Santa Barbara County Oak Restoration Program

Yearly Progress Report for the Period July 2001 - June 2002

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This progress report summarizes the activities of the Santa Barbara County Oak Restoration Program for the period July 2001 through June 2002. Completed activities for the year can be grouped into four main areas: 1) research on methods for restoration of oaks, 2) research to determine factors limiting natural regeneration of oaks, 3) maintenance of cattle and study site infrastructure, and 4) dissemination of information.

I) Research on methods for restoration of oaks and establishment of seedlings and saplings

In the fall of 2001, the oaks on our research site produced extremely few acorns, and thus no acorns were available for a new set of planting experiments. This failure of the acorn crop also occurred statewide. Factors responsible for the production of acorns in a given year are not well understood, but Koenig *et. al*. (1994), suggest that wet weather in the previous spring correlates well with low acorn production in the following fall. It has been speculated that spring rain disrupts oak pollination. Although no new plantings were done this year, we continued to monitor both survivorship and growth of the seedlings that resulted from the previous years' plantings.

Methods

To review, our experimental plantings of acorns have been conducted over four years: 1996-1997, 1997-1998, 1999-2000, and 2000-2001. We did not plant in 1995-1996, 1998-1999, or 2001-2002 because no acorns were available in those years. We used essentially the same experimental treatments each planting year. These employed a stratified random design to designate positions for planting within the large 50 x 50 m plots (Fig. 1).

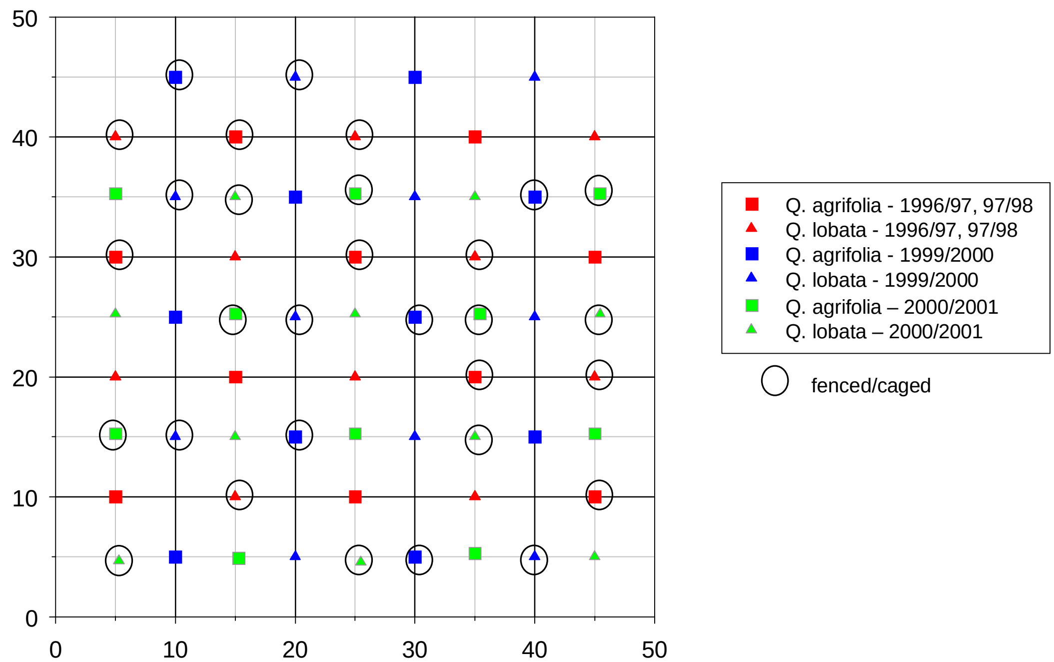

Figure 1. Design for the designation of planting positions within large 50 x 50m plot. Squares indicate positions where *Quercus agrifolia* are planted; triangles are *Q. lobata*. Uncircled figures represent locations for open treatments. All circled figures represent locations that include 2 treatments: fenced to prevent large mammal grazing, and fenced & caged to prevent large and small mammal grazing. At two of the circled locations per plot, one per species, there is one additional treatment in each planting year: cage controls (in 96/97 and 97/98) or alternative cage (in 99/00 and 00/01).

For each species, *Quercus lobata* and *Q. agrifolia*, we had a minimum 16 planting positions per plot: 5 open (Fig. 2A); 5 fenced to prevent grazing by large animals such as cattle, deer and pigs (Fig. 2B); 5 caged and fenced to prevent all mammalian grazing, including by animals such as gophers, ground squirrels and rodents (Fig. 2C); and one alternative cage to test for either secondary effects of the caging (“half-cages”/controls in years 96-97, and 97-98) or effects of removing the bottom of the small cages (open-bottomed cages in year 99-00, and 00-01) (Fig. 2D).

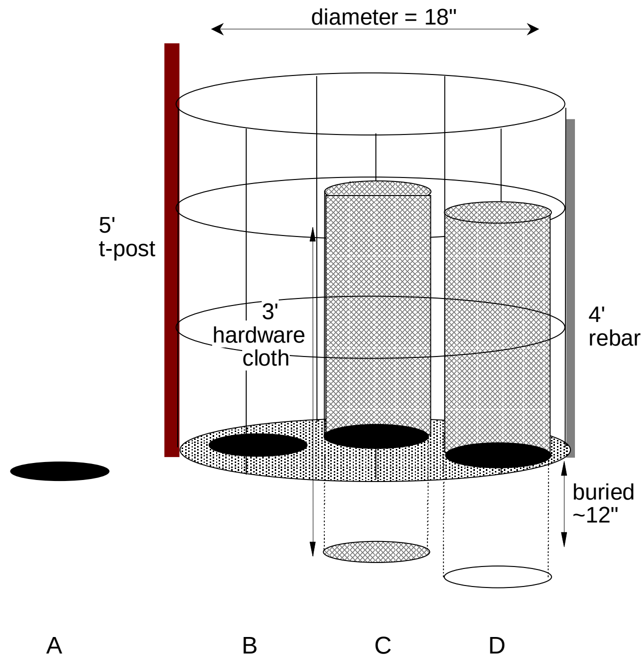

Figure 2. Treatments used for acorn plantings. A: open. B: fenced to prevent grazing by large animals. C: caged and fenced to prevent grazing and herbivory by both large and small mammals (this treatment is referred to as "no rodents"). D: caged and fenced to prevent grazing from large and small mammals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

Fences were constructed of 4' high, 2" x 4" mesh galvanized wire (12 gauge); they were round (diameter = 18") and supported at one side with a 5' t-post, and at the other side with a 4' rebar. Smaller cages to exclude small mammals were cylinders constructed of 3' high hardware cloth (mesh size = 0.5"); they were sealed at both ends with aviary wire. The open-bottom cage (Fig. 2D) had no aviary wire on the bottom. We also treated these cages with an acid wash to remove the galvanization on the lower 6”; this treatment will allow the portion of the cage that is underground to rust and disintegrate more quickly. In positions with cages (small mammal exclusion), the cages were set 12" into the ground. Two viable acorns were planted 1-2" below the soil surface, at each planting location. Prior to planting, acorns were placed into buckets of water. Acorns that floated were discarded; we planted only acorns that sank and appeared viable.

Each year we planted in 29 to 33 of our thirty-three large experimental plots (50 x 50 m): 15 plots which are fenced with electric wire to exclude cattle, 15 plots which are grazed by cattle, and 3 plots which are ungrazed in large ungrazed pastures. Fallen trees prevented planting in 4 plots (2 fenced and 2 grazed) in 1999-2000, and 2000-2001. Each year a total of approximately 2000 acorns were planted (1000 per species).

Survivorship and growth of seedlings

a) Cohort planted in 2000-2001

The highest emergence and survivorship for both species has been for seedlings that are protected from small mammals (Fig. 3). However, there has been relatively high mortality within all treatments and only 9% of the *Q. lobata*, and 4% of *Q. agrifolia* that were planted are still present at this time. Two sources of mortality that are likely to have affected this cohort are 1) very low rainfall in winter 2002, and 2) defoliation by grasshoppers in June 2001. There were similar results in grazed vs. ungrazed plots for both species. *Q. agrifolia* seedlings had higher mortality than *Q. lobata* in all treatments.

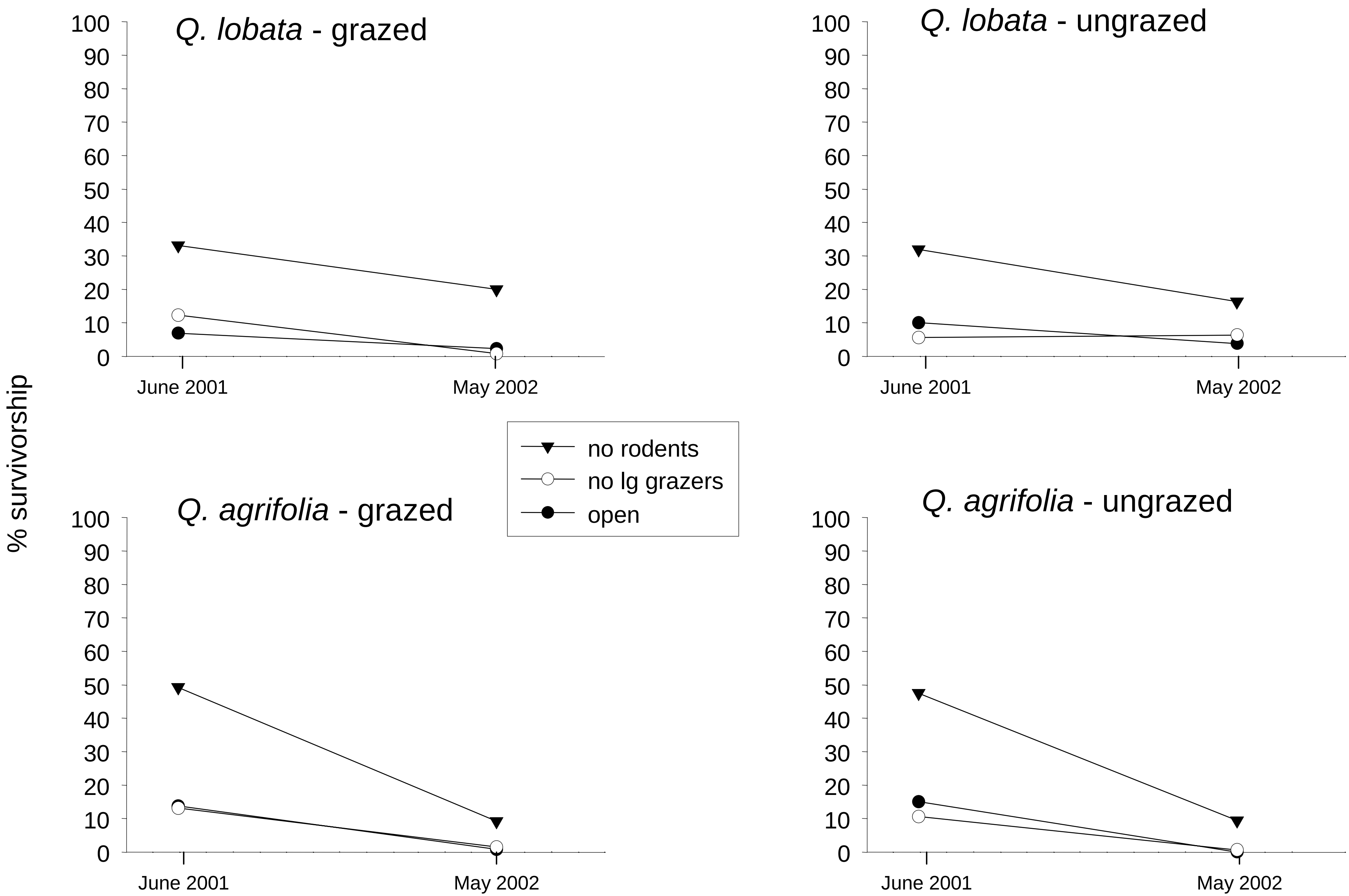

Figure 3. Percent survivorship of 1-yr old seedlings (planted in 2000-2001) in large plots grazed by cattle, vs. those fenced to exclude cattle. Data are totals [100 * (#seedlings/#acorns planted)] for three experimental treatments (see Fig. 2 a, b, and c); for two sampling dates.

Including all treatments and both species, 7% of the acorns planted in 2000-2001, are now established seedlings. There are currently 123 established one-year-old seedlings (85 *Q. lobata*, and 38 *Q. agrifolia*). Eighty percent of these seedlings are in the treatments protected from rodents (Table 1).

Quercus lobata	treatment	# in cattle grazed plots	# in ungrazed plots
	no rodents	26	26
	no large grazers	1	10
	open	3	6
	alternative cage	4	9
	total	*34*	*51*

Quercus agrifolia	treatment	# in cattle grazed plots	# in ungrazed plots
	no rodents	12	15
	no large grazers	2	1
	open	1	0
	alternative cage	4	3
	total	*19*	*19*

Table 1. Number of established one-year-old oak seedlings (planted in 2000-2001) in experimental treatments (all areas combined). "Alternative cage" refers to cages, which exclude rodents, but without bottom wire (see Fig. 2D). Data from June 2002.

Surviving one-year old *Q. lobata* seedlings range in height from 2 to 32 cm (<1 to 13") with a mean of 9 cm (3.5"). Heights of surviving one-year old *Q. agrifolia* seedlings range from 3 to 16 cm (1 – 6") with a mean of 7 cm (3"). The mean height of one-year old seedlings did not vary significantly among treatments.

Comparing survivorship and heights of seedlings in full cages vs. “alternative” cages with no bottoms, we found no significant differences between these two treatments for either species. *Q. lobata* seedling survivorship and mean height in full cages were 18% and 9 cm (se 0.7), vs 22% and 9 cm (se 1.4) in cages with no bottoms. *Q. agrifolia* seedling survivorship and mean height in full cages were 9% and 7 cm (se 0.6), vs 12% and 9 cm (se 1.3) in cages with no bottoms. We conclude that cages do not require bottoms to effectively exclude small mammals and reduce initial mortality from underground herbivores.

b) Cohort planted in 1999-2000

As above, the highest emergence and survivorship for both species has been for seedlings that are protected from small mammals (Fig. 4). However, there has been relatively high mortality within all treatments and only 11% of the *Q. lobata*, and 3% of *Q. agrifolia* that were planted are still present at this time. Two sources of mortality that are likely to have contributed significantly to the losses in this entire cohort are 1) very low rainfall in winter 2002, and 2) defoliation by grasshoppers in June 2001.

Including all treatments and both species, 7% of the acorns planted in 1999-2000, are now established seedlings. There are currently 124 established one-year-old seedlings (101 *Q. lobata*, and 23 *Q. agrifolia*). Fifty-three percent of these seedlings are in the treatments protected from rodents (Table 2).

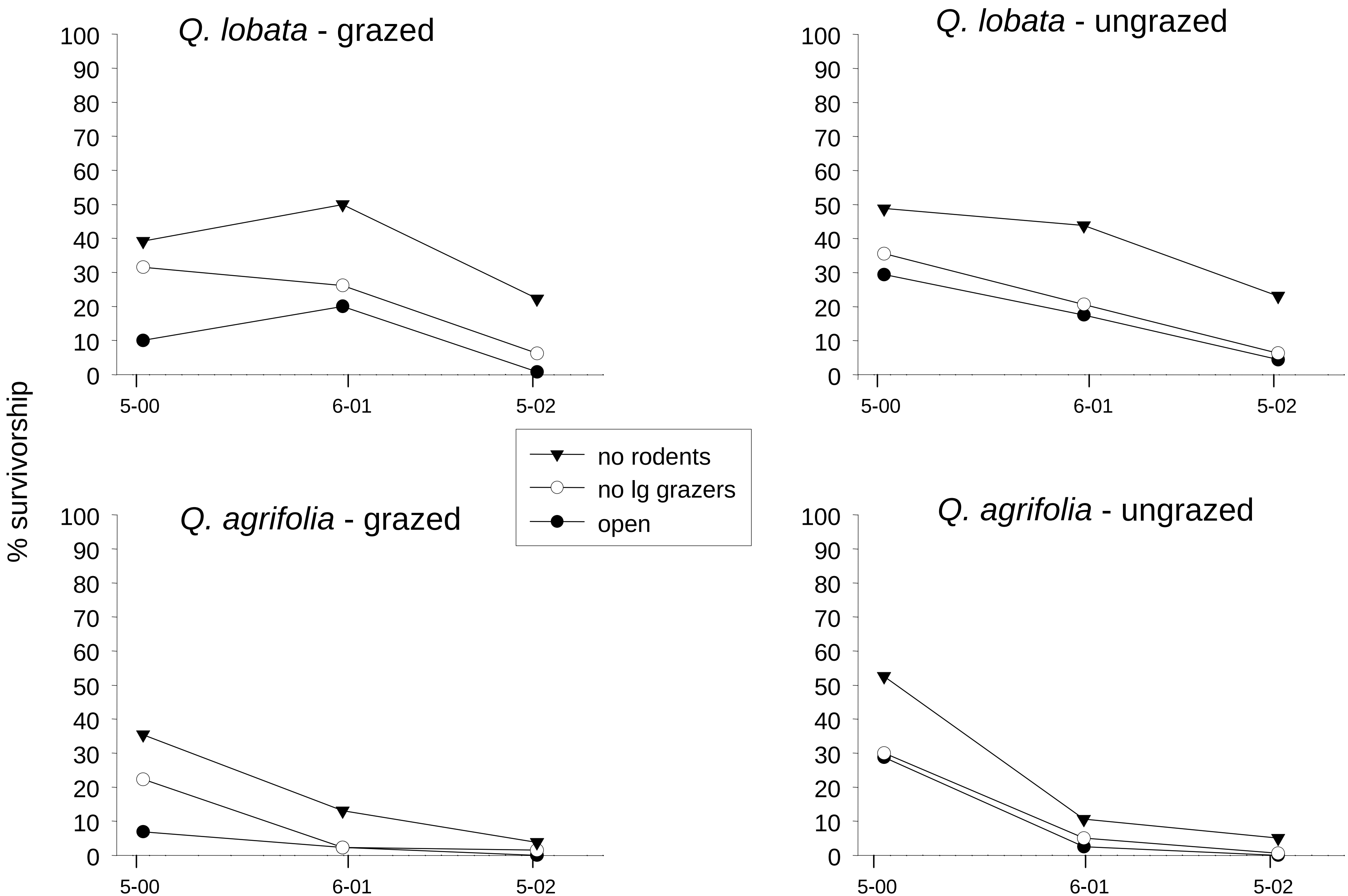

Figure 4. Percent survivorship of 2-yr old seedlings (planted in 1999-2000) in large plots grazed by cattle, vs. those fenced to exclude cattle. Data are totals [100 * (#seedlings/#acorns planted) for three experimental treatments (see Fig. 2 a, b, and c); for three sampling dates.

Quercus lobata	treatment	# in cattle grazed plots	# in ungrazed plots
	no rodents	29	37
	no large grazers	8	10
	open	1	7
	alternative cage	5	4
	total	*43*	*58*

Quercus agrifolia	treatment	# in cattle grazed plots	# in ungrazed plots
	no rodents	5	8
	no large grazers	2	1
	open	0	0
	alternative cage	1	6
	total	*8*	*15*

Table 2. Number of established two-year-old oak seedlings (planted in 1999-2000) in experimental treatments (all areas combined). "Alternative cage" refers to cages, which exclude rodent, but without bottom wire (see Fig. 2D). Data from June 2002.

Surviving two-year old *Q. lobata* seedlings range in height from 2 to 55 cm (<1 to 22") with a mean of 14 cm (5"). Heights of surviving two-year old *Q. agrifolia* seedlings range from 6 to 38 cm (2 – 15") with a mean of 18 cm (7").

Survivorship and heights of seedlings in full cages vs. "alternative" cages with no bottoms were similar between these two treatments for both species. *Q. lobata* seedling survivorship in full cages was 23% (or a mean of 0.5 seedlings per cage) vs 16% (or a mean of 0.3 seedlings per cage) in cages with no bottoms (paired t-test: df = 28, p = 0.136). The mean height of *Q. lobata* seedlings in full cages was 16.4 cm (se 3.8), vs 8.4 cm (se 0.9) in cages with no bottoms (paired t-test: df = 4, p = 0.119).

Q. agrifolia seedling survivorship in full cages was 4% (or a mean of 0.1 seedlings per cage) vs 12% (or a mean of 0.2 seedlings per cage) in cages with no bottoms (paired t-test: df = 28, p = 0.083). The mean height of *Q. agrifolia* seedlings in full cages was 15.7 cm (se 4.9) vs 18.6 cm (se 4.3) in cages with no bottoms (paired t-test: df = 4, p = 0.938). These data confirm our conclusion that cages do not require bottoms to effectively exclude small mammals and reduce mortality from fossorial herbivores.

c) Cohort planted in 1997-1998

The differences in seedling survival among the treatments have been maintained from last year. The highest seedling/sapling establishment rates are for those protected from small mammals (Fig. 5). In all treatments that are not protected from small mammals, the highest mortality thus far appears to have occurred in the first season after emergence. However, there has been relatively high mortality within the past two years in the rodent exclusions as well. Mortality has been greater for *Q. agrifolia*, and for both species there has been higher mortality in the plots that have been ungrazed. As described in our previous report, it is possible that the thick grass cover either attracted higher densities of herbivorous grasshoppers in 2001, or competed with seedlings for water, particularly in the low rainfall year of 2002.

Including all treatments and both species, 12% of the acorns planted in 1997-98, are now established seedlings/saplings (see photos, Appendix 1). There are currently 338 established four-year-old seedlings (198 *Q. lobata*, and 140 *Q. agrifolia*). Seventy percent of these seedlings are in the treatment protected from rodents (Table 3).

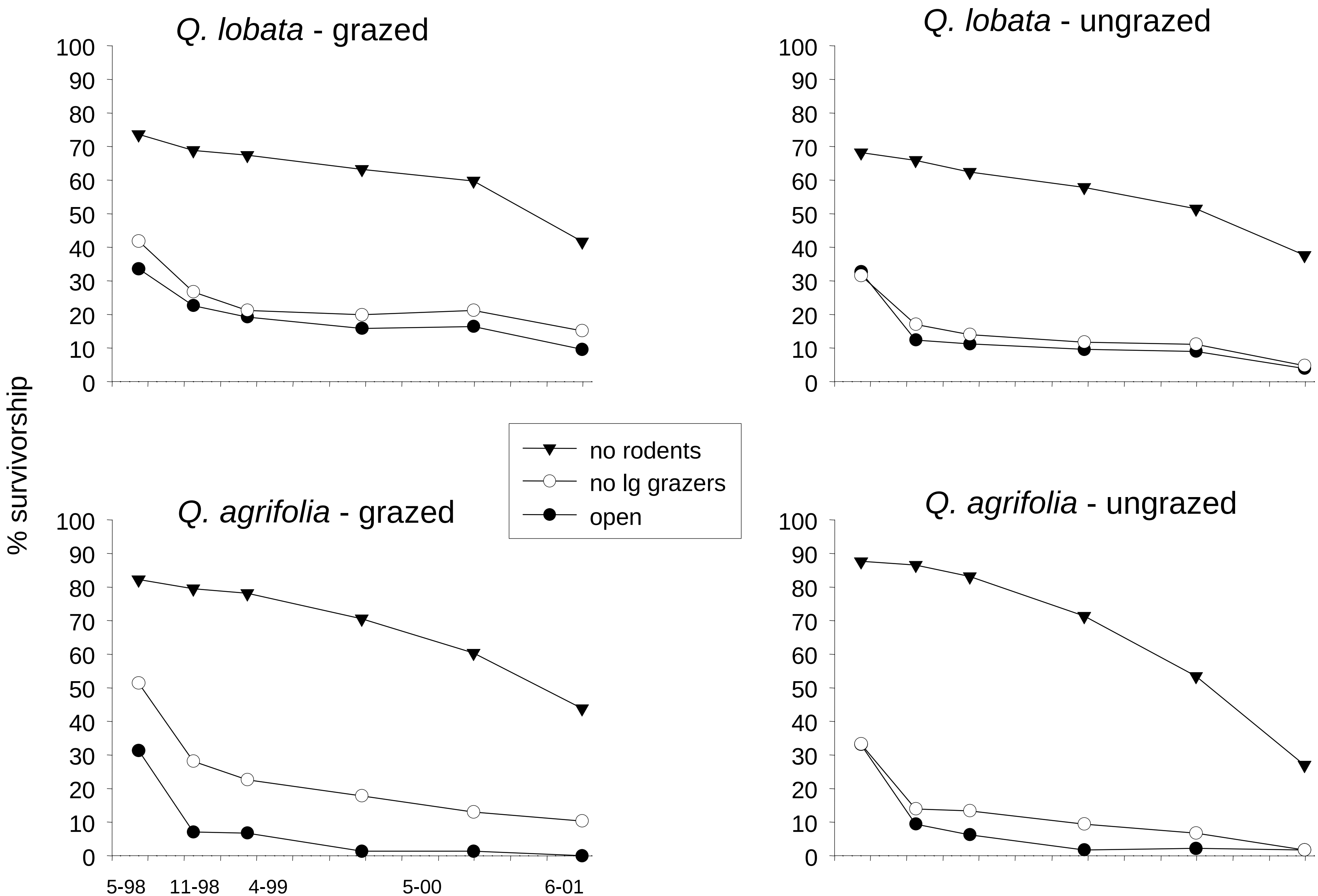

Figure 5. Percent survivorship of 4-yr old seedlings (planted in 1997-98) in large plots grazed by cattle, vs. those fenced to exclude cattle. Data are totals [100 * (#seedlings/#acorns planted) for three experimental treatments (see Fig. 2 a, b, and c); for six sampling dates.

Quercus lobata	treatment	# in cattle grazed plots	# in ungrazed plots
	no rodents	60	65
	no large grazers	22	8
	open	21	16
	cage controls	2	4
	total	*105*	*93*

Quercus agrifolia	treatment	# in cattle grazed plots	# in ungrazed plots
	no rodents	64	48
	no large grazers	15	3
	open	0	3
	cage controls	5	2
	total	*84*	*56*

Table 3. Number of established four-year-old oak seedlings (planted in 1997-1998) in experimental treatments (all areas combined). "Cage control" refers to half cages, which provide shade and other secondary caging effects but allow access to rodents. Data from June 2002.

Surviving four-year old *Q. lobata* seedlings range greatly in height, from 2 to 161 cm (<1 to 63") with a mean of 31 cm (12"). Heights of surviving four-year old *Q. agrifolia* seedlings also range greatly, from 1 to 148 cm (<1 – 58") with a mean of 46 cm (18"). The tallest seedlings present in our experiments are those planted in this cohort. The height of four-year old seedlings varied among treatments (Fig. 6). Seedlings protected from both large and small mammals ("no rodents" treatment) were, on average, taller than those in most other treatments.

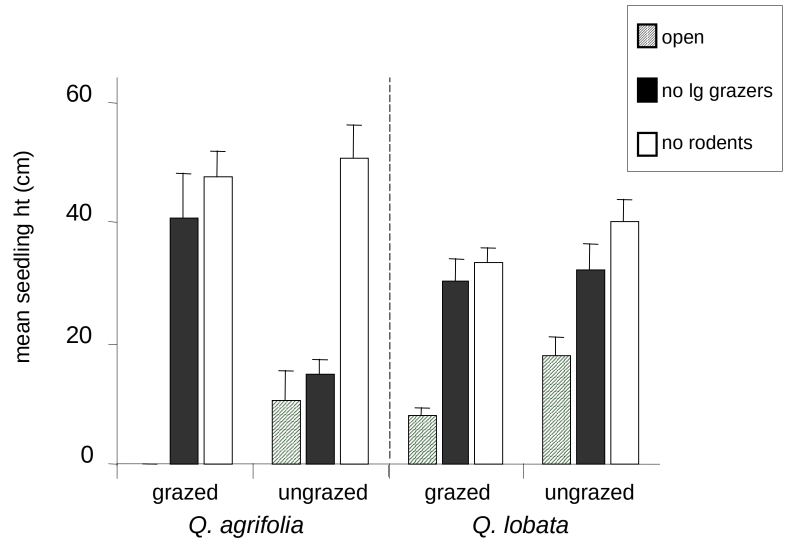

Figure 6. Heights of oak seedlings planted in 1997-98 with various levels of protection from herbivores. Data are mean seedling heights (plus 1 s.e.) per planting treatment in May/June 2002. Seedlings emerged in Spring 1998, and thus were four-year old individuals.

There were no significant differences between cage controls and fenced "open" locations on seedling establishment or seedling heights (Table 4). This corroborates our previous findings that our cages that exclude rodents, do not have unknown secondary effects or "caging artifacts".

	# planted	# alive in 2002	% survivorship	mean ht (se) (cm)	min – max ht (cm)
Q. lobata					
open	56	4	7	33.5 (11.5)	13 - 53
cage control	58	6	10	34.7 (6.9)	16 - 48
Q. agrifolia					
open	70	6	9	40.8 (11.3)	15 - 63
cage control	72	7	10	38.9 (9.5)	10 - 56

Table 4. Number of established four-year-old oak seedlings (planted in 1997-1998) in cage controls vs. "open" (all areas combined). "Cage control" refers to half cages, which provide shade and other secondary caging effects but allow access to rodents. "Open" refers to locations that are protected from large grazers but open to rodents. Data from June 2002.

d) Cohort planted in 1996-1997

Out of 2112 acorns planted in 1996-1997, a total of 17 five-year-old established seedlings have survived. None died in the past year, but a few that had been previously counted as dead resprouted. There are presently 6 five-year old *Q. agrifolia* seedlings, and 11 five-year old *Q. lobata*. Our results suggest that the treatment that was most successful in terms of oak establishment was that which excluded small and large mammals (Fig. 7). There are no seedlings surviving from the 1996 - 1997 planting that were in the open. In addition, there are more seedlings present in areas that are grazed by cattle than in ungrazed areas (10 vs. 7).

Five-year old *Q. lobata* seedlings range in height from 10 to 82 cm (4 to 32"), with a mean of 46 cm (18"). Five-year old *Q. agrifolia* seedlings range from 22 to 95 cm (9 to 37") with a mean of 58 cm (23"). In May 2002, the average five-year old seedlings (planted in 1996-97) of both species were larger than the average four-year old seedlings (planted in 1997-98), although at present the tallest seedlings/saplings in our plots are those planted in 1997-98.

e) Summary

There are currently valley and coast live oaks of four age classes, as a result of our planting experiments (Table 5).

			planting year			
	1996 - 1997	1997 - 1998	1998 - 1999	1999 - 2000	2000 - 2001	Sum
Quercus lobata	11	198	-	101	85	395
Quercus agrifolia	6	140	-	23	38	207
sum	17	238		124	123	602
# planted per sp	1056	1363		928	928	4275

Table 5. Total number of seedlings of each species in each age class surviving to June 2002. No acorns were planted in 1998 – 1999 because acorns were unavailable.

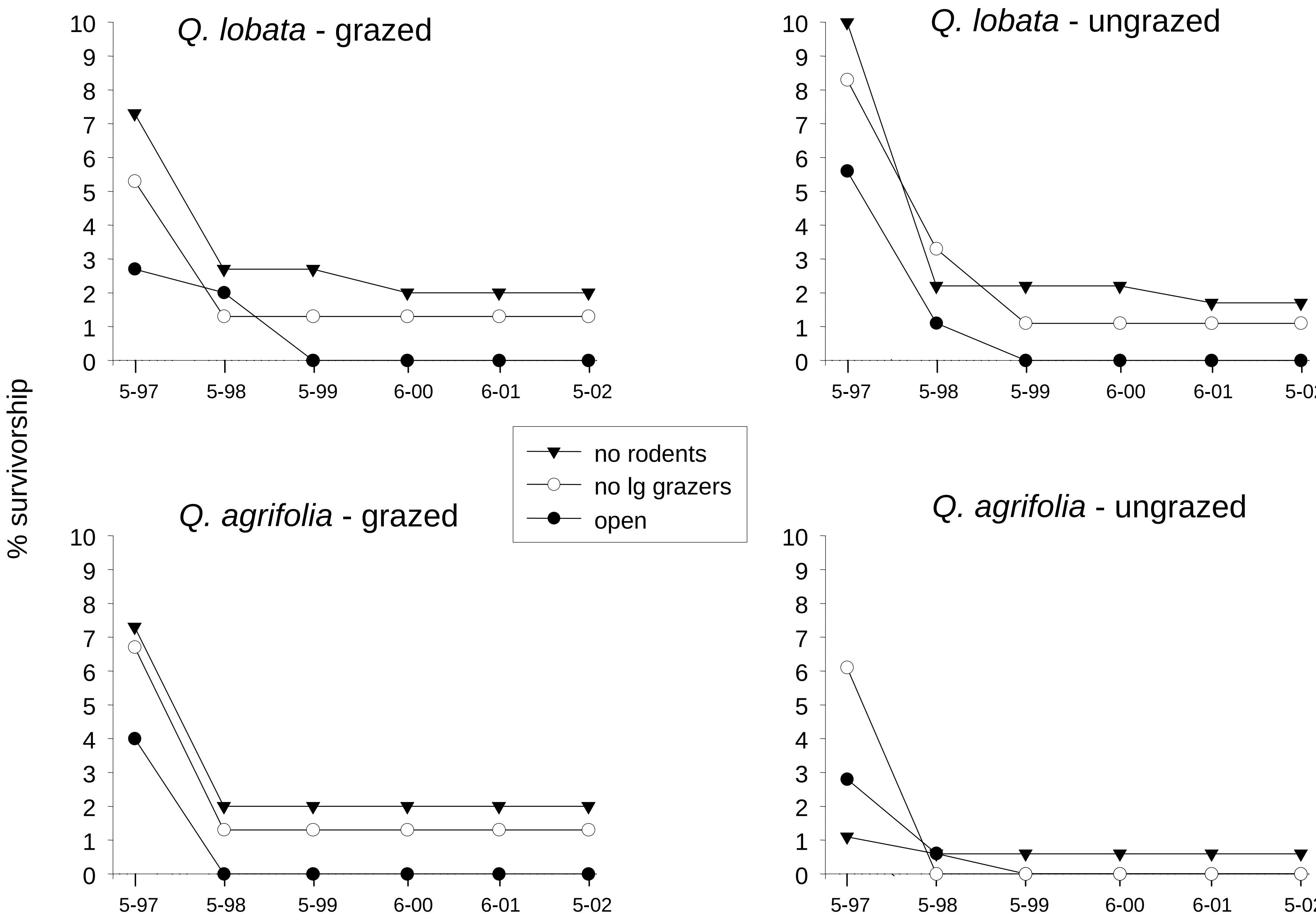

Figure 7. Percent survivorship of 5-yr old seedlings (planted in 1996-97) in large plots grazed by cattle, vs. those fenced to exclude cattle. Data are totals [100 * (# seedlings/#acorns planted)] for three experimental treatments (see Fig. 2 a, b, and c); for six sampling dates. Note scale of y-axis: maximum value = 10.

Results from our four large-scale planting experiments (1996 - 1997, 1997 – 1998, 1999 – 2000, and 2000 - 2001) indicate that several factors play a role in limiting or promoting seedling recruitment of oaks. First, abundant rainfall in late winter, as seen in the El Niño year 1998, can significantly enhance emergence and survivorship; the cohort established in that year remains the largest. In addition, very low rainfall results in low seedling emergence, as seen in the 1996 – 1997 cohort, and in increased seedling mortality as observed in this past dry year. Second, as observed in all four planting years, at all planting sites, and in both grazed and ungrazed plots, seed predation and herbivory by small mammals (most likely gophers and ground squirrels) significantly reduces oak seedling recruitment. While overall establishment rate of acorns planted at this time is 7%, plantings that were protected from small mammals is currently as high as 40%. Third, herbivory by insects such as grasshoppers may reduce seedling survivorship across all treatments in some years, as observed in 2000 - 2001.

II) Research to determine factors limiting natural regeneration of oaks

a) Understory vegetation monitoring. In April - May 2002, we monitored all permanent understory vegetation quadrats in our plots. Claudia Tyler and Dennis Odion conducted the surveys. These permanent sampling quadrats were established in May 1996 within our large experimental plots to characterize the understory vegetation, and to examine effects of cattle grazing on the herbaceous vegetation of oak savannas and woodlands. Within each plot, using a stratified random design, we located 10 rectangular quadrats (100 cm x 50 cm), the corners of which were marked with metal spikes to facilitate resampling over the 10-year study period. For each quadrat, we record all plant species present, their percent cover, and the location of the quadrat relative to oak tree canopy. Ten quadrats for each of 55 savanna and woodland plots were sampled, for a total of 550 quadrats. The data for this year have been entered and we have begun analysis of these and previous year's results. The list of species present in our plots this past May is given in the Appendix (Appendix 2). Species diversity was relatively low in all plots this year, most likely due to the below-average rainfall. One of our preliminary findings is that species associations differ among the areas where our plots are located, e.g., the northern mesa vs. the cleared airstrip. Another finding is that plots that have been fenced, since 1995, to exclude cattle grazing have become less diverse; many of these plots have become dominated by a few non-native grasses, primarily *Bromus diandrus,* or “rip-gut brome” (Fig. 8). These changes in herbaceous cover may be related to increased mortality of some cohorts of oak seedlings observed in ungrazed plots. We will be continuing our analysis of vegetation data and their relationship to oak seedling emergence and survival patterns over the next year.

b) Biomass sampling. In order to determine the productivity of the pastures, as well as to compare understory plant biomass among plots where we have planted oaks, we have collected samples of herbaceous vegetation from our large experimental plots. In 1999, Dr. Tyler conducted this sampling in two savanna sites. Within each of our large 50 x 50 m plots in Lisque Canyon (n = 14) and on the Mesa (n = 8), we established three permanent quadrats. The rectangular quadrats were 2m x 12.5 cm. All quadrats were in areas that were in open grassland, away from tree canopy.

Sampling quadrats were established in both grazed and ungrazed plots. For those in grazed plots, we clipped and collected all vegetation to ground level, a day before cattle entered the pastures. Since cattle grazed all pastures over three rotations during 1999, this sampling was conducted three times (early January, April, and May). The sum of these collections provide an estimate of the total herbaceous biomass produced in each plot. The dead vegetation collected prior to any grazing in early January provides an estimate of residual dry matter (RDM). For comparison, we also clipped and collected samples from ungrazed plots in May at the end of the growing season. This comparison provides information on the effect of rotational grazing on annual herbaceous productivity. All samples were stored in the laboratory where they were sorted (live grass, dead grass, live forb, dead forb), dried, and weighed. We completed our analyses this year and present our findings below.

In winter-spring 1999 annual production (total live biomass produced in one season) was significantly higher in ungrazed plots in both areas (Figure 9). This suggests that there is

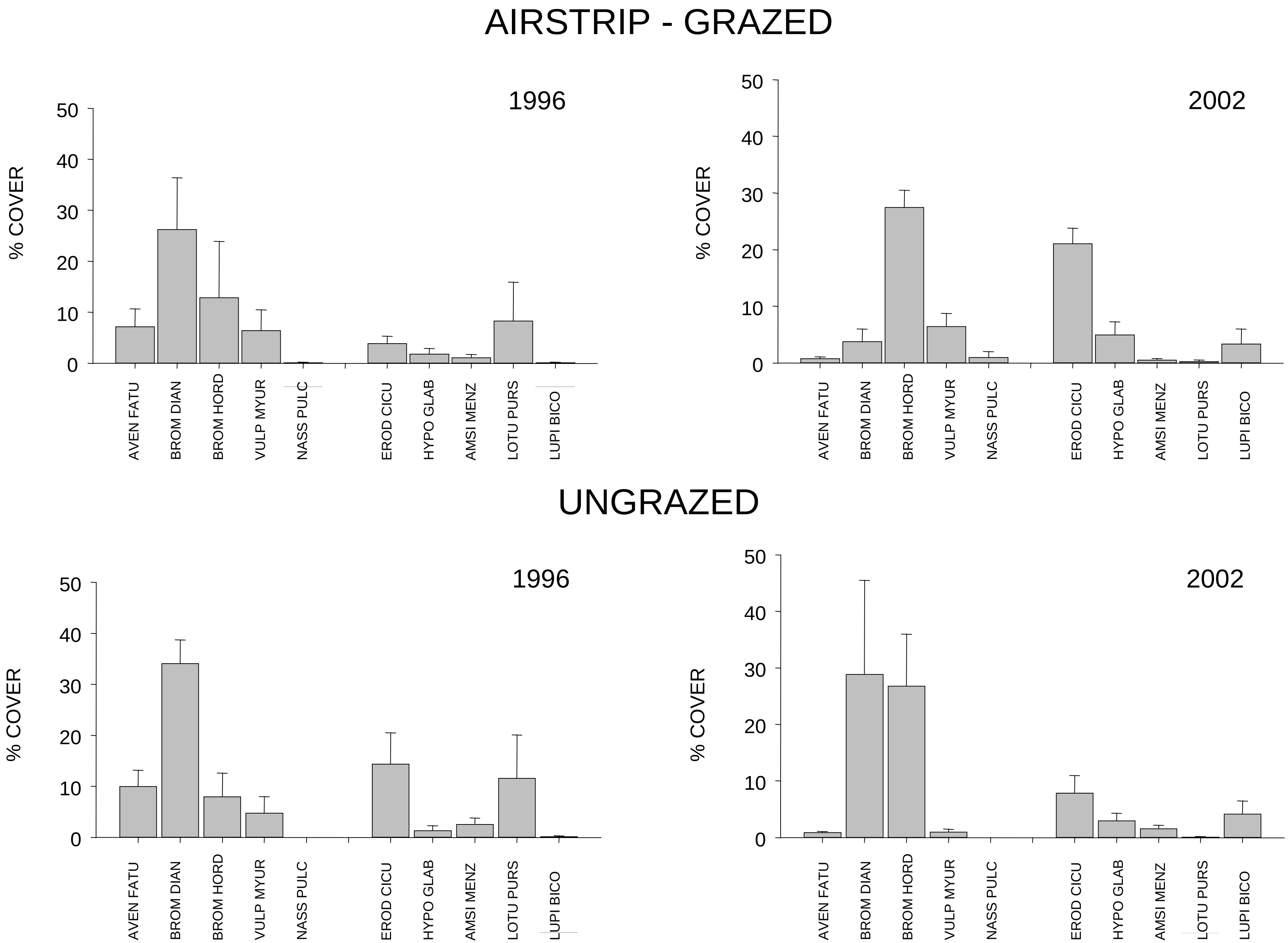

Figure 8. Percent cover of dominant herbaceous vegetation, by species (5 grass species on left and 5 forb species on right), in large plots grazed by cattle, vs. those fenced to exclude cattle. Data are means (+ 1 s.e.) for the plots on the “Airstrip” for two sampling dates (Spring 1996 and Spring 2002). Ten quadrats per plot were sampled and averaged to give cover for each plot (8 plots total).

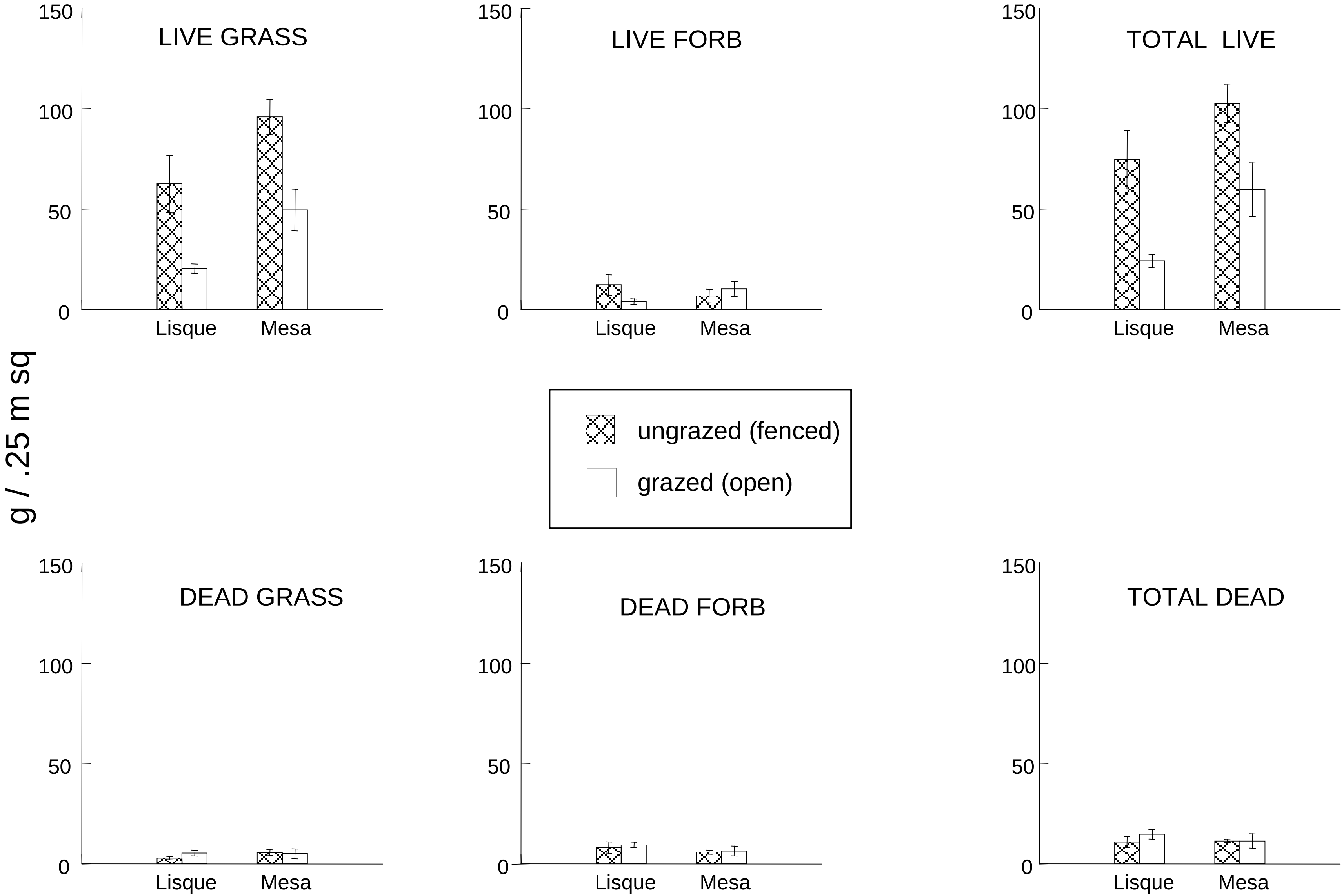

Figure 9. Biomass of herbaceous vegetation in grazed and ungrazed grassland. “Grazed” samples were collected prior to each cattle rotation, and thus represent total biomass produced in grazed pastures. Residual dry matter (RDM) was the total dead vegetation collected in grazed plots, prior to the onset of grazing. Data are means (+ 1 s.e.) for two savanna sites. Data were collected January through May 1999.

not compensatory growth in these herbaceous species, and that, not surprisingly, total production is reduced with grazing. Production varied between the two sites, and was significantly higher on the Mesa relative to Lisque. However, total annual production was relatively low in both these areas: from 96.4 to 238.4 g/m^2 in grazed pastures, and 298.4 to 409.6 g/m^2 in ungrazed areas. Mean residual dry matter (RDM) in grazed pastures was 55.6 g/m^2 in Lisque and 41.6 g/m^2 on the Mesa. These values represent RDM left at the end of the previous year's grazing in 1998.

We also examined the relationship between the maximum height of vegetation within a sampled quadrat and the biomass of the whole sample (Fig. 10). We found a significant correlation between these two variables. This is a useful finding, because we can easily measure maximum vegetation height when we conduct our extensive vegetation monitoring each spring, and we now know that this value is representative of plant biomass. This allows us to compare relative biomass among plots, areas and years.

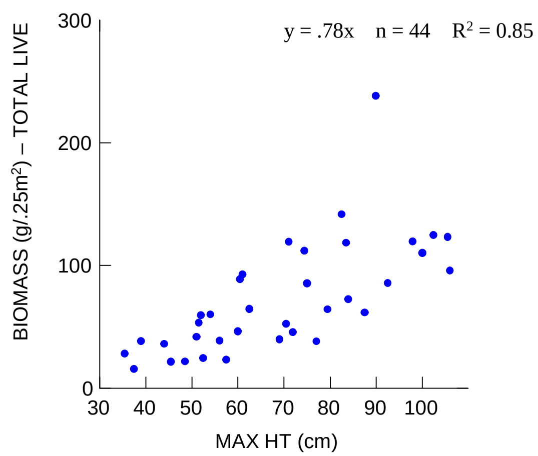

Figure 10. Correlation of maximum vegetation height and biomass. Data are from plant samples collected in open grassland in winter/spring 1999.

In 2000 and 2001 biomass samples were collected by Bart Cremers, the Cal Poly graduate student managing the cattle herd. At the end of each grazing season, he sampled four 1 ft^2 quadrats per plot, and clipped and collected all vegetation from these quadrats. In the laboratory all samples were dried and weighed. Data from 2000 are presented below. Results from 2001 are still forthcoming and will be discussed in a future report.

Total biomass in fenced plots provides an indication of the productivity of a given pasture or grassland in the absence of cattle grazing. Comparing values for biomass estimated in 1999 and 2000 (Table 6), we found that productivity varied among sites and years, but was between 250 – 450 g/m^2 for all savanna sites. Productivity in blue oak woodlands is lower, as has been previously described in the literature. Residual dry matter (RDM) provides an indication of grazing intensity. These values also varied among sites and years, but they indicate that a significant portion of herbaceous vegetation produced remains at the end of the season.

		TOTAL biomass (live + dd) (g/m^2)					
		1999			2000		
		mean	se	n	mean	se	n
Lisque	ungrazed	342.0	56.0	7	270.6	41.5	7
Mesa	ungrazed	455.2	33.6	4	264.8	34.6	4
Airstrip	ungrazed	-	-	-	258.6	59.3	4
Blue oak	ungrazed	-	-	-	121.3	15.6	11
		RDM (g/m^2)					
		1999			2000		
		mean	se	n	mean	se	n
Lisque	grazed	55.6	8.4	7	123.2	20.8	7
Mesa	grazed	41.6	11.2	4	78.5	16.0	4
Airstrip	grazed	-	-	-	139.5	15.4	4
Blue oak	grazed	-	-	-	69.3	6.5	10

Table 6. Biomass of total herbaceous vegetation produced in one growing season, and residual dry matter (RDM). RDM was measured as total biomass of dead grass & forbs prior to grazing in 1999 (early January), and total biomass of remaining herbaceous vegetation in grazed pastures at the end of the grazing season in 2000 (May-June). Two sites were sampled in 1999, and four in 2000.

Biomass samples for the grazing season 2001 - 2002 were collected by Adrian Cuzzick, a graduate student from Cal Poly San Luis Obispo. These samples are currently being processed (sorted, dried, and weighed), and results will be summarized in a future report.

III) Maintenance of cattle and site infrastructure

a) Maintenance of cattle herd for experimental grazing. Cal Poly San Luis Obispo, Animal Sciences Department, manages financial issues, shipping, care and maintenance of the cattle herd. This year the onsite manager of the cattle operation was Adrian Cuzzick, under the direction of Mike Hall, Beef Cattle Specialist in the Animal Science Department. They provided detailed grazing records for the cattle operation for the year 2001 – 2002 (Appendix 3). At Sedgwick Ranch, Cal Poly managed a total of 104 cattle (103 young heifers and 1 steer) (owned by a local 3rd party) grazed on a fee basis during the grass growing season (January - May 2002). The grazing season was shorter than usual because there was little grass/forage remaining by mid-May, due to the below-average rainfall this year. Total animal unit days were 9,200.

b) Maintenance and infrastructure improvement. With assistance from Cal Poly students, existing fences, exclosures, tanks, troughs, and water pipe were repaired and maintained. Riparian fences were also installed to ensure that cattle remain out of Figueroa Creek.

IV) Dissemination of information

a) Tours of project site. The field experiments and oak plantings of the Santa Barbara County Oak Restoration Program were seen by literally hundreds of individuals this year. We led tours for classes from Antioch College, City College Adult Education, UCSB Graduate Courses in Restoration Ecology, and the director and staff of the Santa Barbara County Energy Division. Through docent-led tours at Sedgwick Reserve, over 400 adults and 1300 school children from Santa Barbara County were shown our grazed and ungrazed plots, and told about the goals and present findings of this project.

b) Sedgwick Docent Training Workshop. As described above Sedgwick docents routinely include the oak restoration experiment in their tours for K-12 and adult groups. On November 2, 2001 Frank Davis held a 1-day training workshop for Sedgwick docents to better familiarize them with the goals and findings of the project, and to learn about oak ecology and restoration. The workshop, which was attended by 27 docents, included classroom training and a tour of the project. The slides used for the classroom portion of the training can be viewed online at http://www.biogeog.ucsb.edu/projects/oak/talks/oakintro_files/frame.htm.

c) Oral presentation and published paper in the Fifth Symposium on Oak Woodlands. In October 2001, Dr. Tyler presented a talk on the preliminary results of the Santa Barbara County Oak Restoration Program at the Fifth Symposium on Oak Woodlands held in San Diego, CA. Sponsored by the UC Integrated Hardwood Range Management Program, and the UC Division of Agriculture and Natural Resources, the symposium's theme was "Oaks in California's Changing Landscape", and was designed to provide a forum for current research and case studies on oak woodland conservation and sustainability in California. The conference was aimed at natural resource managers, researchers, policy makers, and public and private interest groups. Our written paper is included in the conference proceedings, and is attached (Appendix 4).

d) Maintenance of project web-site. We have a web-site to make information about the project goals and results available to those with access to the internet. We continue to develop this site, and associated resources. The web-site address is: http://www.biogeog.ucsb.edu/projects/oak/oak.html.

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Appendices

1. Photographs of established oak seedlings/saplings.

2. List of plant species found in experimental plots May 2002.

3. Detailed grazing records for the year 2001 – 2002.

4. Conference proceedings from the Fifth Symposium on Oak Woodlands, Oct 2001.

4-year old *Quercus lobata* sapling (L) protected from small mammals. In the cage-control (R) is a 5-year old *Q. lobata*.

4-year old *Quercus agrifolia* sapling protected from small mammals.

4-year old *Quercus lobata* seedlings protected from small mammals (L) and in a cage-control (R).

4-year old *Quercus lobata* seedlings growing in the open, in a grazed pasture.

Plant species found in experimental plots May 2002. Appendix 2.

forbs, sub-shrubs, tree seedlings

Achillea millefolium
Achyrachaena mollis
Agoseris heterophylla
Amsinckia menziesii
Anagallis arvensis
Artemisia californica
Astragalus gambelianus
Bowlesia incana
Brassica nigra
Calandrinia ciliata
Carduus pycnocephalus
Castilleja exserta
Centaurea melitensis
Cerastium glomeratum
Chlorogalum pom
Chlorogalum pomeridianum
Chorizanthe obovata
Clarkia cylindrica
Clarkia purpurea
Claytonia perfoliata
Collinsia heterophylla
Dichelostemma capitatum
Dodecatheon clevelandii
Epilobium brachycarpum
Eremocarpus setigerus
Erigeron foliosus
Eriogonum elonongatum
Erodium cicutarium
Erodium moschatum
Filago californica
Filago gallica
Galium aparine
Galium porrigens
Geranium dissectum
Gilia sp.
Hazardia squarrosa
Hirschfeldia incana
Hypochaeris glabra
Lactuca serriola
Lagophylla ramosissima
Lamarckia aurea
Lasthenia californica
Lepidium nitidum
Lessingia filaginifolia
Lomatium utriculatum
Lotus humistratus
Lotus purshianus
Lotus scoparius
Lotus strigosus
Lotus wrangelianus
Lupinus bicolor
Marrubium vulgare
Medicago polymorpha
Micropus californicus
Navarretia jaredii
Phacelia imbricata
Phlox gracilis
Pholistoma auritum
Plagiobothrys nothofulvus
Plantago erecta
Polygonum arenastrum
Pterostegia drymarioides
Quercus agrifolia
Quercus douglasii
Quercus lobata
Ranunculus californicus
Rigiopappus leptocladus
Sanicula arguta
Sanicula bipinnata
Silene gallica
Sisymbrium officinale
Sisyrinchium bellum
Sonchus oleraceus
Stellaria media
Stephanomeria exigua
Thysanocarpus laciniatus
Torilus arvensis
Torilus nodosa
Toxicodendron diversilobum
Trichostema lanatum
Trifolium albopurpureum
Trifolium ciliolatum
Trifolium gracilentum
Trifolium microcephalum
Trifolium willdenovii
Uropappus lindleyi
Urtica urens
Viola pedunculata
Yabea microcarpa

grasses

Avena barbata
Avena fatua
Bromus carinatus
Bromus diandrus
Bromus hordeaceus
Bromus madritensis madritensis
Bromus madritensis rubens
Bromus tectorum
Elymus glaucus
Gastridium ventricosum
Hordeum murinum
Koeleria macrantha
Lolium multiflorum
Lolium temulentum
Melica imperfecta
Nassella cernua
Nassella lepida
Nassella pulchra
Poa secunda
Vulpia microstachys
Vulpia myuros

Grazing records for Sedgwick Reserve 2002. Appendix 3.

dates cattle in	# of cows	# of bulls	dates cattle out	reason	# of cows	# of bulls
1/14/2002	40		2/25/2002	shipped		1
1/15/2002	40		4/16/2002	shipped	101	
1/19/2002	23	1	4/23/2002	shipped	2	
TOTALS	**103**	**1**	**TOTALS**		**103**	**1**
						= 104

date in	date out	pasture name	days of use	# of head	stock head days
1/14/02 16:00	1/21/02 17:00	South Heirs	7.04	40	281.67
1/15/02 17:00	1/21/02 17:00	South Heirs	6.00	40	240.00
1/19/02 14:00	1/21/02 17:00	South Heirs	2.13	24	51.00
1/21/02 17:00	2/18/02 12:00	North/South Heirs & Farming Field	27.79	104	2890.33
2/18/02 12:00	2/21/02 11:00	Reserve North	2.96	102	301.75
2/21/02 11:00	2/26/02 11:00	Reserve South/Passage	5.00	102	510.00
2/26/2002 11:00	2/27/2002 18:00	Dead Canyon	1.29	101	130.46
2/27/2002 18:00	3/4/2002	Dead Canyon	4.75	4	19.00
3/4/2002	3/16/2002	Reserve South/North/Passage	12.00	4	48.00
2/27/2002 18:00	3/1/2002 14:30	Airstrip	1.85	97	179.85
3/1/2002 14:30	3/2/2002 10:00	Overlook	0.81	97	78.81
3/2/2002 10:00	3/2/2002 12:30	Hillside	0.10	97	10.10
3/2/2002 12:30	3/4/2002 11:00	Lower Lisque	1.94	97	187.94
3/4/2002 11:00	3/5/2002 9:00	Vernal Pools	0.92	97	88.92
3/5/2002 9:00	3/6/2002	StockPond	1.00	97	97.00
3/6/2002	3/8/2002 9:00	Woodstock	2.00	97	194.00
3/8/2002 9:00	3/9/02 18:00	Middle Lisque	1.38	97	133.38
3/9/02 18:00	3/10/02 8:00	Triangle	0.58	97	56.58
3/10/02 8:00	3/11/02 11:00	Upper Lisque/Grove	1.13	97	109.13
3/11/02 11:00	3/12/02 11:00	Jackass	1.00	97	97.00
3/12/02 11:00	3/13/02 11:00	Picnic/On Ramp	1.00	97	97.00
3/13/02 11:00	3/14/02 13:00	Bottleneck	1.08	97	105.08
3/14/02 13:00	3/15/02 9:00	Quinn Flatt	0.83	97	80.83
3/15/02 9:00	3/16/02 17:00	Stock Tank/KuKu Springs	1.33	97	129.33
3/16/02 17:00	3/19/02 12:00	North Heirs	2.79	100	279.17
3/19/02 12:00	3/26/02 15:00	North Heirs/Farming Field	7.13	100	712.50
3/26/02 15:00	4/16/02 8:00	South Heirs	20.71	101	2091.54
					9200.38

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

Claudia M. Tyler,[2] Bruce E. Mahall,[3] Frank W. Davis,[4] and Michael Hall[5]

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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[1] An abbreviated version of this paper was presented at the Fifth Symposium on Oak Woodlands: Oaks in California's Changing Landscape, October 22-25, 2001, San Diego, California.

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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.

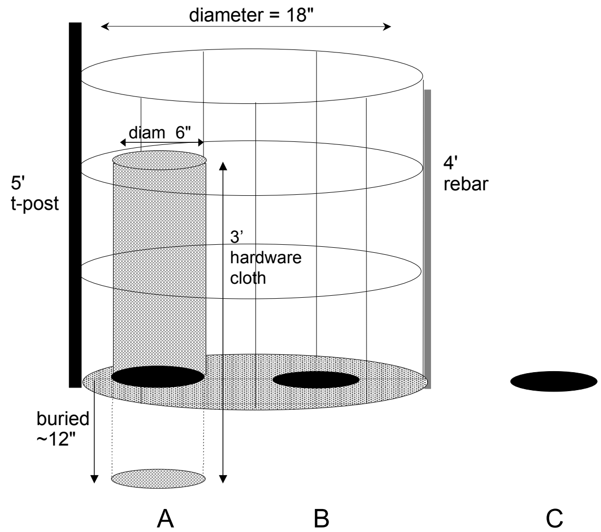

Figure 1—Treatments used for acorn plantings. A: caged and fenced to prevent grazing and herbivory by both large and small mammals (this treatment is referred to as "no rodents"). B: fenced to prevent grazing by large animals. C: open. These treatments are replicated in both 1) plots that are grazed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

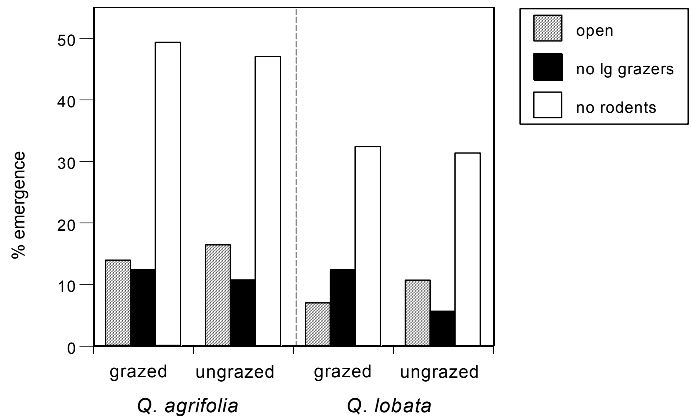

Figure 2—Total percent emergence of seedlings planted in 2000-2001 with various levels of protection from herbivores. Data are from May/June 2001.

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.

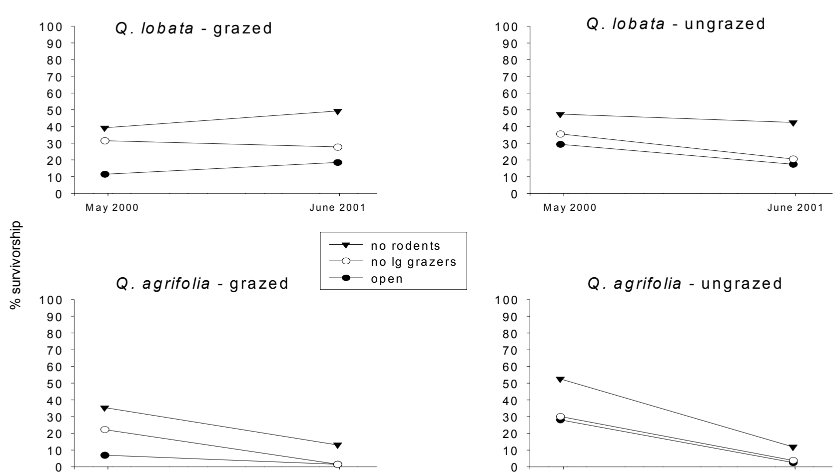

Figure 3—Percent survivorship of 1-yr-old seedlings (planted in 1999-2000) in large plots grazed by cattle, vs. those fenced to exclude cattle. Data are totals for three experimental treatments *(fig. 1)* for two sampling dates

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.

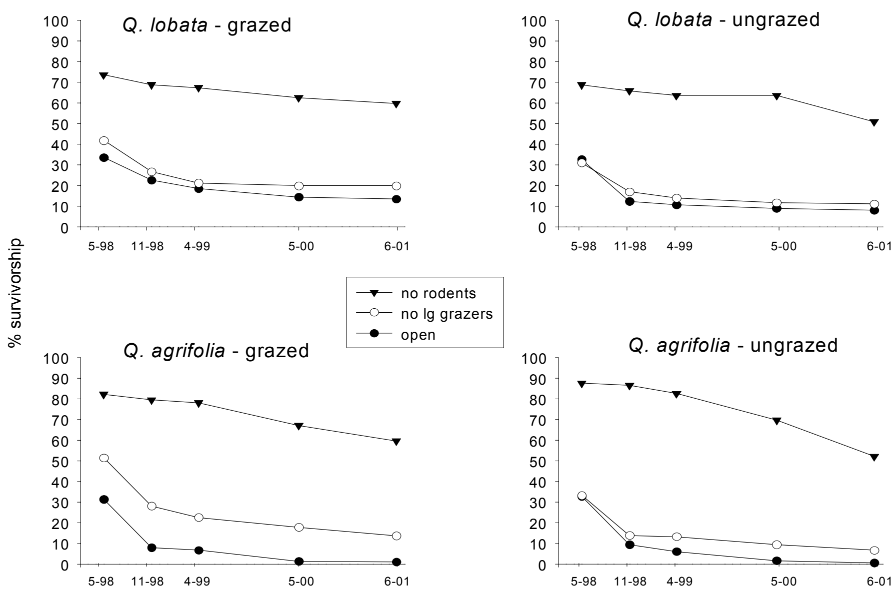

Figure 4—Percent survivorship of 3-yr-old seedlings (planted in 1997-98) in large plots grazed by cattle, vs. those fenced to exclude cattle. Data are totals for three experimental treatments *(fig. 1)* for five sampling dates.

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).

Acknowledgments

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