DEVELOPMENT OF THE SANTA ROSA VERNAL RESERVE SYSTEM.

V. RESPONSES OF VERNAL POOL PLANT POPULATIONS TO MOWING AND PHYTOMASS REMOVAL

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ABSTRACT

The first goal of the Santa Rosa Vernal Reserve System (SRVRS, Sonoma County, California) is to develop management prescriptions for improving the habitat quality of native plant populations, especially those of conservation interest (Pavlik et al. 1998, 2000, 2001, 2003). This report describes fourth year responses of vernal pool characteristic plants (VPC's) of the Santa Rosa Plain to experimental management, and includes the following components: 1) the use of mowing and phytomass removal as ecologically sound and practical manipulations for shifting plant cover from exotic to native (for dominant species) and from sparse to abundant (for rare species), 2) the responses of VPC cover to mowing and removal in spring 2003 and 3) a demographic modeling experiment to determine impact of seed bank on VPC responses to treatment. In section 1 of the report a patch-intercept sampling method was designed and performed to detect responses of the VPC taxa during May 2003. No treatment effects were detected at that time, indicating that cover by patches of VPC taxa did not become more extensive because of fourth year mowing or mowing with phytomass removal. We concluded that low seasonal precipitation, combined with only four years of treatment, contributed to the lack of significant response of VPC taxa. In section 2 of the report we used a demographic method to test for treatment effects on the performance of artificial populations of *Limnanthes vinculans*. We concluded that lack of seed bank, pool hydrology, and herbivory by non-native slugs all have a large impact on the response of *L. vinculans* to restoration treatments.

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SECTION 1:

DEVELOPMENT OF THE SANTA ROSA VERNAL RESERVE SYSTEM.
V. RESPONSES OF VERNAL POOL PLANT POPULATIONS TO MOWING AND PHYTOMASS REMOVAL

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INTRODUCTION

The first goal of the Santa Rosa Vernal Reserve System (SRVRS) is to develop management prescriptions for improving habitat quality for native plant populations, especially those of conservation interest. Since 1999, we have tested the hypothesis that seasonal mowing with phytomass removal reduces annual grass cover and thus improves habitat quality for native plants, especially those of conservation interest (Pavlik et al. 1998, 2000, 2001, 2003). This report describes fourth year responses of vernal pool characteristic plant taxa (VPC's) to mowing with phytomass removal (raking) (Mr) and mowing without phytomass removal (mulching) (Mm) within 45 permanent plots. These plots are on vernal pool margins and evenly spread over three properties within the SRVRS (For more information on plot design see Pavlik et al. 2003).

To determine the impact of Mr and Mm on VPC taxa we used "patch-intercept" sampling method to determine treatment effects on the mean cover of *Limnanthes vinculans, Blennosperma bakeri, Pogogyne douglasii ssp. parvifolia, Downingia concolor,* and *Lasthenia glabberima.* However, only *Limnanthes vinculans* and *Lasthenia glabberima* were intercepted enough times by the sampling method to provide sufficient data for analysis.

METHODS AND MATERIALS

Primary Restoration Experiment: Data Collection of Fourth Year Responses of Vernal Pool Characteristic Plants to Mowing and Phytomass Removal

We designed and performed patch-intercept sampling for detecting responses of vernal pool characteristic (VPC) taxa May 21, 22, and 28, 2003 when VPC plants were in full flower, transitioning to fruit production The sampling method and data analysis were designed for taxa that occurred in a few, isolated, discrete, often elongate patches (0.5-1 m wide and > 2 m long) along the margins of vernal pools and swales. The density of plants within patches is uniform from patch interior to edge, and high enough that individual plants cannot be easily distinguished from one another. Taking these special population characteristics into account allowed the development of an efficient field sampling method based upon cover interceptions with a sample rod.

Field Sampling

The sampling unit (rod) was a rigid piece of half inch PVC pipe, 4.0 m long, with 10 cm graduations marked along one side. The rod was randomly placed within the 30 m long plots perpendicular to the margin plot's edge. The team divided the margin plot edge into 10 strata 3 m long each. At a random position within each stratum, the summed length of a vernal pool characteristic (VPC) cover intercepted by the rod was measured. A random numbers table was used to generate the random position within each stratum. Stratification ensures the rod would be laid randomly, but throughout each plot. At each sample location, the rod was placed perpendicular to the margin plot's edge and aimed at the pool or swale center (defined as where water depth would be greatest). A 0.5 m buffer on the upper and lower edges of the margin plot area was used, so the entire 4 m rod spanned the treatment area.

Each team of field assistants had a pole, meter stick, datasheet and block maps. The meter stick was used to measure the total length (cm) of each VPC's patch ("cover") as intercepted by the rod. For purposes of uniformity between teams, the following definitions were adopted: A patch was defined as two or more VPC plants within 10 cm of each other. A gap between patches was defined as a section of the linear dimension greater or equal to 10 cm that contains no VPC plants. The linear dimension of patches of each VPC were recorded separately and not lumped. A team completed all strata in a plot before moving on to another treatment plot in the same block.

Data Analysis

Generalized estimating equations (GEE, Liang and Zeger 1986) were used to fit the regression model. The statistician assumed a log-linear model and that data were approximately distributed according to a gamma distribution. Control served as the reference site.

RESULTS

Primary Restoration Experiment: Fourth Year Responses of Vernal Pool Characteristic Plants to Mowing and Phytomass Removal

When examining mean cover for *Limnanthes vinculans*, treatment effects varied greatly between sites. Cramer showed no significant differences due to treatment. Mean cover at Cramer was 17.9 ± 6.3 for control, 16.7 ± 4.2 for Mm and 19.5 ± 3.4 for Mr. At FEMA mean cover in control, Mm and Mr were 0.7 ± 0.7, 5.4 ± 4.4 and 4.2 ± 3.1 respectively. At Haroutunian no changes between treatments were found. Cover in control, Mm and Mr were 0, 0.1 ± 0.1, and 0 respectively (Table 1).

In the case of *Lasthenia glabberima*, treatment effects are present. The model estimates that average cover of *L. glabberima* differed by 3.2% between Mm and control (p=0.2929) and by 7.6% between Mr and control (p=0.219) when adding cover at all properties together. At Cramer mean cover in control, Mm and Mr were 8.7 ± 3.2, 7.1 ± 2.2 and 14.1 ± 4.0 respectively. At FEMA, mean cover in control, Mm and Mr were 5.2 ± 4.5, 11.6 ± 7.4 and 30.1 ± 7.9 respectively. At Haroutunian, mean cover for control, Mm and Mr were 7.3 ± 5.3, 13.9 ± 9.1 and 8.0 ± 6.2 respectively.

DISCUSSION

Judging the effects of treatment on vernal pool characteristic (VPC) plants is difficult due to initial, site-specific factors that continue to influence into the fourth year of our experiment. This is especially true for *Limnanthes vinculans*. For example, *L. vinculans*, which had no detectable seed band in some pools, had been virtually extirpated from Haroutunian prior to treatment, making it is impossible for any demographic response to occur. The widespread and abundant *Lasthenia glabberima*, however, demonstrated some presence and response at all sites.

Conversely, at Cramer and FEMA there were relatively large *L. vinculans* seed banks prior to treatment. At FEMA, significant changed based on treatment are present. The control plot cover was much lower than Mr and Mm. These results suggest that mowing, regardless of whether or not phytomass was removed, benefits *L.vinculans.* At Cramer, there was a small difference between *L.vinculans* cover in each treatment plot. However, the small differences between treatments are statistically insignificant due to large standard errors greater than differences in mean cover between treatments. Despite the fact that there were no statistically significant changes in *L. vinculans* cover due to treatment, we can conclude that treatment did not negatively impact *L.vinculans* at Cramer.

At Cramer, Mr cover was much higher than both Mm and control, suggesting that phytomass removal plays a key roll in increasing *L. glabberima* cover. Results at FEMA also suggest that phytomass removal is key. Mr cover was 3 times that of Mm and 6 times greater than control. At Haroutunian cover in Mm plot was greatest, while control and Mr were nearly equal. However, these differences were no statistically significant due to large standard errors.

It is clear that site-specific differences, most importantly VPC seed bank size, play a roll in responses to treatment. It is important to choose pools with a large seed bank to determine if treatments are having an impact. At sites with a healthy seed bank Mr and Mm did not negatively impact mean cover of *L.vinculans* or *L. glabberima* and in some cases seemed to positively impact mean cover. Perhaps one of the clearest messages from these data is the importance of site choice.

SECTION 2:

Effects of Altered Hydrology and Slug Herbivory on the Restoration of a Rare Vernal Pool Plant (*Limnanthes vinculans*)

Bruce M. Pavlik, Cassie Pinnell and Sarah Vroom

INTRODUCTION

Vernal pools are among the most biologically rich and eminently threatened ecosystems in western North America. Plant and animal endemism are high and between 60 and 95% of the original 4 million acres of vernal pool habitat in California have been lost to agriculture, housing and other forms of development (Holland 1986). The remaining pools vary greatly in their species composition and vegetation characteristics – some are still dominated by natives while most have been degraded to various degrees by non-native plants, landscape fragmentation, and alteration of their physical environment. Consequently, habitat destruction combined with habitat degradation have put these ecosystems and many of their component species at risk.

Preserving vernal pools in parks, open space, and mitigation banks is only the first step in their conservation. The second step is the adoption of an adaptive management program that will provide scientifically based prescriptions for maintaining endemic and characteristic populations of plants and animals. The third step is to implement and monitor those prescriptions over long periods of time, adjusting for stochastic variations and improving the overall ability to manage a unique ecosystem. Although the first step is often constrained by lack of money and political will, the second step is constrained by general lack of management know-how and the third step rarely happens for lack of an institutional "home" for restoration activities (Pavlik et al. 2003). Most often, vernal pools that end up preserved by a change in land use are "left alone" and essentially unmanaged. Public agencies that own the land usually lack expertise and a long-term vision that includes active, science-based prescriptions for preserving the biological diversity of the pools.

Mowing has been shown to favor native perennial grasses over exotic annuals in California (Danielsen 1996). Hence, we have chosen to investigate the use of mowing and phytomass removal as ecologically sound and practical manipulations for shifting plant cover from exotic to native (for dominant species) and from sparse to abundant (for rare species). Those investigations (Pavlik et al. 2002, 2003, 2004, 2005) have demonstrated that the vernal pool-coastal prairie complex responds to mowing with phytomass removal by reducing the cover of some exotic grasses (e.g. *Lolium multiflorum*) and increasing the cover of some native vernal pool characteristic forbs (e.g. *Lasthenia glabberima*). However, native species whose seed bank had been extirpated prior to treatment could obviously not respond at some properties (e.g. *Limnanthes vinculans* at Haroutunian).

To overcome the limitation imposed on our experiment by initial conditions (i.e. lack of a seed bank), we reintroduced an exact number of seeds to treated plots in two pool-swale systems on one property, Haroutunian. These systems had no recent (since 1999) record of *Limnanthes vinculans* occurrence (Pavlik et al. 2000, Table 6), so we could be certain that plants in our plots came from the reintroduced seed bank. Our initial goal, therefore, was to measure the demographic responsed of these reintroduced populations to control, mowing with phytomass removal (raking) (Mr) and mowing without phytomass removal (mulching) (Mm) in two swale-pool systems, one with intact and one with altered hydrological characteristics. However, a new, previously undocumented variable soon began to challenge our experiment- intense predation on *L. vinculans* seedlings by a non-native slug, *Deroceras reticulatum.* This report documents the effects of that predation on reintroduced populations *of L. vinculans* in two kinds of swales (intact and altered hydrology), with a somewhat diminished secondary goal of evaluation our habitat treatment effects.

METHODS AND MATERIALS

Acquisition of the Founding Propagules

All of the propagules of *Limnanthes vinculans* were derived from collections made by Sarah Vroom and Cassie Pinnell (Mills College) at two sites of the Santa Rosa Vernal Reserve System (SRVRS). The 2475 nutlets used in the germination and reintroduction experiments were collected from FEMA and Cramer properties in June 2003. The nutlets were taken from many different individuals at five pools per property. The nutlets were stored in paper bags at room temperature.

Germination Trials

Three petri dishes were lined with moist filter paper, and 25 nutlets were placed in each dish. Each dish was wrapped in aluminum foil and placed in a box at room temperature. The nutlets were kept moist and 13 days later, once the cotyledons had emerged in all 3 dishes, the sprouts were transferred to soil. 77% percent of the seeds sprouted cotyledons, so a total of 58 sprouts were planted in potting soil, with 3 to 4 per pot. One half of the pots were placed in a flooded tray, and the other half were placed in a dry tray. The pots were kept in a green house and under sprinklers.

The plants in the flooded tray on average were larger than those in the dry tray. About 95% of the plants survived to develop multiple leaves and eventually flowers. However, most of the plants were small and much less reproductive than the ones observed in the field. When the watering rate was reduced, the plants dried out and died. From this germination experiment we concluded that the nutlets collected from FEMA and Cramer were viable and required no special preparation for planting.

Plot Design and Treatments

Two pools at Haroutunian were chosen for the reintroduction experiment. These sites were chosen for two reasons. Primarily, we had failed to observe any *Limnanthes vinculans*. Secondly, the pools had different hydrological histories. Pool 3 had a history of altered hydrology. It had been trenched and connected to irrigation systems on adjacent properties, and therefore filled and drained quickly with sporadic inundation patterns. Alternatively, Pool 4 was more hydrologically stable. It filled gradually, remained at more constant levels, and drained slowly. Each pool contained three treatment sections: Control (Co), mowing with phytomass removal (raking) (Mr), and mowing without phytomass removal (mulching) (Mm). Within each of these treatment sections, four replicates were created. The locations of these replicates were chosen and flagged five months earlier to further ensure the lack of wild *L.vinculans*.

Sowing the Nutlets

Four 30 cm x 120 cm experimental replicates were created within each treatment plot. These replicates were permanently marked with three stainless steel rods driven into the soil so that 10 cm protruded above the surface. The rods positioned a removable wooden frame, 30 cm x 120 cm, into which a grid of 100 holes (5 holes x 20 holes) had been drilled. The holes allowed exact placement of the nutlets within the plot and subsequent monitoring of seedlings and juvenile plants. A total of 2400 nutlets of *Limnanthes vinculans*, 1200 from FEMA and 1200 from Cramer, were sown on November 22, 23 and 24, 2003. The nutlets were of varying quality and size.

Using the wooden frames, each treatment plot was sown with 400 nutlets, with a total of 1200 per pool. The FEMA and Cramer nutlets were sown in alternating rows to account for any difference in quality between the two sources. The nutlets were pressed into shallow depressions in the mineral soil made with the tip of a finger, covered with about 20 cc of loose, native soil, and tamped down uniformly. No supplements of water or nutrients were applied during the experiment.

Demographic Monitoring of the New Population

Demographic monitoring of all plots was conducted to identify those factors that could limit the establishment or growth of the new population. The monitored parameters included *in situ* germination, stress factors (desiccation, grazing), mortality, phenology, and reproductive survivorship. Monitoring was facilitated by the repeated use of planting frames to locate and identify individuals. After all the nutlets were sown (day 0) in late November 2003, plots were censured with the frames every two weeks until the last census on May 11, 2004 (day 169). During the first census, each plant was marked with a slender wooden stake (20cm potsticker).

RESULTS

Germination

The first large rainstorm (>2.5 cm) was November 8th, 2 weeks prior to planting *Limnanthes vinculans* seeds (day 0). Rainstorms depositing >2.5 cm continued until January 1, 2004. By mid December the pools were inundated. Towards early January the pools reached their peak water level (Pool 3: 10 cm ± 1.52, Pool 4: 12.7 cm ± 1.77). A second set of rainstorms >2.5 cm occurred during the month of February. During this time the pools began shrinking. The rainstorms then ceased and any following precipitation was minor (<1 cm). By late March the pools were dry. (Figures 1 & 2).

Standing water that inundated plots in Pool 3 and Pool 4 differed in depth, extent of coverage and duration. Mean maximum water depth per plot and extent of water coverage (% inundated per plot) was greater in Pool 3 than Pool 4 on day 27. Pool 4 had a greater maximum water depth and extent of coverage per plot until the pools dried. (Figures 2 & 3).

Within each pool there were differences in the extent of water coverage and the maximum water depth. In Pool 3, maximum water depth was greater in Co and Mm than Mr. The extent of water coverage in Pool 3 followed the same pattern with Co highest (96%), Mm second (76%) and Mr lowest (28%). Mr was never 100% inundated, while Co and Mm were. Hydrological differences in Pool 4 were not as severe. In Pool 4, maximum water depth and % inundated for all treatments were almost equal overall. (Figures 2 & 3).

Most germination occurred during the first 3 weeks of the experiment, and the entire germination period lasted only 8 weeks. *L. vinculans* germinules were first observed on day 13 (early December), before either pool had standing water. However, prior storms had moistened the soil. Peak germination was reached once the pools were inundated (late December), although the dry replicates peaked at the same time. (Figure 4). Germination does not appear to rely on water level or inundation.

Total *in situ* germination was significantly greater in Pool 4 compared to Pool 3 (53.7% vs. 36.7% T TEST). (Figure 5). In Pool 4, germination rates did not significantly differ with inundation, however, in Pool 3, germination increased significantly.

The impacts of Mm and Mr treatments on germination were relatively small. Mm consistently improved germination, relative to control, by 10%. Mr had no effect in Pool 3, but improved germination by 10% in Pool 4. (Figure 6).

Survivorship

The first missing/dead seedlings were not detected until 25 days after sowing (mid December) in both pools. Missing/dead seedlings were frequent after day 41 (early January, 2004) and later. Most (80+%) missing/dead seedlings were recorded between days 41-83 and nearly all (85-90%) by day 98 (mid March). The number of seedlings reported missing/dead dropped significantly after that. (Figures 7 & 8).

Seedling survivorship varied greatly between pools. Pool 3 survivorship (mean of 40% ± 20) was less than half that of pool 4 (mean 94% ± 1). (Figure 9).

Treatments had different impacts on each pool. In Pool 3 treatments did not increase survivorship. Mean survivorship in mow rake plots (Mr) was less than 5% that of mow mulch plots (Mm) and control plots (Co). Mm had slightly higher survivorship than Co, but the difference was not statistically significant. Pool 4 showed very different trends. Survivorship for all treatments was greater than 90%. Survivorship for Mm and Mr were almost equal, but Co was greater than both. (Figure 9).

The causes of mortality/disappearance were not always clear. Symptoms of water stress (wilting of leaves) and chlorosis were observed occasionally beginning mid February. However, instances of grazing (bite marks on cotyledons, stems and leaves) and predation (removal of tissue to apex of shoot) were frequent. Plants showing damage (grazing/predation) were observed less than 2 weeks after sowing (early December) and continued into March. (Figure 8). An invasive slug, *Deroceras reticulatum*, was observed eating plants in all experimental plots, especially between days 27-83 (mid December-mid February).

Slug activity (measured by the number of plants showing damage) was observed at both pools, but Pool 3 plots showed far more slug damage. During peak slug activity, the number of damaged plants in Pool 3 plots was 6-40 times the number of damaged plants in Pool 4 plots. (Figure 10).

The number of damaged plants varied greatly with treatments in Pool 3. Mr had the greatest damage during days 27-56. After day 56, Mm and Co had more than Mr due to the fact that most Mr plants were dead or missing. In Pool 4, all plots averaged less than 1 damaged plant per plot (Mm had the greatest, while Mr had the lowest). (Figure 10). In general, plots with high slug activity had lower survivorship than plots with low slug activity. (Figure 11).

Reproduction

In early April (day 138) we found early signs of reproduction, with both pools having many buds and few open flowers. Peak flowering occurred in mid April. By early May (day 168), most flowers had senesced and the nutlets were enlarged and hardened. The timing of reproduction was similar between pools, which remained dry for most of the period.

The average reproductive output of the hydrologically altered Pool 3 (121.1 ± 59.6 nutlets) was significantly lower than the hydrologically stable Pool 4 (366.7 ± 37.8 nutlets). (Figure 12).

In Pool 3, there was not a significant difference in reproductive output between Co and Mm. Both were significantly higher than Mr. However, in Pool 4, there was a significant trend of increasing reproductivity from Co to Mm to Mr. (Figure 13). (Need ANOVA).

DISCUSSION

The differences in hydrology between Pools 3 and 4 mediated three impacts on the reintroduction of *Limnanthes vinculans*. Primarily, plots with altered hydrology showed lower levels of *in situ* germination. Secondly, altered hydrology and low water levels corresponded with high levels of slug predation and low rates of survivorship.

Thirdly, altered hydrology indirectly mediated lower levels of reproduction. In addition, treatment effects of biomass removal were made less clear by differences in hydrology. Therefore, these trials suggest that the restoration of rare vernal pool plants, specifically *L. vinculans*, first requires intact hydrology and secondly necessitates measures to address the effects of slug herbivory.

Germination

Though inundation is not required for germination, the hydrology of the Pool and it's potential to retain moisture appears to impact germination rates. Initial germination rates were much higher in Pool 4 than in Pool 3. At this time, neither pool was inundated, though storms in the previous month may have moistened the soil. It is possible that Pool 4 may have retained more moisture from these storms than Pool 3, and therefore, Pool 4's high initial germination may be due to the intact hydrology or soil qualities of the Pool. Throughout the course of germination, the hydrology of Pool 4 was more constant than Pool 3. It filled slowly, retained a consistent water level, and drained slowly. The germination rates of Pool 4 were also more constant. However, Pool 3 had an initial low rate of germination prior to inundation. The Pool then filled quickly, had a significant increase in germination, and drained quickly. Overall, Pool 4 had a higher germination rate than Pool 3. These results suggest that intact hydrology may contribute to a higher and more sustained germination rate.

Treatment effects were impacted by factors such as slug predation and hydrology. In Pool 3, no significant germination trend was observed between treatments. The low water levels and high slug predation in the Mr plots, which had the lowest germination, may have overridden treatment effects. In Pool 3, Mm plots had the highest level of germination, averaging 10% higher than the Co plots. The high germination rate of Mm plots was also observed in Pool 4, where both Mm and Mr had 10% higher germination rates than Co. These results suggest that Pools with an intact hydrology may have increased germination rates with treatment.

Survivorship

During the period of maximum growth (vegetative interval, days 27-138) we observed a strong correlation between survivorship and slug activity. Pool 3 had low, variable survivorship (mean = 40% + 20% SE) and high slug damage (mean = 3.5 ± 1 SE) while Pool 4 had high survivorship (mean = 94% ± 1% SE) and low slug damage (mean = .3 ± .1 SE).

Differences in pool hydrology affected the impacts of slug herbivory on survivorship. Slug herbivory was retarded by intact pool hydrology. Pool 4 had a greater water cover and stayed wet longer than Pool 3, thereby denying slugs "easy access" to plants.

Differences in hydrology and survivorship were dramatic when comparing individual treatment plots. Plots that were least inundated during the vegetative interval had the lowest survivorship and greatest slug damage. Conversely, plots that were the most inundated had the greatest survivorship and lowest slug damage. Slugs are believed to tbe the dominant seedling predators in many forest communities (Nystrand & Granstrom, 1997; South 1992). Overall, seedlings tend to be more palatable to *Deroceras reticulatum,* the slug we observed grazing at the sites (Fenner et.al 1999).

This would explain why mature plants present in dry pools later in the season were not drastically impacted by slug herbivory. Additionally, mature plants can sustain higher levels of grazing than seedlings "A mollusk can kill a whole seedling with the removal of one bite of the hypocotyls while a similar bite to a mature leaf would have a negligible effect on the survival of the plant" (Fenner et al 1999). Therefore, plants that are inundated as seedlings seem more likely to avoid potentially lethal slug predation, even if the pool dries when the plant is mature.

D. reticulatum is dependant on moist soils (Shirley et al 2001). *Limnanthes. vinculans* germinated soon after the first rains. Therefore, it is likely that this VPC is especially vulnerable to slug predation, being in it's seedling stage while the slugs are 'rehydrated' exhibiting 'unconstrained behaviours' including foraging (Shirley et al 2001).

Treatments did not appear to impact survivorship to reproduction. In Pool 3, neither Mm nor Mr had statistically greater survivorship than Co (though Mm survivorship was greatest). In Pool 4, survivorship did not vary greatly between plots (mean of all plots > 90%).

Reproduction

Reproduction rates were largely determined by survivorship. Mean reproductive output of Pool 3 (121.1 ± 59.6 nutlets per plot) was significantly lower than that of Pool 4 (366.7 ± 37.8 nutlets per plot). High levels of slug predation in Pool 3 Mr plots reduced the reproductive population to two plants, and reproductive output to only 16 nutlets (4 ± 2.4 nutlets per plot). However, even when Mr plots are factored out, the average of Co and Mm plots are still lower in Pool 3 than in Pool 4. Reproductive output appears to be effected by hydrology. Plots with intact hydrology produced a significantly higher amount of nutlets than plots with altered hydrology.

In Pool 3, treatment effects on reproduction were not evident. However, in Pool 4, there was a trend of increasing reproduction with treatment. The effect of treatments on reproduction were suggested in Pool 4, but were obscured by low survivorship in Pool 3. In Pool 4, with intact hydrology and high survivorship rates, the reproductive output of Mr plots are significantly higher than Mm plots, which are significantly higher than Co plots **(Need ANOVA).** However, in Pool 3, with altered hydrology, the highest output was in the Co plots, and the lowest was in the Mr plots. Therefore, it is suggested that treatment effects on reproduction are indirectly mediated by hydrology, and the resulting protection against slug predation.

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Table 1:

Table 1. Effects of mow-mulch (Mm) and mow-rake (Mr) treatments on two vernal pool characteristic plants at three sites, spring 2003. Cover values (%) shown with 1 SE.

Limnanthes vinculans

	Control	**Mm**	**Mr**
Cramer	17.9 ± 6.3	16.7 ± 4.2	19.5 ± 3.4
FEMA	0.7 ± 0.7	5.4 ± 4.4	4.2 ± 3.1
Hartounian	0	0.1 ± 0.1	0

Lasthenia glabberima

	Control	**Mm**	**Mr**
Cramer	8.7 ± 3.2	7.1 ± 2.2	14.1 ± 4.0
FEMA	5.2 ± 4.5	11.6 ± 7.4	30.1 ± 7.9
Hartounian	7.3 ± 5.3	13.9 ± 9.1	8.0 ± 6.2

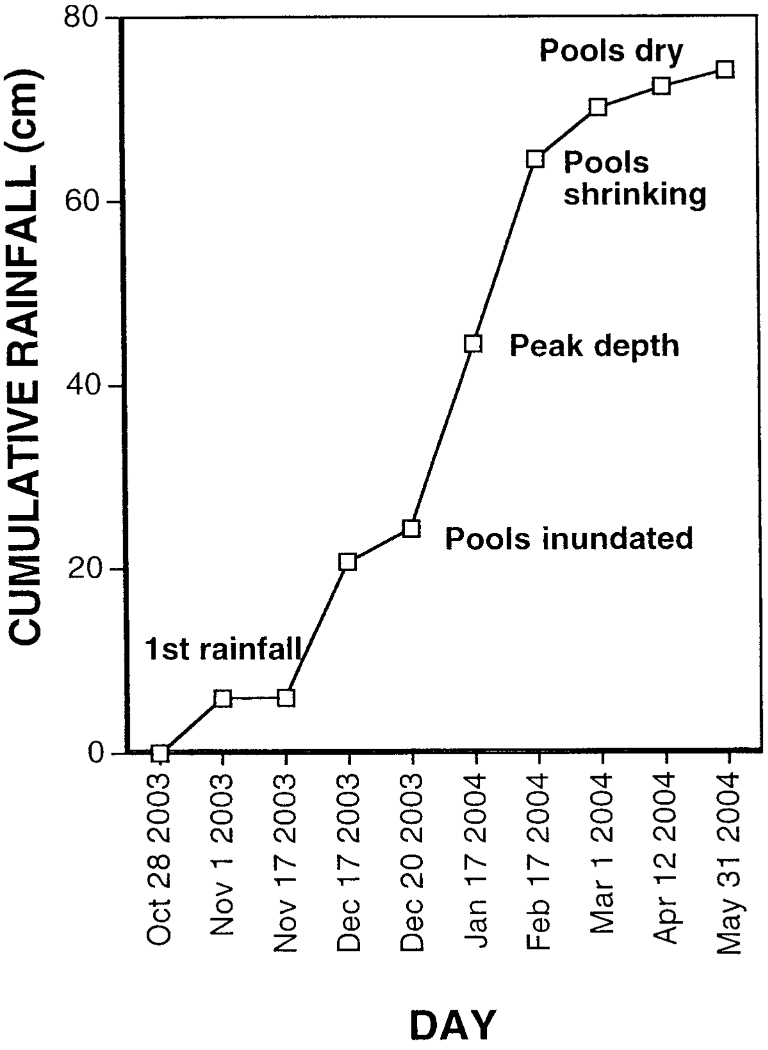


Figure 1: Cumulative rainfall (cm) throughout the 2003-2004 growing season of *L. vinculans* in Santa Rosa, Ca. Data from NOAA.

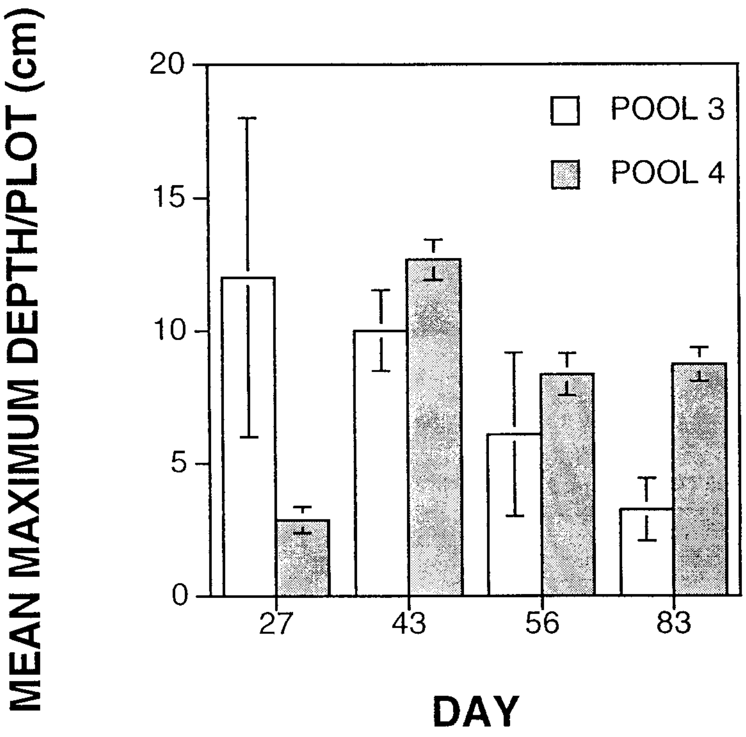
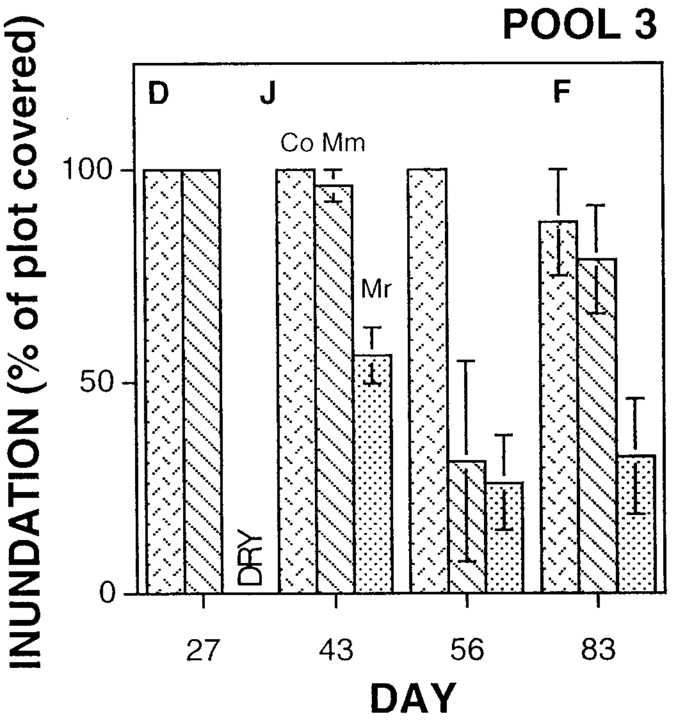


Figure 2. Mean maximum water depth/plot (cm) during the vegetative interval. Bars are ± 1 SE.



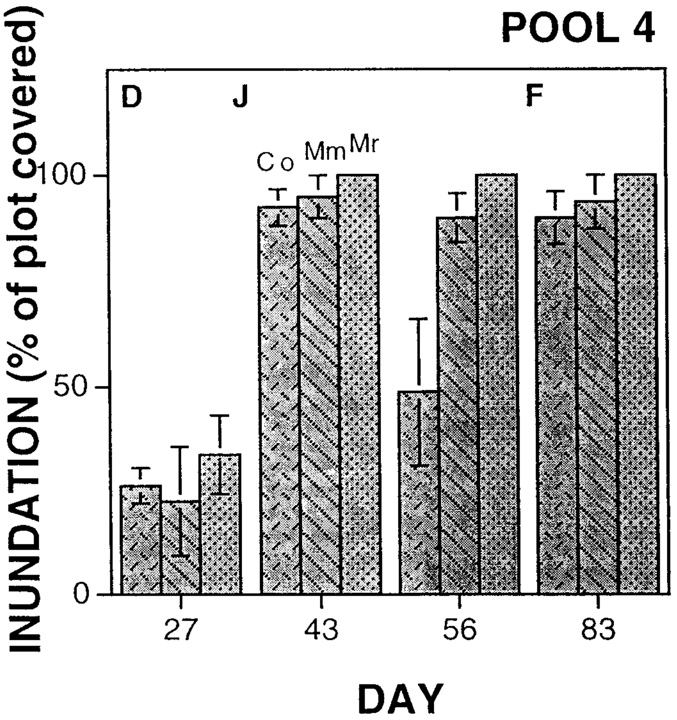


Figure 3. Inundation trends by treatment during the vegetative interval, 2003-2004. Bars are ± 1 SE. If no bar present SE < 1%.

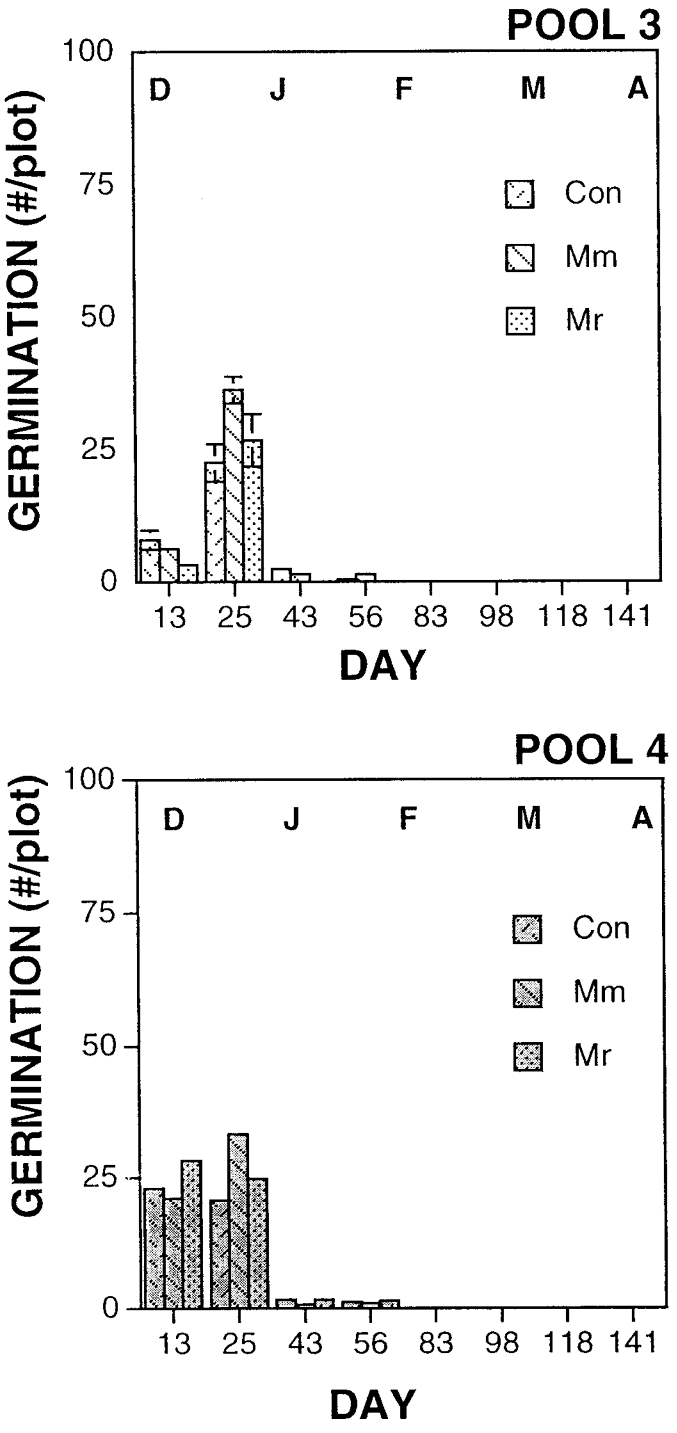


Figure 4: Mean germination (# individuals) during growing season of *L. vinculans* as a function of plot treatment. Bars are ± 1 SE. If no bars shown SE < 1%.

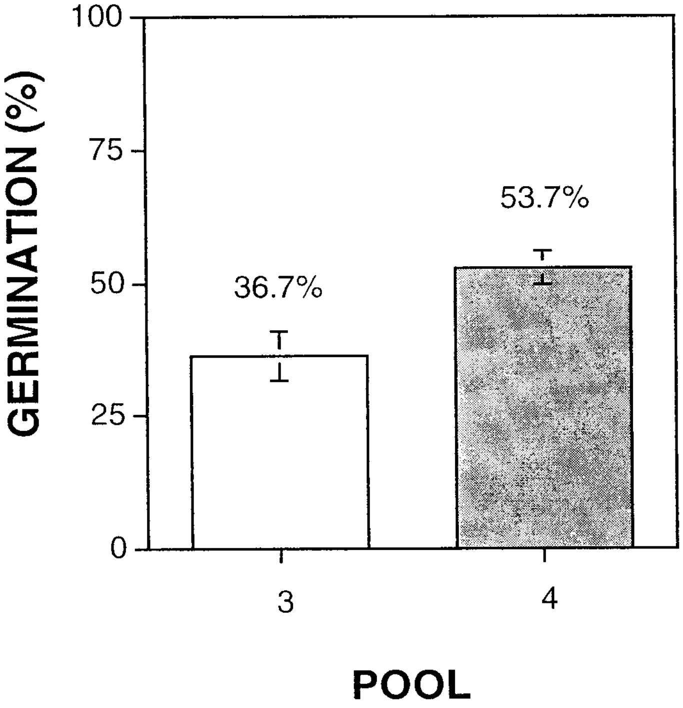
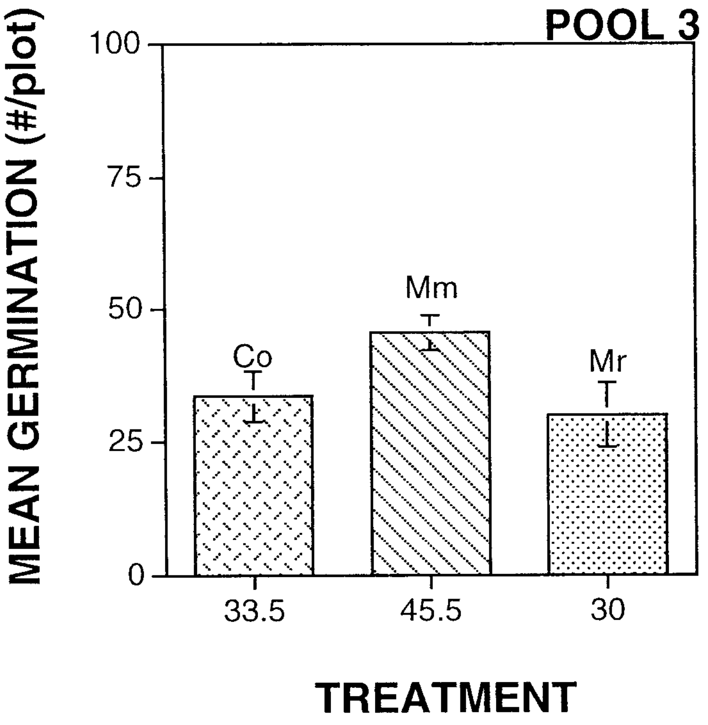


Figure 5: Mean cumulative germination of *L. vinculans* per pool. Bars are ± 1 SE. If no bars shown SE < 1%.



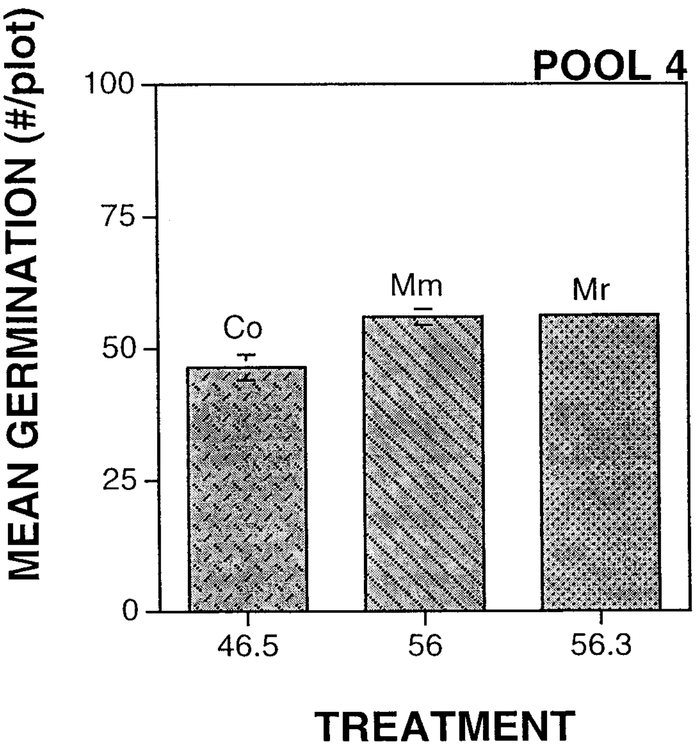


Figure 6: Mean cumulative germination of *L. vinculans* per treatment. Bars are ± 1 SE. If no bars are shown SE <1%.

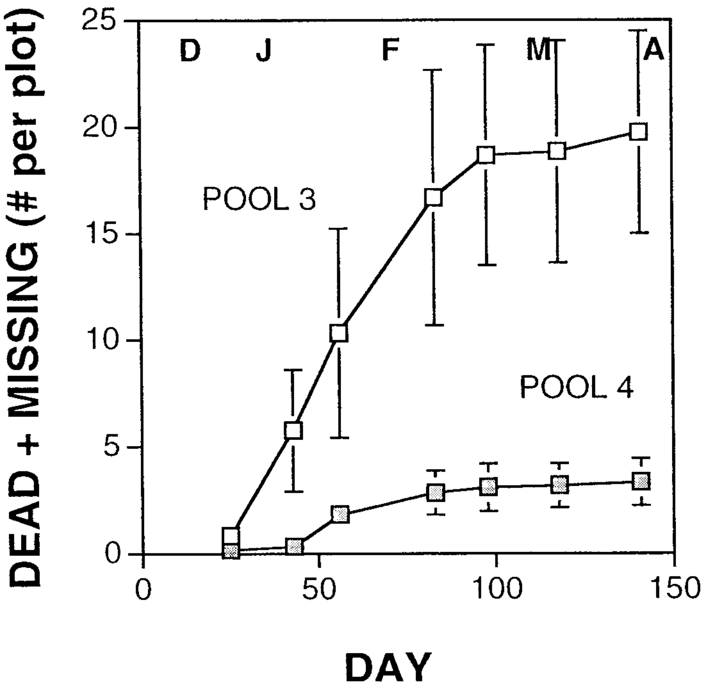


Figure 7. Mean cumulative # dead + missing plants during the vegetative interval 2003-2004. Bars are ± 1 SE. If no bars shown SE < 1.

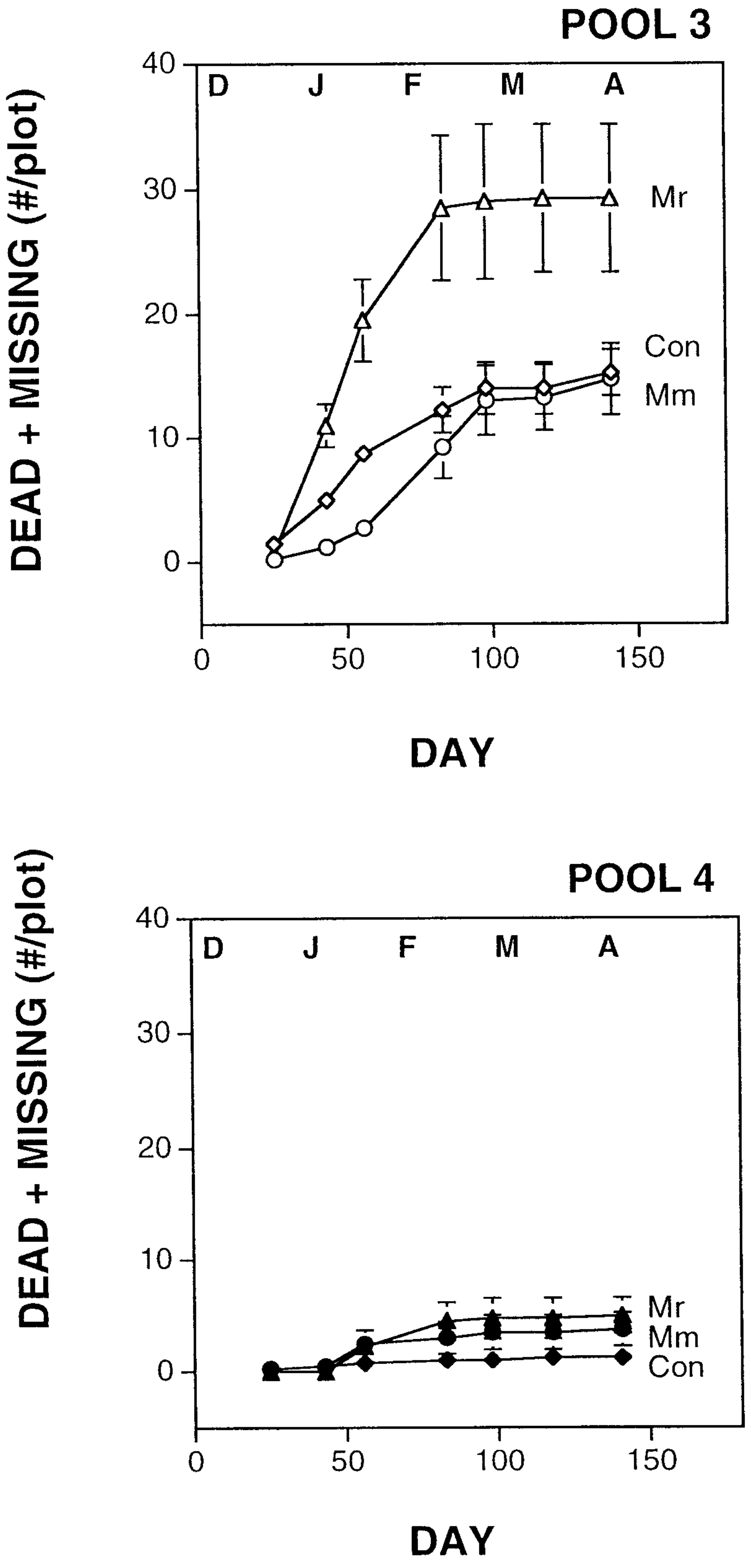


Figure 8. Mean cumulative dead + missing plants during the vegetative interval. Bars are ± 1 SE. If no bars shown SE < 1.

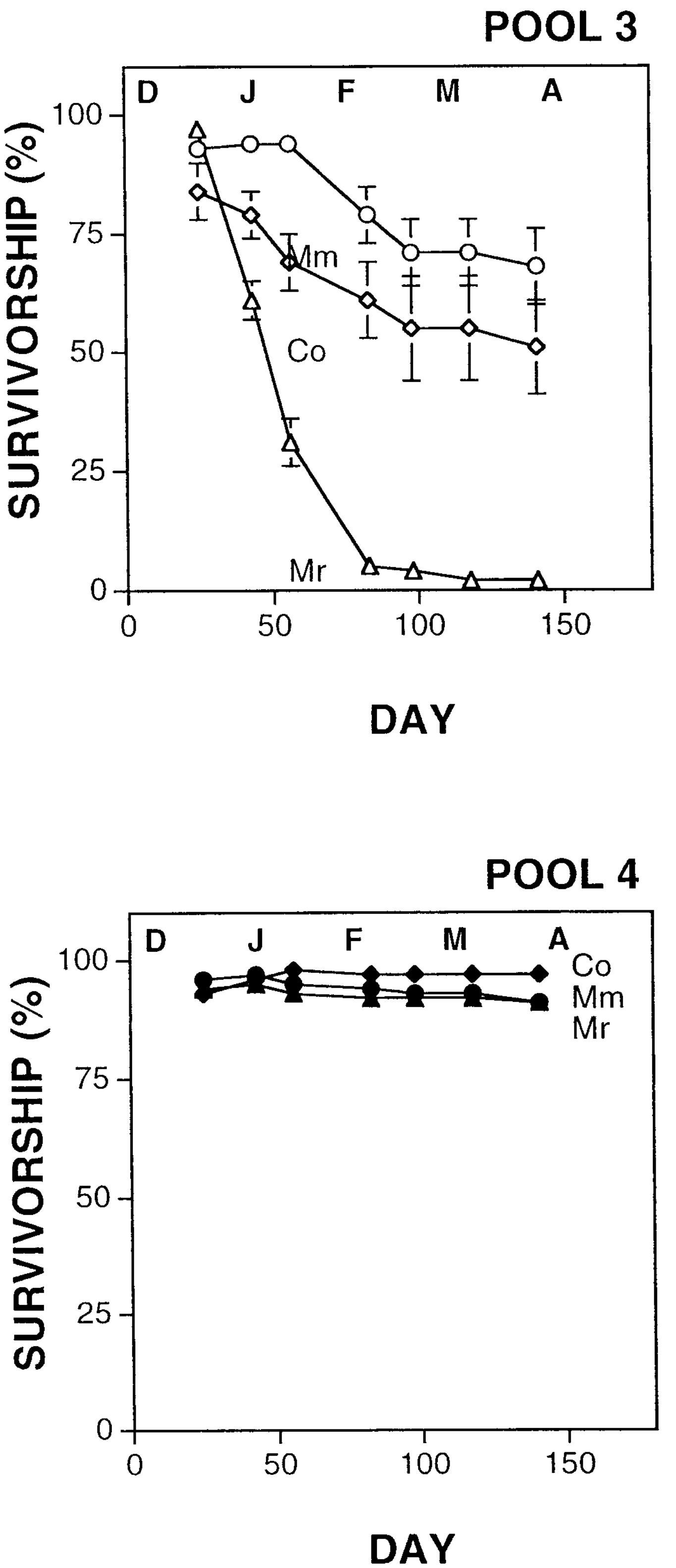


Figure 9. Mean survivorship of *L. vinculans* during the vegetative interval 2003-2004. Bars are ± 1 SE. If no bars shown SE < 1%.

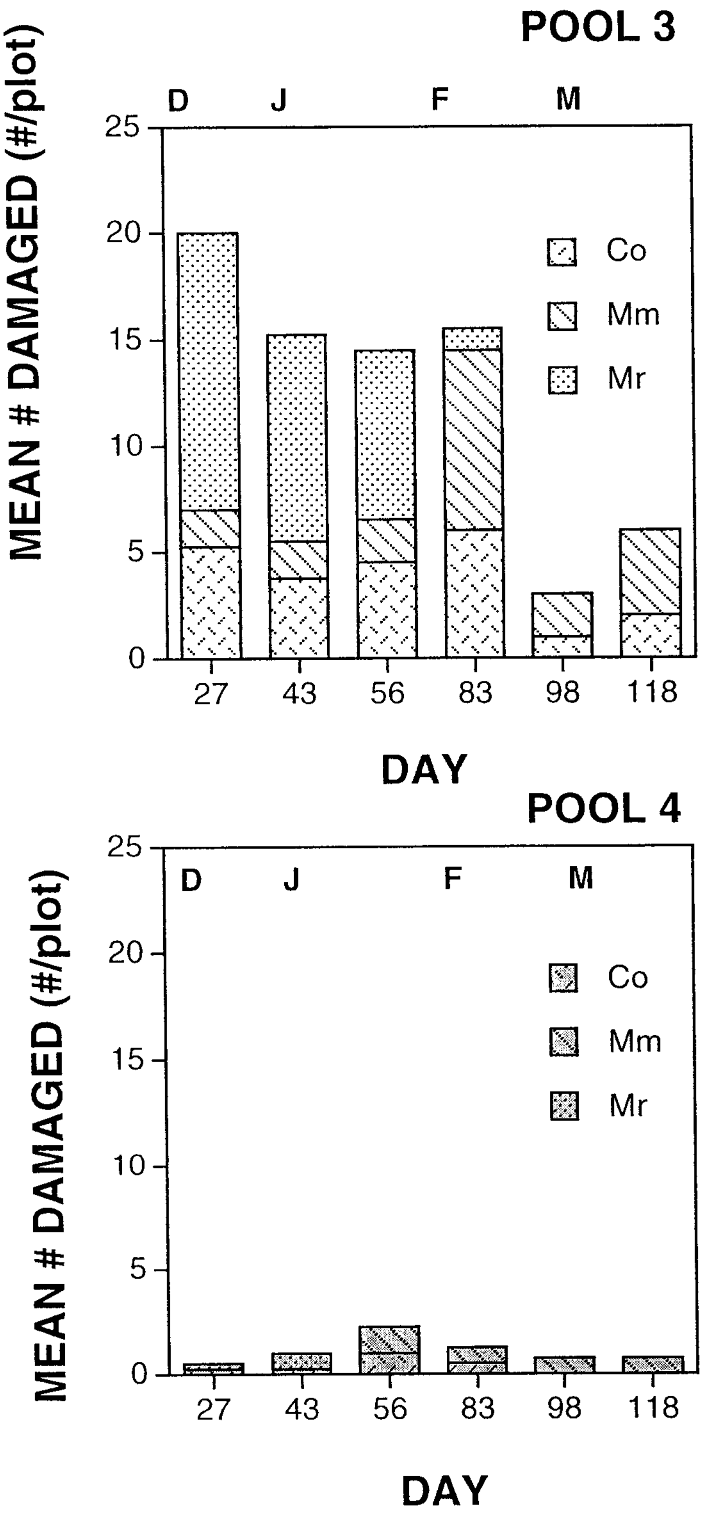


Figure 10. Mean number of plants damaged by slugs during the vegetative interval 2003-2004.

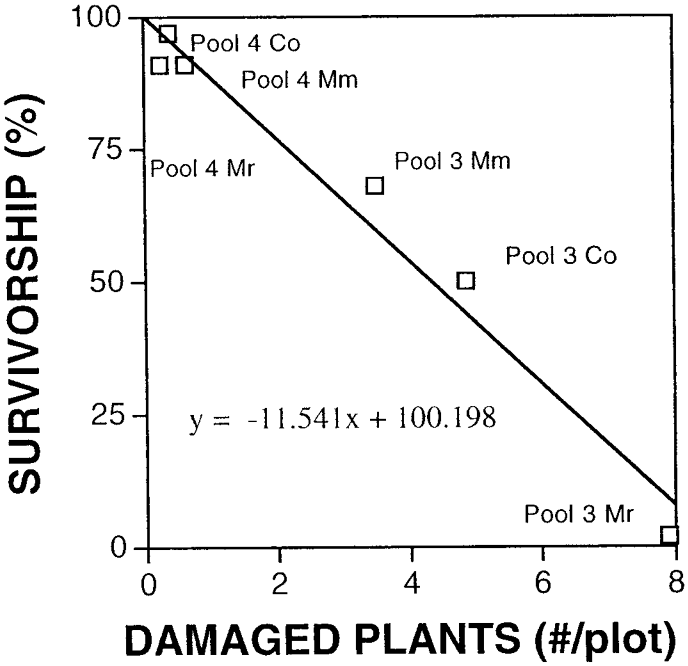


Figure 11. Mean survivorship (%) of *L. vinculans* as a function of the # damaged plants per plot.

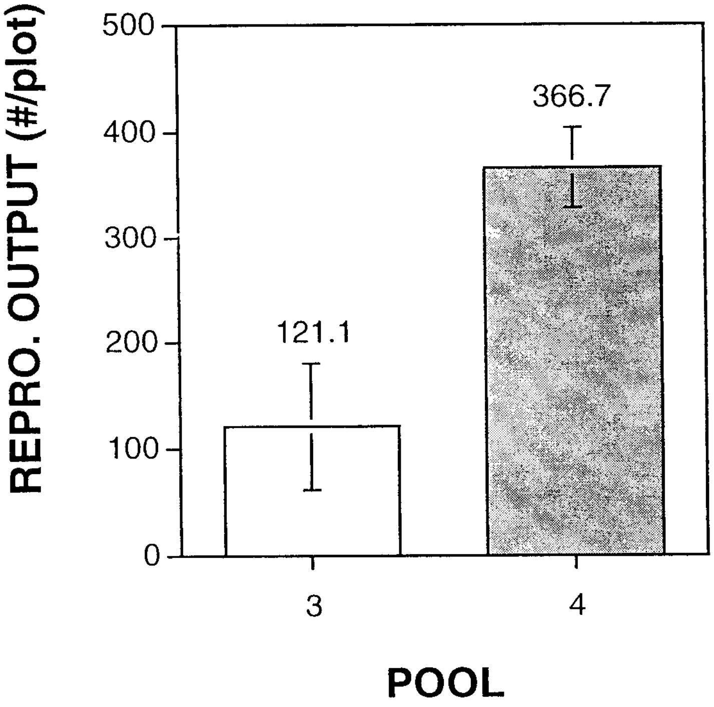


Figure 12: Mean reproductive output (# nutlets/plot) of *L.vinculans* for 2003-2004. Bars are ± 1 SE. If no bars are shown SE < 1%.

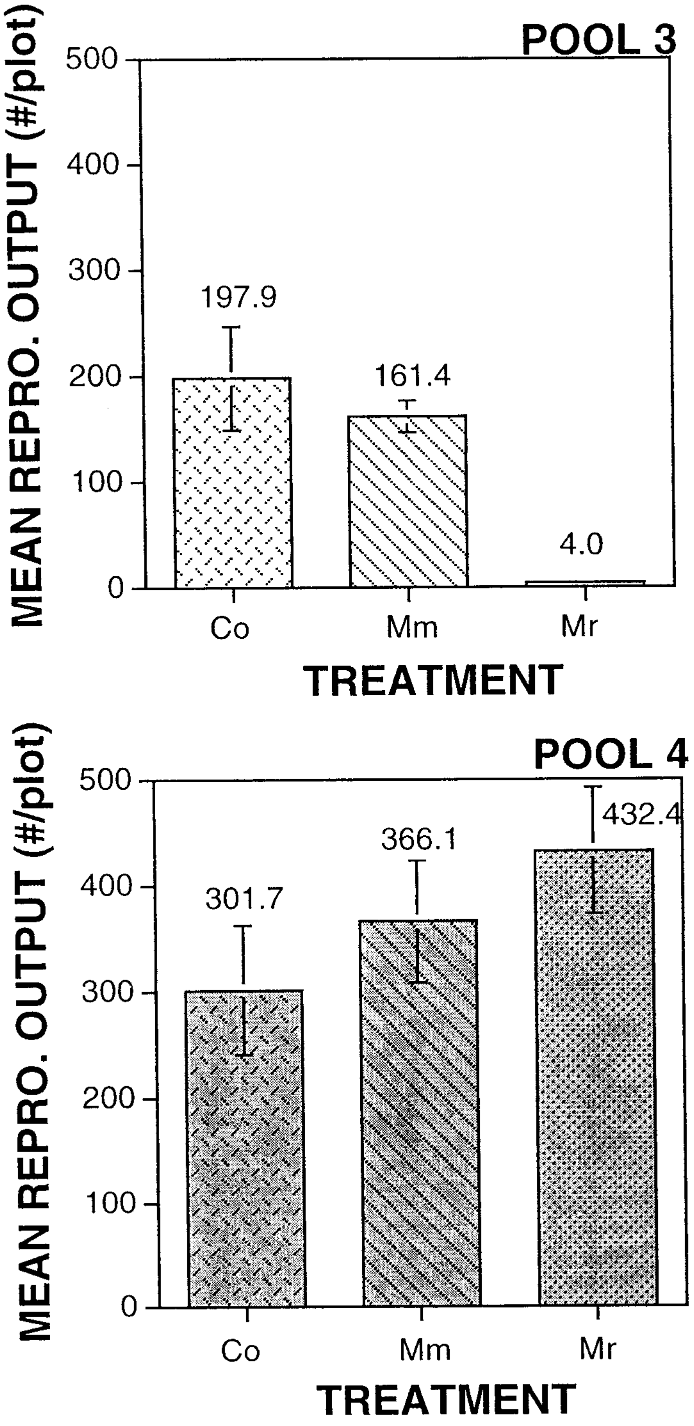


Figure 13: Mean reproductive output per plot of *L.vinculans* for 2003-2004 as a function of treatment. Bars are ± 1 SE. If no bars are shown SE < 1%.