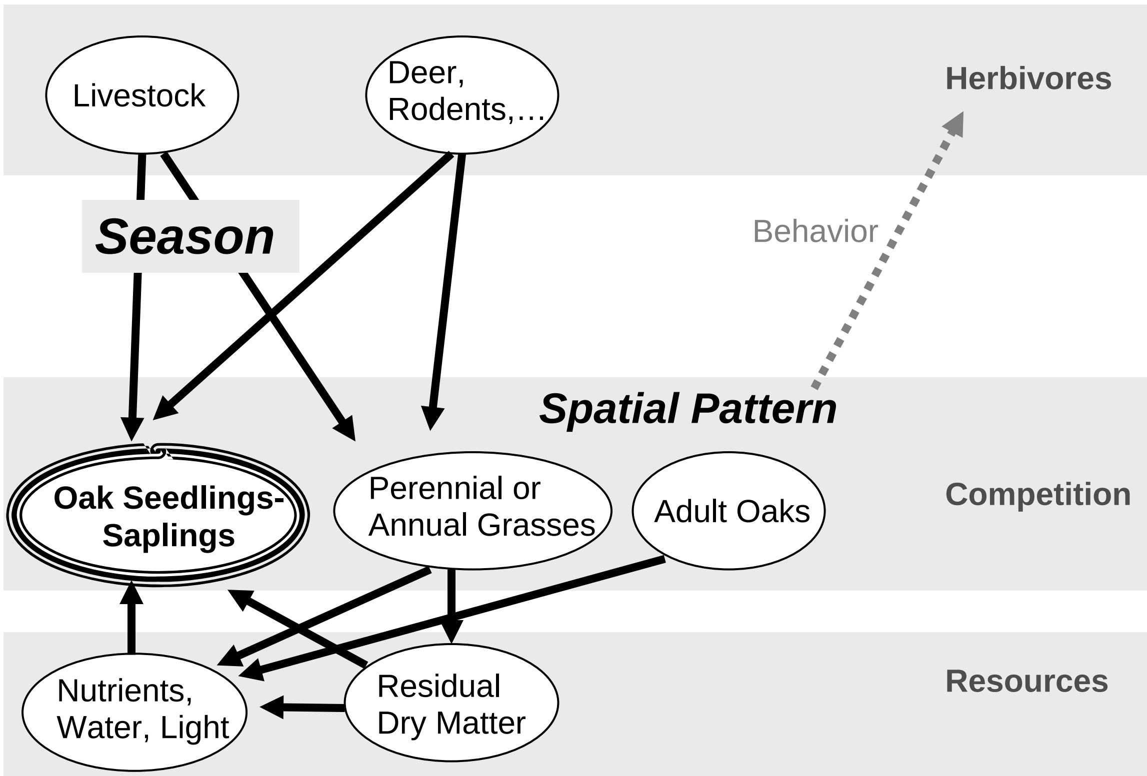

Figure 1. Pathways by which the timing of grazing on the landscape can influence the transition of oak seedlings to saplings and oak recruitment. We focus on several interactions: direct browse and trampling effects from livestock in different **seasons**, **spatial pattern** with preferred forage species or adult oaks, **competitive interactions** with annual and perennial grass species, and the influence of wildlife populations.

IV. Major Objectives of the Proposed Project. We have two main objectives:

1) <u>Determine the relationship between seasonal grazing management on oak recruitment.</u>
There are several lines of evidence that season of grazing may influence blue oak seedling growth and survival. Few studies have evaluated this component of rangeland management, particularly at the landscape scale and across size classes. We will evaluate whether rangeland pastures that have been grazed at different times during the year (for the last 6+ years) have different patterns in oak recruitment. We will also follow marked seedlings and saplings over five years in areas with different seasonal grazing management. This monitoring will allow us to determine how the incidence of herbivory varies spatially and with oak size classes.

2) <u>Isolate several potential factors that contribute to effects of seasonal grazing.</u> We will identify how the following factors change due to different temporal grazing management practices: a) direct browse and trampling effects from livestock, b) spatial association with preferred forage species or adult oaks, c) competitive

interactions with different herbaceous species, d) levels of residual biomass at time of acorn dispersal and germination, and e) other herbivore (deer, small mammal, insect) populations (Fig. 1). We focus on seedling survival and the growth of persistent seedlings to sapling stage.

In the following sections, we will detail the rationale for these objectives and then describe procedures to achieve these objectives.

V. Justification for the Proposed Project.

Many factors likely contribute to low levels of oak recruitment in hardwood rangelands (McCreary 2004). Causes of poor recruitment are complex and often vary across sites and environmental gradients. Environmental conditions such as high soil moisture and/or reduced evaporative demand favor blue oak saplings (Kertis et al. 1993, Swiecki et al. 1993). There is evidence that livestock grazing, tree cutting, and fire can affect blue oak recruitment, although these effects are often variable (Allen-Diaz and Bartolome 1992, Bartolome and McClaran 1992, Swiecki et al. 1993).

Overall, the influences of livestock and non-native annual grasses are generally implicated as the major causes of the failure of oak recruitment. Cattle and deer can browse and trample seedlings (McClaran and Bartolome 1989, Hall et al. 1992). Cattle and deer, and along with smaller mammals such as ground squirrels, also eat acorns (Pulido 2002). Cattle compact the soil, which may reduce seedling recruitment (Tate et al. 2004). Competition with herbaceous species, particularly non-native annual grasses, for soil water and nitrogen can also influence recruitment (Gordon and Rice 2000, Rice and Nagy 2000, Cheng and Bledsoe 2004). In this proposal, we address how the timing of cattle grazing influences oak recruitment through both direct herbivory effects and indirect effects mediated by the herbaceous community.

California oak woodland landscapes vary strongly across time and space. The landscape mosaic of open grassland and adult blue oaks drive processes above- and below-ground. Annual grasses begin to grow after the first fall rains and senesce by June, while leaves of deciduous oaks emerge in spring and drop in the fall. The growth and fine root production of annual grasses is high during most of their growing season, while fine root production in mature oaks occurs throughout the year, is high in late spring, and extends into the summer (Cheng and Bledsoe 2002). Spatially, most of the root distribution of annual grasses is in the top 20cm of soil, while adult oaks root deeper, with 25% of roots below 50 cm depth. Adult oaks redistribute water (Ishikawa and Bledsoe 2000), provide mycorrhizal network (Egerton-Warburton and Allen 2001), reduce evapotranspiration through shading, and increase nitrogen turnover (Herman et al. 2003).

Blue oak seedlings germinate in the fall (Griffin 1971, McClaran 1986). In place of a seed bank, persistent seedlings form a bank of potential recruits known as advance regeneration (McClaran and Bartolome 1989, Allen-Diaz and Bartolome 1992, Swiecki and Bernhardt 1998). These seedlings can show little shoot growth for many years, although they can produce a large root system. Root reserves may help seedlings to regrow from herbivory damage. While most seedlings are often found under canopies of adult oaks due to acorn dispersal patterns and environmental conditions, saplings are more often found on edges of oak canopies, suggesting that factors associated with adult oak canopies may inhibit the release of seedlings to the sapling stage (Muick and Bartolome 1987, Swiecki et al. 1993).

It is reasonable to expect that cattle supplement their herbaceous-dominated diet with woody vegetation as the herbaceous biomass dries in late spring. Hall and co-workers (1992) found evidence suggesting that winter grazing, when grasses were actively growing but oaks seedlings and saplings are leafless, resulted in greater oak survival than grazing in either spring or summer. The authors suggest that negative impacts on oak saplings during the spring were largely by chance: trampling or accidental grazing. These effects likely would have a strong spatial component due to cattle behavior. For instance, seedlings near bedding areas, preferred forage species, or shade from canopies may be more likely to be impacted by cattle (Hall et al. 1992, Harris et al. 2002). In contrast, impacts when the grasses are dormant may be more likely due to direct effects of herbivory because alternative green forage is not available. These effects due to active foraging may be less variable spatially.

The impact of grazing on herbaceous community is variable and likely to be complicated by grazing severity and timing, individual species responses, and abiotic factors such as weather, soil characteristics and light availability (Bartolome and McClaran 1992, Harrison et al. 2003, Hayes and Holl 2003, Kimball and Schiffman 2003, Bartolome et al. 2004). Keeley and co-workers (2003) found that areas with a cattle grazing had greater non-native species densities than areas ungrazed for the last 100 years, but these differences were relatively subtle. Other studies have found that cattle grazing can reduce the abundance of non-native species, particularly if these species are preferred as forage (Germano et al. 2001). Reductions in residual dry matter may also facilitate the establishment of native species (Dyer 2003, Bartolome et al. 2004). Bartolome and co-workers found that spring grazing may increase the success of *Nassella pulchra*, a native bunchgrass.

Several lines of evidence suggest that interactions of oak seedlings and saplings with native perennial grasses will differ from interactions with introduced annual grasses (Dyer and Rice 1999, Gordon and Rice 2000, Aanderud et al. 2003). Gordon and Rice (2000) found that neighborhoods of non-native annuals depleted shallow soil moisture more rapidly than neighborhoods of perennial grass seedlings. Mature native perennial grasses deplete soil water deeper in the soil profile (60 cm) than do annual grasses (Seabloom et al. 2003). The water status of oak seedlings often determines the extent and duration of growth (Koukoura and Menke 1995, Gordon and Rice 2000, Matzner et al. 2003), a factor that could influence the transition of a seedling to the sapling stage.

The timing of grazing will influence interactions between the herbaceous community and oak recruitment. Residual dry matter, an index of grazing intensity of the herbaceous component (George et al. 2002, Jackson and Bartolome 2002, Bartolome et al. 2003), may influence resource availability (e.g., litter decomposition and light levels) and competitive intensity among oaks and grasses. Grazing can also influence the composition of herbaceous neighbors interacting with the oak seedling, potentially influencing competitive interactions. In addition, Tyler and co-workers (2002) found damage due to rodent and insect herbivory have strong impacts on oak success. They speculate that different grazing regimes, through impacts on residual dry matter and herbaceous structure, may influence these other herbivore populations (Tyler et al. 2002).

Predictions. Based on previous work, we predict that several factors influencing oak recruitment in hardwood rangelands are influenced by the presence and timing of livestock grazing.

1) Oak recruitment is greater in pastures that are grazed when the grasses are actively growing due to decreased herbivory on oak seedlings than in pastures grazed in other seasons. In pastures that are grazed only in spring (when the grasses are actively growing), herbivory on oak seedlings and saplings will be related to spatial patterns in cattle use, such as with oak canopy location and preferred forage species.

2) Competitive interactions will influence the performance of oak seedlings and eventual transitions to sapling size classes. Competition for soil water will be most acute during the late spring and summer, and will contribute to the severity of grazing effects during these times. Reductions in residual dry matter of the herbaceous community will reduce competitive effects. Shifts from non-native annual to native perennial communities will change competitive interactions by altering the depth and timing of water stress.

3) Rodent and insect herbivore populations will depend on herbaceous structure of the community. Damage by these species will be influenced by the impact of cattle grazing on herbaceous composition and production.

VI. Procedures to Achieve Objectives.

We propose three activities to achieve our objectives. A) To describe associations among timing of livestock grazing, oak populations, herbaceous communities, and environmental factors, we will conduct a **landscape-scale survey** across multiple pastures with different seasonal grazing management. B) We will **experimentally plant acorns** and manipulate protection from herbivory and herbaceous structure to isolate several possible processes that may contribute to the effects of the presence and timing of grazing. C) We will conduct a **greenhouse experiment** where we simulate herbivory at different times relative to the phenology of competitors.

Study Site

We propose to conduct this research in hardwood-grass rangeland at the Sierra Foothill Research and Extension Center (SFREC) in Browns Valley, California. This site is excellent to pursue our questions because pastures within the same watersheds have varied in the timing of grazing management for many (over 6) years (Swiecki et al. 1993, Hall et al. 1992). Doug McCreary and Dustin Flavell from SFREC have helped us identify pastures that may be suitable for this proposed work. We are in the process of submitting a research proposal to the research advisory committee at SFREC and will work with the staff to finalize pasture selection and coordinate our activities.

A. Descriptive component: Landscape-scale survey

To determine the relationships between seasonal grazing management, oak recruitment and other community and environmental variables (objective 1), we will conduct a landscape-scale survey across multiple pastures at SFREC that have had different seasonal grazing management. This component of the research project has two parts: large landscape-scale surveys in summers 2006 and 2007, and demographic monitoring of selected individuals from different size classes for five years to 2010.

Selection of Pastures. We will identify 2-3 replicate pastures for each of four types of grazing management (a total of 8-12 pastures). Factors that we will consider in our pasture selection are grazing intensity, adult oak density, pasture size, fire history, and topography. We have not finalized selection of these pastures; the final selection will depend on further consultation with SFREC and visits to the pastures.

We describe season of grazing based on the phenology of the annual grasses: *ungrazed pastures* refer to ones without cattle grazing, but are presumed to be used by wildlife, and *multiple season grazing* describes management practices which graze pastures at more than one season. This can include constantly year-around grazing or multiple times on a rotational basis. We use the terms *growing season grazing* for grazing when the annual grasses are green and growing and *dormant season grazing* is for grazing when most of the annual grasses have set seed and senesced.

We will focus on four types of grazing management:

a) Ungrazed. Two pastures at SFREC (Sh1-31 and K1-21) have been ungrazed for over thirty years.

b) Multiple season grazing. Several pastures at SFREC are grazed once during the growing season and once during the dormant season. These rotations have been occurring for 6-8 years.

c) Growing season grazing. Some pastures at SFREC are grazed only during the winter/spring growing season. One (F1-51) pasture at SFREC has had this management since 1995; others have been managed in this manner for 4-5 years.

d) Dormant season grazing. Two pastures at SFREC have been grazed between August and December for 5-8 years. Depending on the timing of rains, some grazing in these pastures does occur during initial growth of grasses but while oak seedlings and saplings have leaves.

Population Survey. In each pasture, we will utilize the sampling design similar to Swiecki et al (1993). We will use a relatively large number of plots (49) spread over a relatively large area 32 hectares) in each pasture. This design will allow us to examine the frequency and pattern of recruitment at the stand or landscape level. Each plot will be circular with a 16 m radius (0.08 ha). We will locate these plots on an 80m by 80m grid, for an approximate sampling density of one plot per 4 ha or 12% of the study area. We will use a global positioning system (GPS) and aerial photographs overlaid with topographic maps from a GIS system to locate plots. This first survey will occur in summer of 2006.

In each plot, we will census all blue oak seedlings, saplings and adult blue oaks. We will record the height of seedlings and saplings that are shorter than 1.5 meters (the approximate height of browse line). We will measure the dbh of all individuals. In addition, we will note several additional growth and environmental characteristics: whether individual appears to be from basal resprouts (originating from a trunk with a basal diameter greater than 8cm), insect damage, stunted growth due to repeated browsing, evidence of trampling, location in relationship to adult oak or other tree canopy (under: directly beneath foliage; edge: partial canopy shade; open: no canopy shade), and topographic position (slope and aspect).

We will use these data to select a set of seedlings and saplings for further monitoring. This selection will concentrate on seedlings and transitional sapling stages with basal diameters ranging from 1 to 3 cm. We hope to identify 40 individuals in each pasture, stratified by size, plot location, and canopy position. In pastures that have low recruitment, we will use as many individuals as possible. We will map and tag all selected individuals.

Incidence of Herbivore Damage. To describe the incidence of herbivory within and across these pastures, we will monitor herbivore damage on the selected oak seedlings and saplings (described above) for the five years of this project. Summer 2006 will be our initial measure of damage, and we will we survey these individuals each summer or fall in 2007, 2008, 2009, and 2010. We will measure height and stem diameter, and note whether individuals appeared to be a basal resprout (originating from a trunk with a basal diameter greater than 8cm), insect damage, stunted growth due to repeated browsing, and evidence of trampling. We will also take photographs of selected individuals to record changes in morphology due to herbivory.

We propose to monitor naturally occurring individuals over multiple years similar to the approach used by Allen-Diaz and Bartolome (1992). They followed cohorts for three years in different experimental treatments and found that sheep grazing and fire had little effect on the growth or survival of oak seedlings. We will focus on cattle grazing, using multiple types of grazing managements, and several size classes of blue oak, forming a robust test of the generality of the previous results. The larger spatial extent of the proposed work can also be used to examine Allen-Diaz and Bartolome's hypothesis that factors affecting oak growth rates, rather than mortality, control the critical transition from seedling to sapling.

Vegetation and Environmental Characteristics. We will conduct a second series of measurements in relation to these selected individuals to determine small-scale and larger-scale relationships between recruitment and the herbaceous community (objective 2). First, we will collect data on *residual dry matter* by harvesting 10cm x 1m strips, drying to constant mass, and weighing (Bartolome et al. 2003). We will harvest these strips adjacent to (within 1 m) the saplings/seedlings selected from the initial survey. We will also quantify the cover of the *abundant herbaceous species* within a 50 cm radius of the seedling with a point-frame. Comparable residual dry matter and composition measures will be performed ~15 m from each monitored seedling/sapling and adult oak. The measures of residual dry matter will occur during fall 2006 (late September, October). The measures of herbaceous species composition will occur the following spring, at peak biomass (April-May 2007). Depending weather variability, we may resample these components in other contrasting years for integrated measures of the herbaceous community.

Small Mammal Trapping. To determine whether small mammal densities vary due to seasonal grazing treatments, we will live trap for a period in the fall (October 2006) and spring (April 2007) in all pastures. In each pasture, a pair of traps will be placed at 2m to the north and south of each of the 40 selected oak saplings. We estimate that a grid of 80 live traps will enable us to describe spatial variation and differences between the pastures (~320 trap nights/pasture), although will conduct initial trappings to verify and modify the trapping intensity if needed. Loralee Larios, a technician in the Suding lab, has trapping experience and will be involved with this aspect of the project.

Data Analysis. We will take three approaches to analyze the data collected. First, we will describe how the population structure (size class) of the oaks differs due to the four seasonal grazing management types. Although the exact size classes used will depend on the characteristics of the sampled population, we will likely use ANOVA and MANOVA models to determine these overall patterns. We will use repeated measure ANOVA models to describe the multiple year demographic measures, as well as discrete event analyses to determine effects following a damage event. Second, we will analyze the relationships among oak sapling presence and size, distance to adult oak canopy, residual dry matter, herbaceous community composition, and insect damage within and among pastures using a multiple regression model. We will also be able to describe pasture differences in rodent population densities and the above parameters using regression or MANOVA models. Third, in the likelihood that many of these variables co-vary across pastures, multivariate analyses can be used to further describe the characteristics across pastures.

Relationship to Objectives. The descriptive component of the research addresses our first research objective: to determine the relationship between seasonal grazing management and oak recruitment. With the proposed design, we will be able to describe the relationship between landscape-level patterns of oak recruitment and seasonal grazing management.

Working at SFREC allows us to utilize replicate pastures with different seasonal grazing management.

Our approach will also allow us to gain some insight with regards to our second objective: to investigate several potential factors that contribute to effects of seasonal grazing. In particular, we will determine spatial association with preferred forage species or adult oaks with different seasonal grazing management. We will be able to relate spatial associations of residual dry matter and herbaceous composition to the damage and growth of individual oak saplings, and scale these relationships to variability across the landscape. We will also gain information about the potential relationships between small mammal populations, insect damage and different types of grazing management. Demographic monitoring of selected individuals from different size classes for five years will enable us to examine the role of spatial position and grazing management on different regeneration stages. We will further investigate the importance of herbivory and competition factors in a field experiment and greenhouse experiment, described below.

B. Experimental plantings of oak seeds (acorns)
In the winters of 2007 and 2008 we will plant acorns to experimentally test the response of oak seedlings to different seasonal grazing (objective 2). We plan to do these plantings in two different years due to the strong interannual weather effects associated with recruitment (McClaran 1986). We will conduct this work in one pasture that has been grazed in multiple seasons each year. We acknowledge that the results from this experiment might be dependent on the particular pasture and site used, but logistical constraints restrict our ability to replicate this experiment in many pastures. This work will serve as basis for further work that will address questions to encompass variability in other pastures and other rangeland sites.

Experimental Treatments. The experiment will consist of the following treatments:

a) Simulated herbivory (in growing season, in dormant season, none)

b) Competitive interactions (no vegetation, annual grasses clipped, perennial grass replacement, annual grass not clipped (control)).

c) Spatial location (underneath canopy, edge, open)

In consultation with SFREC staff, we will select four replicate areas in a livestock pasture, each 0.25 ha in size (50m x 50m). We will place these areas to run from areas with dense canopy coverage to open rangeland. Within each area, we will designate areas with >50% canopy coverage (under canopy), partial shading (edge), and full sun (open). The spatial zones will serve as the main split, in a split plot experimental design (Fig. 2). Within each spatial zone, the 4 competitive interaction treatments will be randomly arranged as the split in the split-plot design. Finally, with each split plot, oak seeds (acorns) will be planted and randomly assigned to 1 of the 3 simulated herbivory treatments. Within the competitive treatments, 9 acorns will be planted and thinned to 3 plants separated by 50 cm. All treatment combinations (36) will be replicated 4 times for a total of 144 plots in each of two years.

Because the aim of this experiment is to determine the response of oak seedlings to seasonal herbivory, we will protect seedlings from herbivores and simulate herbivore damage in seedlings starting one year after planting. We chose to simulate herbivory because we feel that we cannot depend on grazing animals to visit all the grazed locations with seedlings. We will stimulate herbivory by clipping the main stem of the oak seedling to 50% of plant height unless the landscape-scale survey documents a different defoliation rate.

To exclude livestock, deer and small mammals, we will follow the general design of Tyler et al (2002). We will install 3 ft high cages with small mesh (0.5 inch x 0.5 inch) sunk 1 foot into the ground, supported by t-posts and rebar, and covered with bird netting. These cages will reduce light availability, which will monitor, although other work suggests these effects will be minimal (Koukoura and Menke 1995, Tyler et al. 2002). All seedlings in each split-split competitive interaction treatment will be protected under a single cage, for a total of 48 cages per year.

For the competitive interaction treatments, we will manipulate the herbaceous vegetation in an 80 cm diameter plot. There will be four manipulations. First, we will remove all herbaceous vegetation by spraying systemic herbicide (Roundup) to kill the vegetation, removing the dead vegetation, and weeding any subsequent growth. Second, to determine the indirect effects of grazing through changing in residual dry matter, we will clip biomass to reduce annual grasses production and residual dry matter by half. Third, native perennial bunchgrasses vary in resource use and phenology, which may influence interactions with oaks. We will attempt to replace annual grass with native perennial bunchgrass (*Nassella pulchra*) to determine how grazing management, through changing the dominance of exotic annuals, affects oak recruitment. We will add seeds of native bunchgrass to these plots (10 g/m^2) at the same time when the acorns are planted. We do not expect to establish 100% cover of native grasses, but to increase their relative cover appreciably (by 30-50%). Previous work has had good success with seed addition in Sedgwick Ranch in Southern California (Seabloom, Harpole, et al. 2003) and in McLaughlin Reserve in Northern California (Seabloom, personal communication). We will also have a non-manipulated control.

Oak Seed (Acorn) Planting and Monitoring. Following acorn drop in the fall, we will plant 10 freshly collected acorns in each split-plot competitive interaction treatment. We will auger each hole to a depth of 10 cm, refill the holes, and plant a viable acorn at 5 cm depth. Acorns will be collected at SFREC during 2006 and 2007. We will use the float test and visual inspection to estimate viability. We will plant the entire experiment winter 2007 and again (within the same pasture areas, if possible) in winter 2008. Three months after planting, we will thin germinating oaks to 3 per competition treatment sub-plot. The experimental simulations of herbivory will start one year after planting.

We will monitor these plots until fall 2010. We will measure seedling emergence, growth (height, leaf number), and survival in March, July, and October during the first year of planting, and in July in the years thereafter. We will also record evidence of insect damage, small mammal activity, and wildlife browsing.

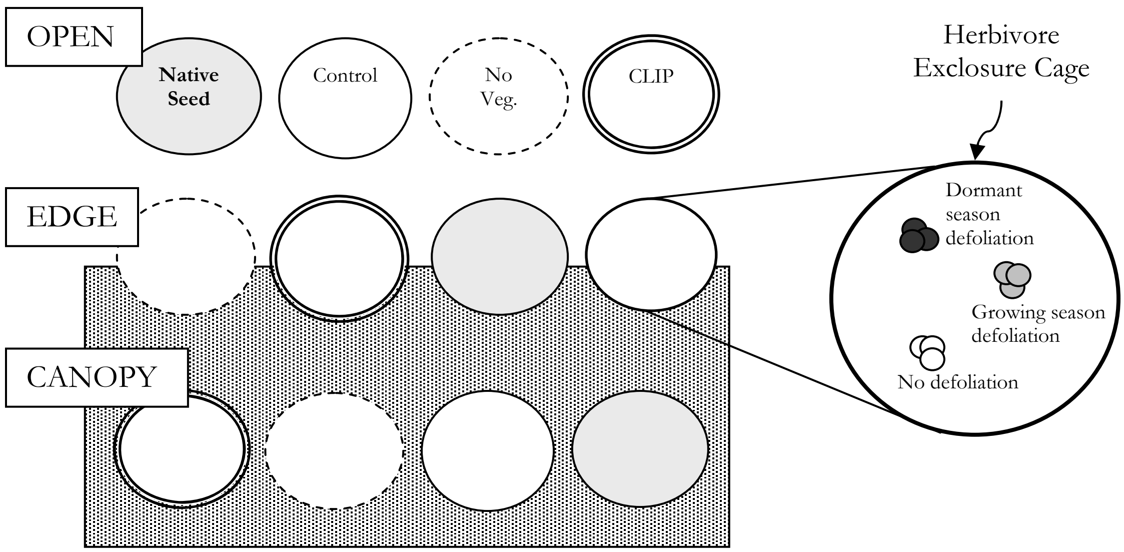

Figure 2. A stylized diagram of one replicate block of the split plot experimental design. We will vary the spatial location of the planted acorns (in the open, at the edge, or underneath adult oak canopies), competitive interactions (no vegetation, annual grasses clipped, native grass replacement by seeding, or control), and season of simulated defoliation (dormant season, growing season, none). All herbivores (livestock, deer, and small mammals) will be excluded with cages.

We will focus on the experiment started in 2007 to describe resource dynamics. In the 2009 growing season, in half of replicate blocks, we will install TDR soil moisture probes to measure soil moisture across the growing season at 6-9 week intervals during 2009 and 2010. We will also measure the water potentials of the oak seedlings with a Scholander pressure chamber during the spring to summer period. In fall, we will measure residual dry matter and herbaceous species composition in these plots as well. In 2010, we will continue these measurements and then harvest the seedlings (in July) to determine biomass. This will be a full plant harvest, including aboveground and belowground (to a depth of 30cm) biomass. If survival is high, we will harvest one half of the experiment and continue to monitor the remaining seedlings longer-term.

Data analysis. We will analyze each of the two planting years separately but in a similar fashion. A split-plot ANOVA model will be used to determine the effect of spatial location (main plot factor; 3 levels), competitive interaction (4 levels, split-plot), and effects of season and type of herbivory (3 levels), and their interactions on oak growth and survival. Similar models can be used to determine effects on such factors as water availability, residual dry matter, and seedling water potentials. If there are strong environmental effects, we will include appropriate covariates in the models.

Relationship to Objectives. This experiment will directly achieve objective two: to isolate several potential factors that contribute to effects of seasonal grazing. Through experimental manipulations of herbivory and competition, we will identify how seasonal livestock herbivory, wildlife herbivory, and competitive interactions with herbaceous species influence oak recruitment. All seedlings will get artificially defoliated in this experiment, making this a robust test of the effects of the timing of herbivory. We will combine this information with information on the incidence of herbivory, another important component to management, from the population survey (described above). Together, these measures will form a comprehensive picture of seasonal grazing management responses.

C. Greenhouse experiment

To further tease apart the effects of grazing season and competition on oak seedling growth and survival (objective 2), we will conduct an experiment under controlled greenhouse settings at UCI. This experiment will start in winter 2006. We will focus on the initial recruitment dynamics and effects of live vegetation in this experiment.

In 10 gallon pots, we will simulate oak seedling herbivory and manipulate the herbaceous neighborhood. We will use local topsoil and add soil inoculum collected from SFREC to all pots. We will establish four types of neighborhoods (similar to the experimental plantings above): no neighbors, annual grass neighborhood (*Bromus diandrus*), annual grass neighborhood that is clipped; native bunchgrass neighborhood (*Nassella pulchra*). These neighborhoods will be established for ten months prior to planting 3 viable acorns (thinned to one after emergence) in each pot in December 2007. We will simulate herbivory of oak seedlings by clipping the top half of the main stem at different times relative to the phenology of the grass neighbors: prior to grass flowering, at peak grass biomass, and following grass senescence.

The pots will be harvested in fall 2008, 2 months after grass senescence. Watering treatments will approximate soil moisture (measured by TDR) throughout the season based on the data collected at the SFREC (Cheng and Bledsoe 2005). Light and temperatures will be controlled to mimic seasonal variation: we are able to get grasses to follow their natural life history stages using these protocols. At the harvest we will measure aboveground and belowground production.

Data analysis. This experiment will be analyzed with a two-way ANOVA model with neighborhood and time of clipping as fixed factors.

Relationship to Objectives. This experiment will serve as a controlled test of objective two: to isolate factors that might contribute to the effects of seasonal grazing on oak recruitment. Here, we focus explicitly on the direct effects of browsing (with clipping at different time periods) and interactions with the herbaceous community.

VII. Application to Conservation and Management. More than 75 percent of oak woodlands in California are grazed by cattle. Determining how livestock rangeland management influences the conservation of oaks and native grassland species has been a major research goal in California for several decades. Grazing alternatives, such as rotational grazing, flash grazing and seasonal grazing, can be managed to optimize impacts on oak seedling and sapling recruitment. However there have been few attempts to determine landscape-scale relationships between oak recruitment and livestock management. Knowledge concerning how the timing of rangeland grazing influences ecological processes and conservation goals will add to the growing effort to understand how oak woodland systems can be managed sustainably.

This project will make several valuable contributions to management of hardwood rangelands. We will combine multi-year natural-recruitment surveys with experimental manipulations of planted seedlings to determine the relative importance of potential factors. In addition, we describe factors that influence seedling mortality and factors that may influence the transition of seedlings to the sapling stage. This approach will enable us to understand the importance of seedling age distribution, controls on survival relative to growth, and the interactive effects of herbivory and phenology in hardwood rangelands. Addressing multiple interactions at the landscape-scale will help tackle the complexities associated with oak recruitment, giving insight into why oak recruitment often varies across sites and environmental gradients.

VIII. Timeline and Responsibilities. We propose to start this project January 2006 and complete all aspects of the work by December 2010. Suding will have the primary responsibility for communication with SFREC and preparation of annual reports. Suding, McClaran and Harpole will be responsible for the landscape survey. Harpole will be responsible for the field experiment, with assistance from Suding, McClaran and Larios. Larios and Suding will be responsible for the small mammal trapping. Harpole will also take the lead on the greenhouse experiment. Suding, McClaran and Harpole will contribute to the data analysis and manuscript preparation.

Table 1. Anticipated timeline for the proposed research.

Task	2006				2007				2008				2009				2010			
Finalize pasture selection	□																			
Landscape survey																				
First survey		□																		
Individual oak selection			□																	
Second survey (RDM, herb, env)				□	□	□														
Mammal trapping				□		□														
Repeated monitoring						□				□				□				□		
Field Experiment																				
Set up & plant (twice)				□	□			□	□											
Monitor, field measures					□		□		□		□		□		□		□	□		
Final harvest																		□	□	
Greenhouse Experiment					□	□	□	□	□	□	□	□								
Data analysis and manuscript preparation								□	□	□	□	□	□	□	□	□	□	□	□	□

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