Factors Limiting Recruitment in Valley and Coast Live Oak[1]

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Abstract
The Santa Barbara County Oak Restoration Program was initiated in 1994 to determine the major factors limiting recruitment of valley oak (*Quercus lobata*) and coast live oak (*Q. agrifolia*). At Sedgwick Reserve in Santa Barbara County, California, we have replicated large-scale planting experiments in four different years to determine the effects of cattle and other ecological factors on oak seedling establishment in oak savannas and woodlands. In 33 large experimental plots (50 x 50 m) we planted acorns collected from *Q. lobata* and *Q. agrifolia* on the site. Fifteen of these large plots are controls, open to grazing, fifteen exclude cattle with the use of electric fence, and three are ungrazed in large ungrazed pastures. Within the plots, experimental treatments included: 1) protection from small mammals such as gophers and ground squirrels, 2) protection from large animals such as cattle, deer, and pigs, and 3) no protection from mammalian grazers. In winters 1997, 1998, 2000, and 2001, we planted approximately 1,000 acorns of each species. Results confirm that seed predation and herbivory by small mammals are a significant "bottleneck" to oak seedling recruitment on the landscape scale. Comparing results among years indicates that lack of late winter rainfall can significantly reduce oak emergence and establishment. Survivorship of protected acorns and seedlings is comparable in grazed and ungrazed areas.

Introduction

Oak woodland and savanna habitats, among the most diverse communities in North America, have suffered significant losses in the past century (Bolsinger 1988), primarily due to agricultural conversion and urban development. In addition, natural regeneration of the keystone species (in the genus *Quercus*) of these systems appears to be insufficient to maintain current populations. Many reasons for this lack of recruitment have been proposed including: 1) intense browsing of saplings and seedlings from large mammals (both deer and introduced cattle) (Griffin 1971); 2) acorn predation by cattle, deer, ground squirrels and others (up to 100 percent predation in some cases) (Borchert and others 1989); 3) trampling by cattle (Griffin 1973); 4) underground root attack from fossorial rodents (primarily gophers); 5)

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competition with exotic annual grasses for water (Danielson and Halvorson 1991); and 6) soil compaction by cattle (Braunack and Walker 1985).

More than 75 percent of oak woodland in California is grazed by cattle, making cattle the most pervasive anthropogenic influence on these ecosystems. Thus, the effects of cattle grazing must be a central theme in a comprehensive investigation of natural regeneration and restoration in today's oak savanna/woodland communities. Although cattle have been implicated as a primary cause of the failure of natural oak recruitment (Griffin 1973), their effects are clearly not straightforward. Even in areas that have not been grazed by cattle for almost 60 years (e.g., the U.C. Hastings Reserve), there is still a lack of significant oak regeneration.

The Santa Barbara County Oak Restoration Program was initiated in 1994 with the goals of determining the major factors limiting recruitment by valley oak (*Quercus lobata*), and coast live oak (*Q. agrifolia*). and identifying cost-effective techniques for large-scale oak restoration in grazed savannas. The primary foci of this program are the effects of cattle, small mammals, and interannual weather variations. Here we present preliminary results from four years of experimental plantings in this long-term oak regeneration program.

Methods

Research was conducted on the Sedgwick Reserve, a 5,883-acre (2,382-ha) ranch located in the Santa Ynez Valley in Santa Barbara County, California. The climate is Mediterranean, with hot dry summers and cool wet winters. Mean annual rainfall is 397 mm. Total precipitation (as recorded at the nearest National Weather Service recording station) for the rain years 1996-1997, 1997-1998, 1998-1999, 1999-2000, and 2000-2001 was 298 mm, 828 mm, 309 mm, 387 mm, and 649 mm, respectively. Under a cooperative grazing agreement with the College of Agriculture at California Polytechnic University, San Luis Obispo, students and faculty from Cal Poly maintained and cared for the cattle herd at Sedgwick, and assisted with the application of grazing treatments in our experiments.

Our large experimental plots were 50 x 50 m. Fifteen of these large plots were controls, open to grazing, and fifteen excluded cattle with the use of electric fence. These plots were established in 1995. They were chosen as pairs, with one randomly selected to be fenced to exclude cattle. In addition, three single 50 x 50 m plots were established in 1996 in three large ungrazed areas.

Within the plots, experimental treatments included: 1) protection from small mammals such as gophers and ground squirrels *(fig. 1a),* 2) protection from large animals such as cattle, deer, and pigs *(fig. 1b),* and 3) no protection from mammalian grazers *(fig. 1c).* Large cages were constructed of 4 ft high, 2 x 4 inches mesh galvanized wire (12 gauge); they were round (diameter = 18 inches) and supported at one side with a 5 ft t-post, and at the other side with a 4 ft rebar. Smaller cages to exclude small mammals were cylinders constructed of 3 ft high hardware cloth (mesh size = 0.5 inches); they were sealed at both ends with aviary wire. In positions with cages (small mammal exclusion), the cages were set 12 inches into the ground. Each of these treatments was replicated five times within each plot for each species.

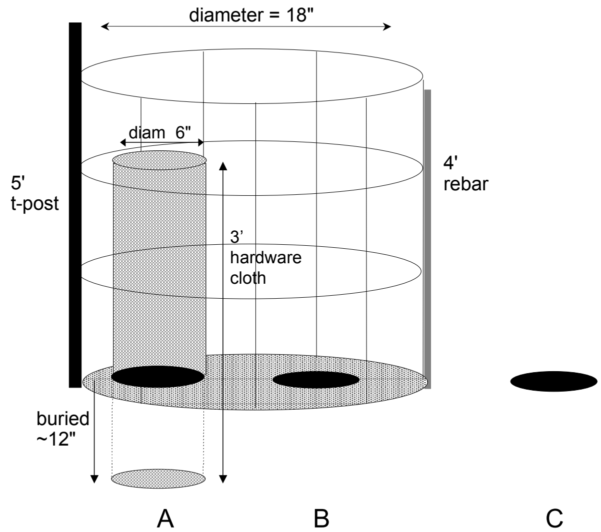

Figure 1—Treatments used for acorn plantings. A: caged and fenced to prevent grazing and herbivory by both large and small mammals (this treatment is referred to as "no rodents"). B: fenced to prevent grazing by large animals. C: open. These treatments are replicated in both 1) plots that are grazed by cattle and 2) plots that are fenced to exclude cattle.

Following the onset of consistent seasonal rains (December or January), at each planting location holes were augured to a depth of 12 inches, soil replaced and two viable acorns planted 1-2 inches below the soil surface. We planted acorns collected from *Quercus lobata* and *Q. agrifolia* on the site in the fall of the same year. Prior to planting, acorns were placed into buckets of water. Acorns that floated were discarded; we planted only acorns that sank and appeared viable. Acorns and seedlings did not receive supplemental watering through artificial irrigation.

In winters of four years, 1996-1997, 1997-1998, 1999-2000, and 2000-2001, we planted approximately 1,000 acorns of each species. In 1996-1997, and 1997-1998, we planted in all 33 plots. In January 1998 (El Niño year), the trees in the middle of two of these plots were blown over. The broken trunks and downed large limbs made future planting in these plots unfeasible. Because the plots are paired, we removed the two sets of plots (total of four) from additional planting experiments, reducing the number of plots in 1999-2000, and 2000-2001 to 29: 13 fenced, 13, unfenced, and 3 in large ungrazed pastures.

Results

2000-2001 Planting

Grouping all treatments, 17 percent of *Q. lobata* seedlings emerged, and 26 percent of *Q. agrifolia*. There were striking differences in emergence rates among experimental treatments *(fig. 2)*. The highest seedling emergence was found in locations that were protected from both rodents and large grazers. It appears that there were no differences in initial emergence rates in large grazed versus ungrazed plots, indicating that cattle grazing did not affect emergence of oak seedlings. At present, grouping all treatments, there are 405 newly emerged seedlings from the 2000-2001 plantings (160 *Q. lobata* and 245 *Q. agrifolia*).

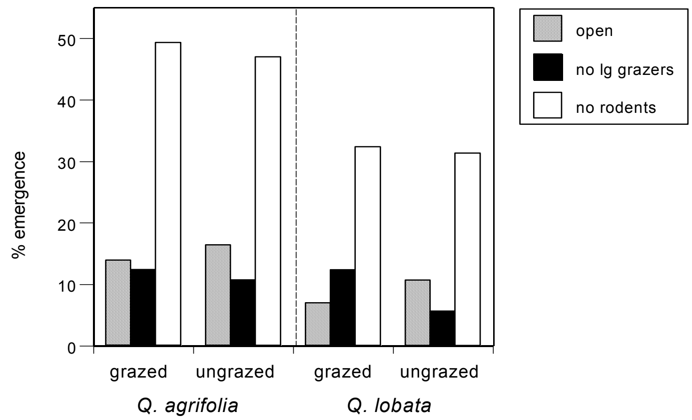

Figure 2—Total percent emergence of seedlings planted in 2000-2001 with various levels of protection from herbivores. Data are from May/June 2001.

1999-2000 Planting

The highest emergence and survivorship has been for seedlings that are protected from small mammals *(fig. 3)*. However, mortality of 1-year-old seedlings, especially *Q. agrifolia*, has occurred over the past year. It appears that there was relatively higher mortality for both species in the large ungrazed plots. In terms of actual seedling numbers, there are currently 337 established 1-year-old seedlings (273 *Q. lobata*, and 64 *Q. agrifolia*). Fifty percent of these seedlings are in the treatment protected from rodents.

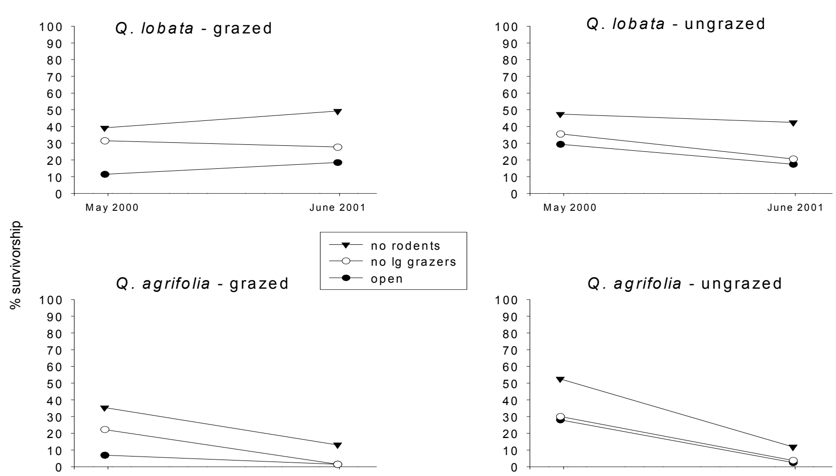

Figure 3—Percent survivorship of 1-yr-old seedlings (planted in 1999-2000) in large plots grazed by cattle, vs. those fenced to exclude cattle. Data are totals for three experimental treatments *(fig. 1)* for two sampling dates

1997-1998 Planting

The highest seedling/sapling establishment rates are for those protected from small mammals *(fig. 4)*. In nearly all treatments highest mortality thus far appears to have occurred in the first season after emergence. However, it is interesting to note that there was higher mortality for both species in the plots that have been ungrazed (see "no rodent treatment," *fig. 4)*. In terms of actual seedling numbers, there are currently 526 established three-year-old seedlings (300 *Q. lobata*, and 226 *Q. agrifolia*). Sixty-seven percent of these seedlings are in the treatment protected from rodents.

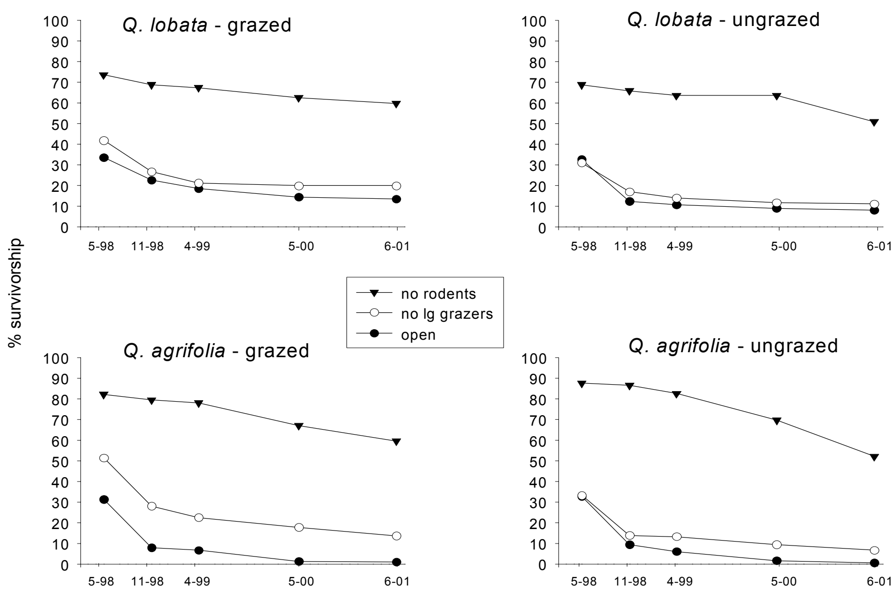

Figure 4—Percent survivorship of 3-yr-old seedlings (planted in 1997-98) in large plots grazed by cattle, vs. those fenced to exclude cattle. Data are totals for three experimental treatments *(fig. 1)* for five sampling dates.

1996-1997 Planting

Out of 2,112 acorns planted in 1996-1997, a total of 13 four-year-old established seedlings have survived, or less than 1 percent of each species planted *(table 1)*. There are presently 4 four-year old *Q. agrifolia* seedlings, and 9 four-year old *Q. lobata*. Our results suggest that the treatment that was most successful in terms of oak establishment was that which excluded small mammals. There are no seedlings surviving from the 1996-1997 planting that were in the open.

Table 1—*Percent survival of seedlings of each species in each age class to June 2001 (all treatments combined). No acorns were planted in 1998-1999 because acorns were unavailable.*

	Planting year				
	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001
Quercus lobata	0.9	21.6	-	29.4	17.2
Quercus agrifolia	0.4	16.3	-	6.9	26.4
No. planted per sp	1,056	1,386		928	928

Discussion

Results from our four large-scale planting experiments indicate that several factors play a role in limiting or promoting seedling recruitment of oaks, most notably rainfall and herbivory by small mammals. Abundant rainfall in late winter, as seen in the El Niño year 1997-1998, can significantly enhance emergence and survivorship, while very low rainfall, as seen in 1996-1997, results in low seedling numbers. The effects of annual variation in precipitation levels, which are directly related to soil-moisture levels, on oak establishment have been described in previous studies. Griffin (1971) proposed that reduced rainfall greatly reduced establishment of blue and valley oak in central California. Plumb and Hannah (1991) concluded that low rainfall was the primary cause for poor success in regeneration work with coast live oak. In our study, which aims to determine cost-effective methods for oak restoration on a large landscape scale, plants have not been artificially watered because a) irrigation is expensive and may be economically infeasible on a large scale, and b) the long-term survivorship of saplings following weaning of supplemental watering is unknown. However, it is clear that adequate rainfall in the first year after planting will directly affect the success of restoration efforts.

As observed in all four planting years, at all planting sites, in both grazed and ungrazed plots, and for both oak species, seed predation and herbivory by small mammals (most likely gophers and ground squirrels, both of which are abundant at the site) significantly reduces oak seedling recruitment. The role of small mammals in oak seedling mortality has been suggested by a number of studies (e.g., Adams and others 1987, Adams and others 1997, Berhardt and Swiecki 1997, Borchert and others 1989, Davis and others 1991, Griffin 1976, McCreary and Tecklin 1997). However, in cases where seedlings are protected from herbivory with the use of window screening or tree shelters, it is difficult to separate the effects of small mammals from insects, since these treatments exclude both. The present study indicates that small mammals play a major role in limiting recruitment of valley and coast live oak.

Finally, although there appears to be no difference in initial seedling emergence in large grazed vs. ungrazed plots, our results suggest that there may be higher mortality in ungrazed plots. These latter plots, which have been ungrazed since January 1995, now have dense herbaceous vegetation. It is possible that this thick cover of thatch and grasses either 1) negatively affected the oak seedlings directly by competing for water (Gordon and Rice 1993), or 2) attracted higher densities of herbivores. We believe that the higher mortality was due to the latter, in particular herbivory by insects. This past summer (2001) we observed an outbreak of grasshoppers at our site, and many of our seedlings, in all treatments, were defoliated. Previous studies have found that reducing cover of grasses, either by weeding or grazing, significantly enhanced emergence or survivorship in oaks (Adams and others 1997, Berhardt and Swiecki 1997, McCreary and Tecklin 1997). While reduced competition was one outcome of these treatments, several studies note that weed control also reduced damage by animals that are attracted to thick herbaceous cover, such as voles (Bernhardt and Swiecki 1997) and grasshoppers (McCreary and Tecklin 1994).

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