Final Report on NFWF Grant for Habitat Restoration at Edgewood Natural Preserve, San Mateo County, CA

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Photograph by E. Ross

Report Summary

This report consists of 11 sections, which are briefly summarized below.

1. (Page 6) The habitat requirements of the Bay checkerspot butterfly are reviewed, and key plant species listed.
2. (Page 9) The history and structure of the Edgewood butterfly population from 1971-2001 showed wide fluctuations, and a crash from thousands in 1997 to near or complete extinction in 2002. The population is unlike to recover on its own, given the extremely small numbers that can be inferred from 2002 larval (1) and adult (0) sightings.
3. (Page 14) Aerial photography in Spring 2001 provided a base map, and an analysis of grass invasion patterns from color IR photography showed that only ~20% of the habitat is not dominated by annual grass.
4. (Page 17) Plant composition across the grassland was surveyed using a transect system. The introduced annual grass *Lolium multiflorum* was the most abundant species (~30% cover), and the key larval hostplant *Plantago erecta* had 9% cover. Two nectar sources were very abundant, the other two relatively uncommon. Comparisons with other sites indicates that Edgewood has higher annual grass cover than other sites, and lower *Plantago* cover.
5. (Page 31) The pattern of grass invasion is consistent with NO_x deposition from Highway 280 enriching the soil. Highway 280 produces 15-58 metric tons of NO_x per kilometer. Grass cover is higher closer to the freeway on the downwind (E) side, correcting for soils depth.
6. (Page 35) Restoration experiments included springtime mowing, raking, disturbance, *Plantago* seeding, and two levels of goat grazing. Mowing was highly effective in reducing *Lolium* cover and increasing *Plantago* cover and native species diversity and cover. Raking and seeding did not produce strong effects, but are being tested again in 2002-03. Goat grazing has not been fully evaluated but the lighter grazing was not as effective as mowing. Fire was not able to be implemented because of late season rains and administrative barriers.
7. (Page 47) *Plantago* seed was propagated from seed collected on site in 2001. Estimated seed production in the first year was ~280,000 seeds. If similar numbers of seed/plant can be produced, there is currently enough seed for both use in seeding experiments and growing enough seed to treat many acres at 400 seeds/m^2 if necessary.
8. (Page 48) A preliminary list of considerations for reintroduction of the butterfly addresses issues of potential timing and needs for such a project
9. (Page 50) Impacts on other species, including grassland nesting birds, are considered
10. (Page 51) Management options are considered and a preliminary plan is presented for rotational mowing. Costs and time are estimated with a maximum cost of $1000/acre.
11. (Page 56) The next steps to be taken by San Mateo County Parks and Recreation are suggested.

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Introduction

The nutrient poor serpentine grasslands at Edgewood Natural Preserve support the last remaining population of the threatened Bay checkerspot butterfly on the San Francisco Peninsula, along with a dazzling diversity of native wildflowers and bunchgrasses. The Edgewood population numbered in the thousands in the mid-1990's, but numbered less than 100 butterflies in 2000. A major cause of the decline has been invasion by introduced annual grasses that choke out the larval hostplants of the butterfly, an invasion that has progressed rapidly since 1993.

In March 2001, San Mateo County Parks and Recreation Foundation obtained a $70,000 NFWF grant to initiate habitat restoration studies at Edgewood Natural Preserve. Funding was provided for the period March 2001 to Oct. 2002. Grant activities included an inventory of current habitat conditions including aerial photography (color and IR), ground level transects, and small-scale restoration experiments such as prescribed fire, mowing, goat grazing, and seeding in larval hostplants.

This document serves as a final report on activities under the grant, and present a set of management recommendations for initiating long-term restoration of the serpentine grasslands.

Section 1: Habitat Requirements of the Bay Checkerspot Butterfly

The Bay checkerspot butterfly requires both larval food (hostplants) and adult nectar. The key plant species for the butterfly are listed below (Table 1.1). Serpentine grassland generally provides an abundance of larval food and nectar, but the annual plants undergo wide fluctuations in abundance and vigor. *Plantago erecta*, the primary larval hostplant (foodplant) is generally one of the most abundant species on serpentine and can reach > 50% cover locally. *Castilleja sp.* (Owl's clover) also provides larval food for a short time in the spring, but is much more variable in abundance than *Plantago*. A diversity of nectar sources supplies nectar through the entire flight season. Edgewood supports at least four known nectar sources (Table 1.1) but they vary greatly in distribution and abundance, and fluctuate widely from year to year. Reviews of the entire life-cycle and biology of the butterfly are available (Murphy and Weiss 1988a).

Photo 1.1 shows an area of high quality habitat at Edgewood with 15-20% *Plantago* cover, numerous *Castilleja densiflorus*, *Lasthenia,* and *Layia*. Photo 1.2 shows high quality habitat on Coyote Ridge in Santa Clara County, with average ~20% *Plantago* cover and all major nectar sources.

Bay checkerspot populations respond strongly to annual weather, and require substantial areas to persist through climatic extremes. Coyote Ridge, in Santa Clara County, supports the largest populations of checkerspot butterflies (100,000-1,000,000+) on thousands of acres of topographically diverse habitat (Photo 1.2). Edgewood contains the largest remaining continuous serpentine grasslands on the Peninsula, and has supported moderate and large populations (1000 -100,000 butterflies) up until the late 1990s (see below). Edgewood is relatively flat, with only limited topographic diversity, and the habitat is naturally fragmented into patches by intervening non-serpentine rocks, as well as by Highway 280. Butterfly populations occupying small serpentine grassland patches on Jasper Ridge Biological Preserve (~4 acres in JRH and ~20 acres in JRC) fluctuated over a range of 100-10,000 butterflies during 1961-1990. JRC went extinct in the 1990, and JRH went extinct in 1997, following several years in which only a few individual butterflies were sighted.

Serpentine grassland is threatened by invasions of introduced annual grasses, which can crowd out the small-statured native wildflowers (Weiss 1999). Italian ryegrass, *Lolium multiflorum*, is the major invasive grass in degraded sites in Santa Clara County, and dominates the dense sward to the right of the fenceline (Photo 1.3). The grazed side still supports abundant *Plantago* and nectar and serves as butterfly habitat. Several large populations in Santa Clara County have gone extinct because of these grass invasions following removal of cattle. Butterfly populations do not persist when *Plantago* is reduced to small isolated patches on thin soils where grass invasion is weak. Grass invasions are linked to deposition of reactive nitrogen oxides from air pollution (see smog cloud in background of Photo 1.1). Cattle grazing is used extensively in Santa Clara County sites to maintain suitable habitat. The N-deposition process and supporting evidence are found in Weiss 1999.

Similar grass invasions and a reduction of *Plantago* habitat at Edgewood were noted from 1998 through 2002. Highway 280 bisects the serpentine at Edgewood and provides a source of reactive nitrogen, which may be the primary cause of habitat deterioration and must be considered in any restoration plan. This possibility is explicitly considered in Section 5 below.

Table 1.1

Species	**Role**
Plantago erecta	Primary larval food
Castilleja densiflorus	Secondary larval food
Lasthenia californica	Adult nectar source
Layia platyglossa	Adult nectar source
Lomatium sp.	Adult nectar source
Muilla maritima	Adult nectar source
Lolium multiflorum	Invasive annual grass
Bromus hordaceous	Invasive annual grass

Photo 1.1 High quality habitat at Edgewood

Photo 1.2 Coyote Ridge Habitat and smog

Photo 1.3 Fenceline on Coyote Ridge

Section 2: History of the Edgewood Population

Prior to urban development on the San Francisco Peninsula, large areas of serpentine soils supported multiple populations of checkerspot butterflies, including San Francisco, Hillsborough, Pulgas Ridge, Edgewood, Woodside, and Jasper Ridge. (The San Bruno Mountain population was not on serpentine soils, but was still in a native grassland rich in *Plantago* and nectar sources). Through time, housing, freeways, and golf courses have progressively reduced and fragmented the habitat, driving populations to extinction (Murphy and Weiss 1988).

The Edgewood population has occupied 6 distinct patches of serpentine grassland in and near Edgewood Preserve (Map 2.1, Table 2.1). EWB is the main block of habitat (34.1 acres) extending east from Highway 280. EWA is a small area (5.6 acres) on the Triangle west of Highway 280. EWC extends across 5.1 acres in the saddle near the Sunset Gate, and EWD is the isolated patch (2.8 acres) of grassland below Hillcrest Drive. EWE is the flat area north of the main hill (17.1 acres), and EWF (6.8 acres) is directly adjacent to Highway 280, north of the drainage swale. Intervening habitats between patches include open grassland, chaparral, an 8 lane freeway, oak woodland, and various combinations thereof.

The Edgewood population has studied intermittently since 1970 by Stanford University biologists. Data prior to 1993 have been derived from published and unpublished material. Mark-recapture studies were done in several years, which provide population estimates and dispersal rates. A detailed description of the population structure at Edgewood is given in Attachment A6 in the Master Plan Report.

In 1993, standard searches for postdiapause larvae were first done at Edgewood, according to protocols developed at Kirby Canyon and other sites in Santa Clara County (modified from Murphy and Weiss 1988b). Larval counts in a 10-person minute search over a 1500-2000 m^2 area can be translated into absolute larval densities, which can then be averaged across the habitat to estimate the total number of larvae. Systematic larval searches began again in 1997 and extend to the present. The number of adult butterflies is less than the number of larvae because of late larval and pupal mortality and a figure of 50% is used in the absence of field data (Weiss et al. 1988,).. Pupal mortality rates do vary from year to year – the maximum recorded was 80% during extended El Nino rains in 1983 (White 1986). Adult estimates are therefore doubled to develop larval estimates.

The first recorded estimates were 10-20,000 butterflies in the early 1970's. Highway 280 was constructed through the site soon thereafter. No records indicate population response to the 1975-77 drought, an event that greatly reduced local Bay checkerspot populations. By 1981, the population had exploded to more than 100,000 butterflies. All outlying areas beyond EWB were occupied. The population crashed to around 1000 butterflies in 1984, following the 1982-83 El Nino deluges. The population west of 280 (EWA) went extinct around 1985. The population north of the main hill (EWE) went extinct at the same time. EWB recovered to several thousand butterflies from 1985 to 1992, based in qualitative yearly surveys by SBW. Populations in the hundreds persisted in the other areas (EWB, EWC, and EWD).

In 1993, the population in EWB was estimated at 3500 larvae (~1750 adults) (Table 2.2). EWC and EWD had 200-400 hundred larvae each. In 1997, the population in EWB had increased to 8000, and EWC and EWD were still occupied by larvae. EWB then declined sharply to 3000 in 1998 and 500 in 1999. EWC and EWD were extinct by 1999. In 2000, the estimate from larval counts was less than 100 larvae. Only 5 adults were observed that year, three on the small hilltop in EWB, 1 near the E-end of EWB, and one N of the PG&E road.

No postdiapause larvae were observed in 2001. Three adults were sighted on the small hilltop on Mar 29, Mar 30 and Apr 5. The first two may have been the same freshly emerged male. The third sighting was of undetermined sex.

In 2002, 1 postdiapause larva was observed near the small hilltop on February 19 (Photo 2.1). No adults were observed. All observations in 2001 and 2002 show a butterfly population at the brink of extinction. Based on the larval encounter rate in 2002, the larval population was likely on the order of 10 individuals, and the population is clearly at the edge of extinction. Only 3 adult sightings the year before along with the lack of adult sightings in 2002, despite multiple deliberate searches and numerous incidental search time, suggests that the population may be extinct. Low numbers (1-10 butterflies) were seen in the final years of each Jasper Ridge subpopulation, and fluctuations at low numbers over several additional years may be possible. However, the likelihood of substantial recovery is low, at best. Reintroduction options will be discussed later in the report.

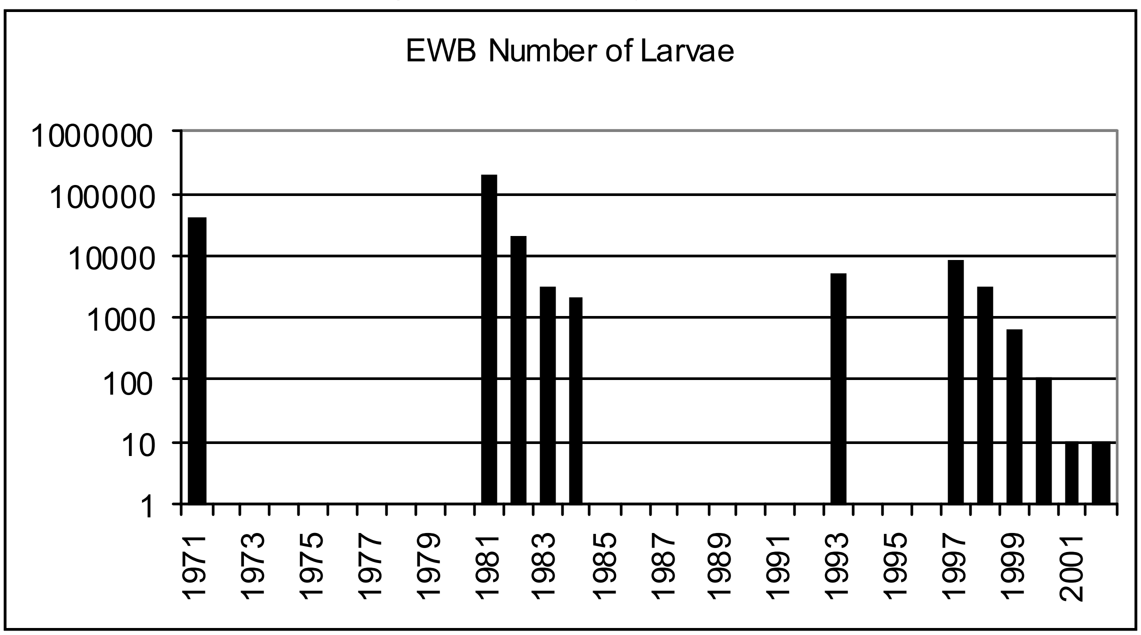
Table 2.1 Subarea Acreage

Subarea	Acres
EWB	34.1
EWA	5.6
EWE	17.1
EWD	2.8
EWC	5.1
EWF	6.8

Table 2.2 Larval counts 1993-2002

Year	Number Sites	#larvae/ site	Larvae/ m^2	Std Dev	Std Err	Lower 95%	Upper 95%
1993	12	2.3	0.026	0.023	0.007	0.012	0.037
1997	15	5.1	0.059	0.045	0.012	0.034	0.084
1998	10	1.4	0.022	0.025	0.008	0.004	0.040
1999	10	0.4	0.005	0.007	0.002	0.000	0.010

Figure 2.1 History of EWB



Map 2.1 Edgewood Park Serpentine units

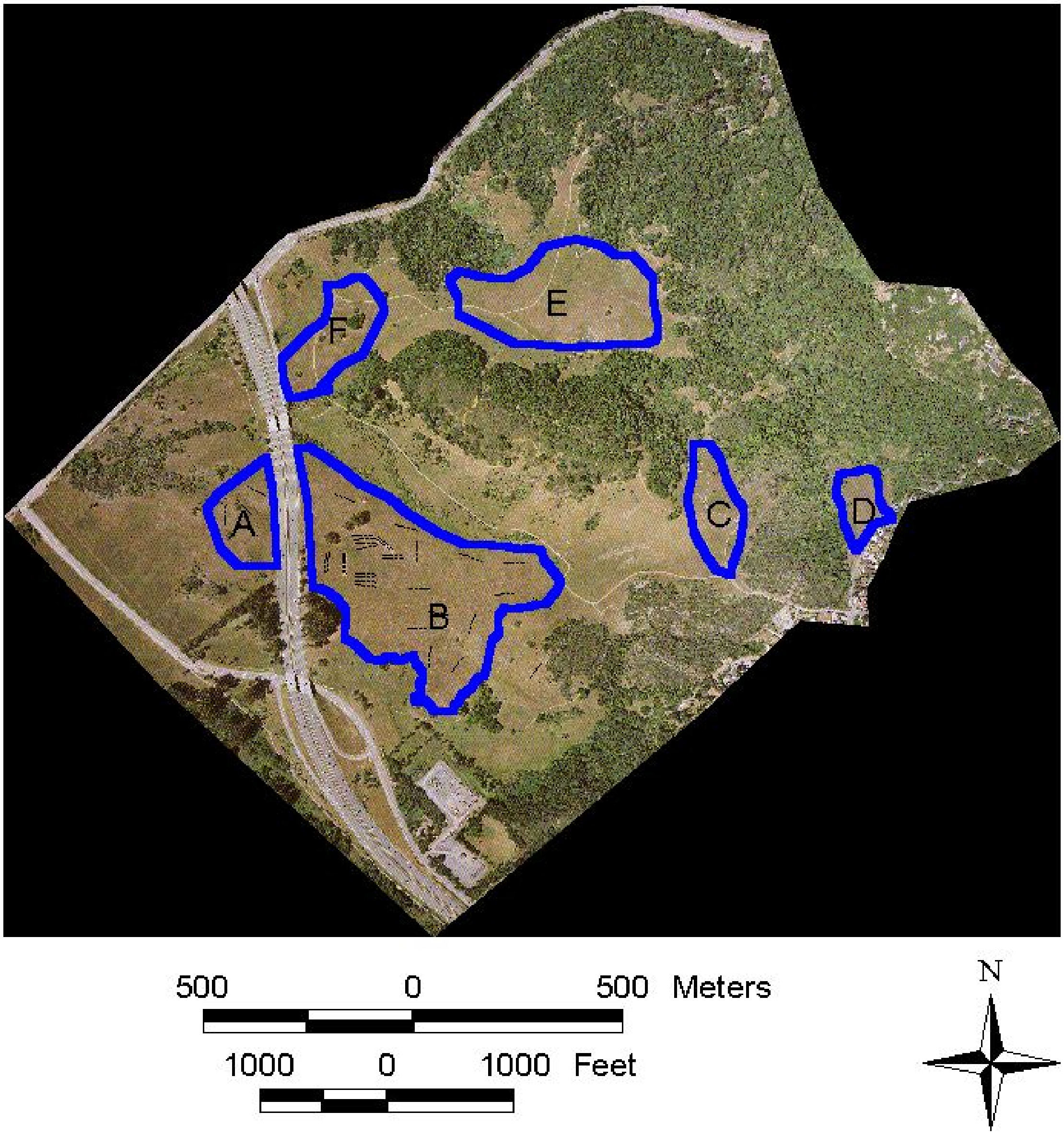


Photo 2.1 Postdiapause larva Feb 19, 2002

Section 3. Aerial Photography 2001

Aerial photography with 1 ft resolution was flown on May 7 2001, and orthorectified color and color IR (CIR) images produced. Grasses were still green but annual forbs had largely senesced. The CIR image was classified into four classes for habitat assessment – bare, forb-dominated, grass dominated, and non-grassland -- using an unsupervised classification in ArcView Image Analyst and manual selection of breakpoints along the green vegetation gradient.

The true color photo shows the mosaic of vegetation at Edgewood (Map 2.1). The serpentine areas are outlined and labeled A-F, described in Section 1. The vast majority of the work was done in Area B, where the last butterflies were seen. The smaller patches once supported populations, but now appear to be extinct. The distribution of all transects are shown.

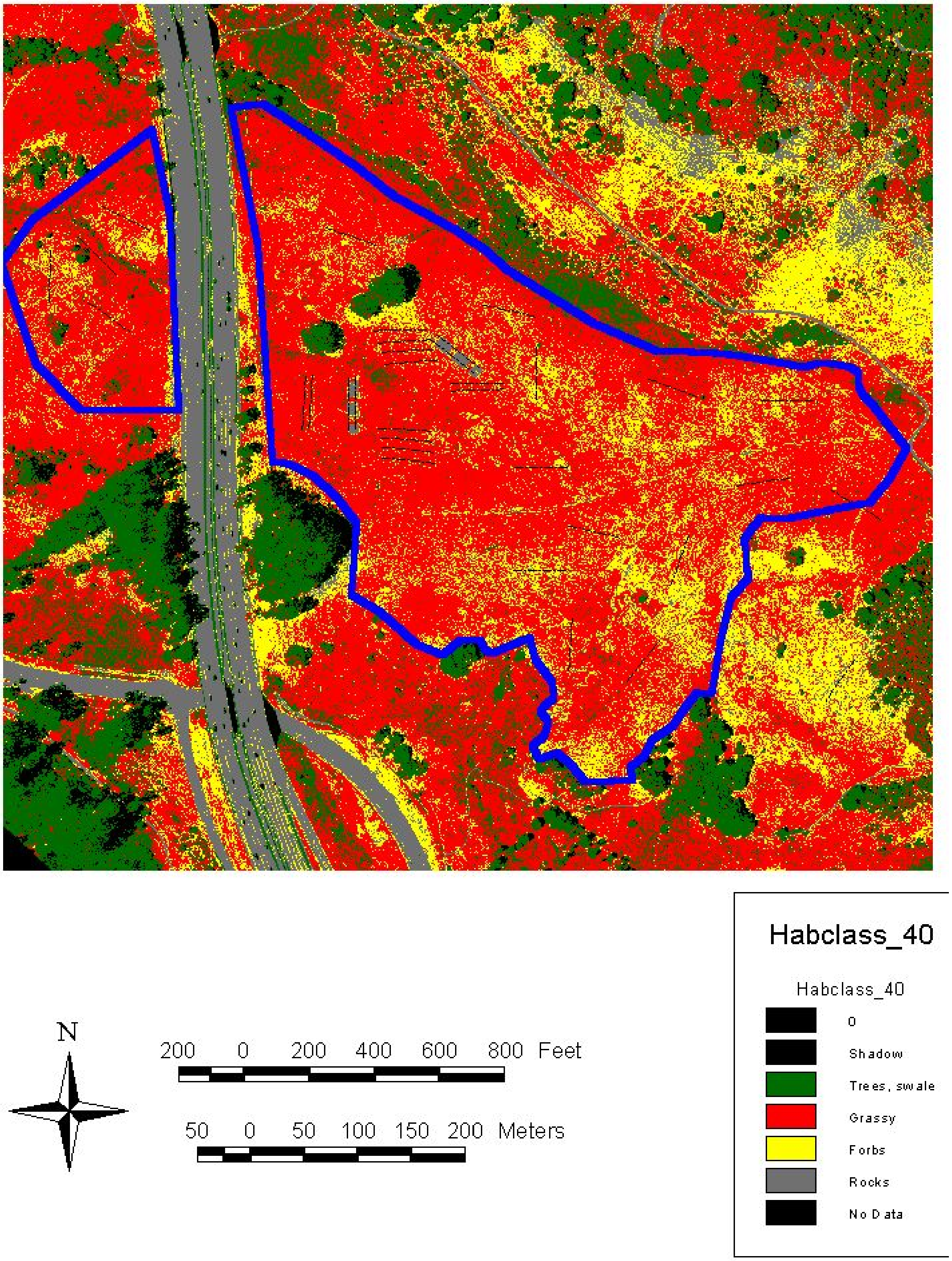
The close in CIR photo of Area B (Map 3.1) shows green grass-dominated areas as red, and dry senescent forbs with some grass as pink, and relatively bare areas as blue. Note the complex fine-scale patterns in the grassland. Areas of thick soils on mounds dominated by grass alternate with thinner soils dominated by forbs.

The habitat classification (Map 3.2) based on live vegetative cover further highlights the vegetation patterns. The red areas within the serpentine grasslands are heavily invaded by grasses, and currently have little *Plantago*. The yellow areas are forb-dominated and may or may not contain *Plantago* in high densities, but represent an upper limit on available habitat.

According to this analysis, the amount of forb habitat in the 34.1 acre Area B is about 6 acres (<20%). <2% is covered by rocks, and the remainder is dominated by grass (Map 3.2). It is important to note that not all forb dominated areas support dense *Plantago erecta* stands (see below Section 4).

Map 3.1 EWB and EWA Color Infrared (CIR)

Map 3.2 Habitat Classification



Section 4: Plant species composition

Serpentine grassland is a highly variable plant community from year to year and from place to place. Cover of individual plant species are affected by the unique precipitation, temperature, sunshine, and other weather factors of each growing season, and interactions with other plant species. Some years (generally wetter) favor grass growth, others (usually drier) favor forbs. Annual species can appear, dominate, and virtually disappear over the course of several years. The muted topography at EWB does provide some topoclimatic variability, for example, certain species such as *Ranunculus californica* and *Dodecatheon hendersonii* are restricted to the limited areas of N-facing slopes in EWB.

The purposes of monitoring the overall composition of the serpentine grassland is to provide a reliable system for detecting major changes in grassland composition in response to climate, topography, and management. A standard methodology is being used at multiple sites across Santa Clara and San Mateo Counties, so that inter-site comparisons can be made. The system is designed to monitor large changes in composition from year to year (interannual) and across topographic, edaphic (soil), and management gradients, while at the same time being efficient for data collection.

32 transects were established in the serpentine grassland on both sides of Highway 280 (Map 3.1). Transects are 50 meters long. The ends are permanently marked with rebar. Ten 0.25 m^2 quadrats were located at 5 meter intervals along each transect, and can be accurately relocated using a measuring tape. In each quadrat, percent cover of all species and bare ground were visually estimated using a scale 0, 1, 2, 5, 10, 20, 30, 40 … 90% (Appendix A shows a data sheet). The method is designed to detect large differences in plant cover and be relatively rapid. 22 transects were used for inventory because they are evenly distributed across the grassland. 10 transects are not used for inventory because they were clustered in dense blocks in degraded habitat for experiments, and over-represent such areas. In 2001, all transects were done by Stuart Weiss (SBW). In 2002, SBW and David Luth (DCL) did the majority of transects, and Toni Corelli did a smaller amount (Photo 4.1). In Spring 2001, 4 soil depths were taken in each quadrat using a sharpened metal stake driven into the ground with a hammer.

Lolium was the most abundant species in 2001 (32% cover, Table 4.1, Fig. 4.1). *Lasthenia* was second (15%), *Plantago* third (9%), and *Layia* was fifth (3.5%) (Fig. 4.2). *Castilleja* was twelfth at 2%. *Muilla* had low cover (0.3%), and *Lomatium* was found in only 2 quadrats. In 2002, *Lolium* cover appears to have dropped to about 20%, and average cover of the other species did not change.

Frequency (percentage of quadrats with species present) did not substantially change between years for *Plantago* (81-88%), *Castilleja* (56-60%), or *Lolium* (75-78%). *Lasthenia* frequency increased from 58% to 81%.

The habitat does provide a diversity of nectar sources. *Muilla maritima*, although at low cover, provides the earliest available nectar. The low abundance of *Lomatium* contrasts with observations in the early 1980's when numerous robust plants were widespread across EWB (SBW pers. obs.). Both *Lasthenia* and *Layia* were widespread and abundant in both 2001 and 2002. Nectar at this point does not appear to be a limiting factor for the Bay checkerspot butterfly. However, increases in *Lomatium* and *Muilla* through seeding may be possible, but not as important as increasing *Plantago* cover in degraded areas.

The cumulative frequency distribution of *Plantago* cover shows 80% of the quadrats had 10% or less *Plantago* cover, conversely, only 20% had more than 10% cover, and both years were quite similar(Fig. 4.3). Nearly all of the high cover *Plantago* plots were in the easternmost transects farthest from Highway 280. The cumulative frequency distribution of *Lolium* cover shows that in 2001, 50% of the plots had ≥20% and 30% of the quadrats had ≥50% *Lolium* cover (Fig. 4.4). In 2002, *Lolium* exhibited a general decrease in cover (only 10% of quadrats had ≥50% cover), but it still was the most abundant species in EWB.

The photographs of several transects show some of the different situations encountered at Edgewood, including high quality *Plantago* habitat (Photo 4.1), high forb cover, but little *Plantago* (Photo 4.2), and high grass cover and low *Plantago* cover (Photo 4.3).

A total of 71 species were encountered in the quadrats. Average species richness per quadrat was 10.4 ± 3.2 (s.d.), with a maximum of 17 and a minimum of 3. Annual forbs were the most diverse group of species. Bunchgrass cover and diversity are recognized as an outstanding feature of the serpentine grassland at Edgewood. Perennial bunchgrasses are abundant (8.3% cover on average), and are primarily *Nasella pulchra* and *Elymus multisetus,* with small amounts of *Poa sp., Bromus carinatus*, *Danthonia californica*, *Koeleria macrantha, Hordeum brachyanthemum*. A full treatment of the grassland biodiversity at Edgewood is beyond the scope of this report.

Grass dominated areas tended to have standing dead biomass (duff) from previous years as a major component of cover. A dense layer of thatch also tended to be present directly on the soil surface (Photo 4.4). The accumulation of dead biomass as duff and thatch reduces the areas of bare mineral soils that favor forbs such as *Plantago*. In addition, the short rosettes of *Plantago* and other forbs cannot effectively penetrate upwards through the thatch, while narrow vertical grass seedlings can.

Lolium experienced a reduction in cover in 2002 compared with 2001. While the overall reduction in *Lolium* cover from 2001 to 2002 is encouraging, it may represent a cycle where a high biomass year leaves enough additional duff and thatch to suppress the growth the following year. Or, differences in weather between the years could be driving changes in *Lolium* cover (Figs 4.4 and 4.5). For example, in 2000-01, late October rainfall of 2+" brought early germination, followed by a period of dry weather with average temperatures. Rainfall was concentrated late in the rainy season (Feb-Mar). Temperatures were near average for most of 2000-01. In 2001-02, rainfall was concentrated in Nov-Dec, with warmer than average temperatures, but with quite dry conditions from Jan-Mar. How these differences may affect *Lolium* is speculative without longer term observations.

Comparisons with reference sites 2001 and 2002

Ongoing studies at other serpentine grassland sites using the same transect methodology provide comparisons and will assist in the development of targets for hostplant, nectar, and grass cover. All graphs represent overall site averages for ready comparison.

The sites include:

1) Edgewood Natural Preserve, San Mateo County
2) West of Highway 280 At Edgewood
3) Jasper Ridge Biological Preserve
4) Coyote Ridge – Kirby Canyon Butterfly Trust Lease
5) Tulare Hill

Composition at other sites can enhance our understanding of nitrogen deposition and grazing dynamics. Coyote Ridge provides a reference conditions for densely populated checkerspot butterfly habitat in grazed habitat under high N-deposition. Tulare Hill was heavily grazed for several decades, and recently was ungrazed for one year. Jasper Ridge Biological Preserve represents a relatively clean air site, with a long-term record of plant cover in serpentine grassland. The Edgewood sites are described in this report.

Plantago densities were highest at 17-25% at Tulare Hill (Fig. 4.6), followed by Jasper Ridge. Coyote Ridge had 10-15% cover, and both Edgewood sites were at or below 10%. It is important to note that Coyote Ridge has thousands of acres of habitat and highly diverse topography, so mean *Plantago* density may not be as important as in a limited area such as Edgewood. At Edgewood, high cover *Plantago* plots on other than the shallowest soils were in a relatively limited areas distant from Highway 280.

Castilleja cover was low at all sites, with the most at Edgewood, and the least at Tulare Hill in 2001 (Fig. 4.7). Note that the dominant *Castilleja* species at Coyote Ridge is *C. exserta,* although *C. densiflorus* is present at the site. *Castilleja* is highly variable from year to year at any given site.

Lasthenia was relatively abundant at all sites, ranging from 5-15% cover (Fig. 4.8). *Layia* was abundant at Edgewood, rare at Coyote Ridge, and absent at Tulare Hill, (Fig. 4.9). *Allium* was found only on Tulare Hill and Coyote Ridge (Fig. 4.10). *Muilla* was most abundant on Coyote Ridge, and relatively rare at Edgewood and Tulare Hill (Fig. 4.11).

Native species richness per quadrat was highest at Coyote Ridge, intermediate at Edgewood and Jasper Ridge, and lowest at Tulare Hill (Fig. 4.12). *Lolium* cover was highest at Edgewood, and lowest at Tulare Hill (Fig. 4.13). Total annual grass cover was highest at Edgewood, and Coyote Ridge and Tulare Hill were similar at around 20% cover in both years (Fig. 4.14). In contrast, *Bromus hordaceous* cover was highest at Tulare Hill in both years and lowest at Edgewood (Fig. 4.15). *Vulpia* cover was highest at Edgewood and Coyote Ridge, intermediate at Tulare Hill, and lowest at Jasper Ridge (Fig. 4.16).

The overall comparison of Edgewood to other serpentine sites demonstrates the significance of the habitat degradation due to invasive grasses . As detailed above, Edgewood has the lowest percent cover of Plantago and the highest cover of invasive grasses, especially Lolium, when compared to the prime habitat sites at Coyote Ridge and Tulare Hill. Nectar sources for the Checkerspot butterfly do not appear to be a limiting factor at Edgewood.

Table 4.1

Species	**%Cover 2001**	**%Freq 2001**	**%Cover 2002**	**%Freq 2002**
Lolium multiflorum	32.0	75	20.0	78
Lasthenia californica	14.7	58	12.4	81
Plantago erecta	8.8	81	9.0	88
Layia platyglossa	3.5	49	5.5	48
Castilleja densiflorus	1.5	56	1.4	60
Muilla maritima	0.3	17	0.2	12
Lomatium sp.	0.08	1	0.03	1

Figure 4.1

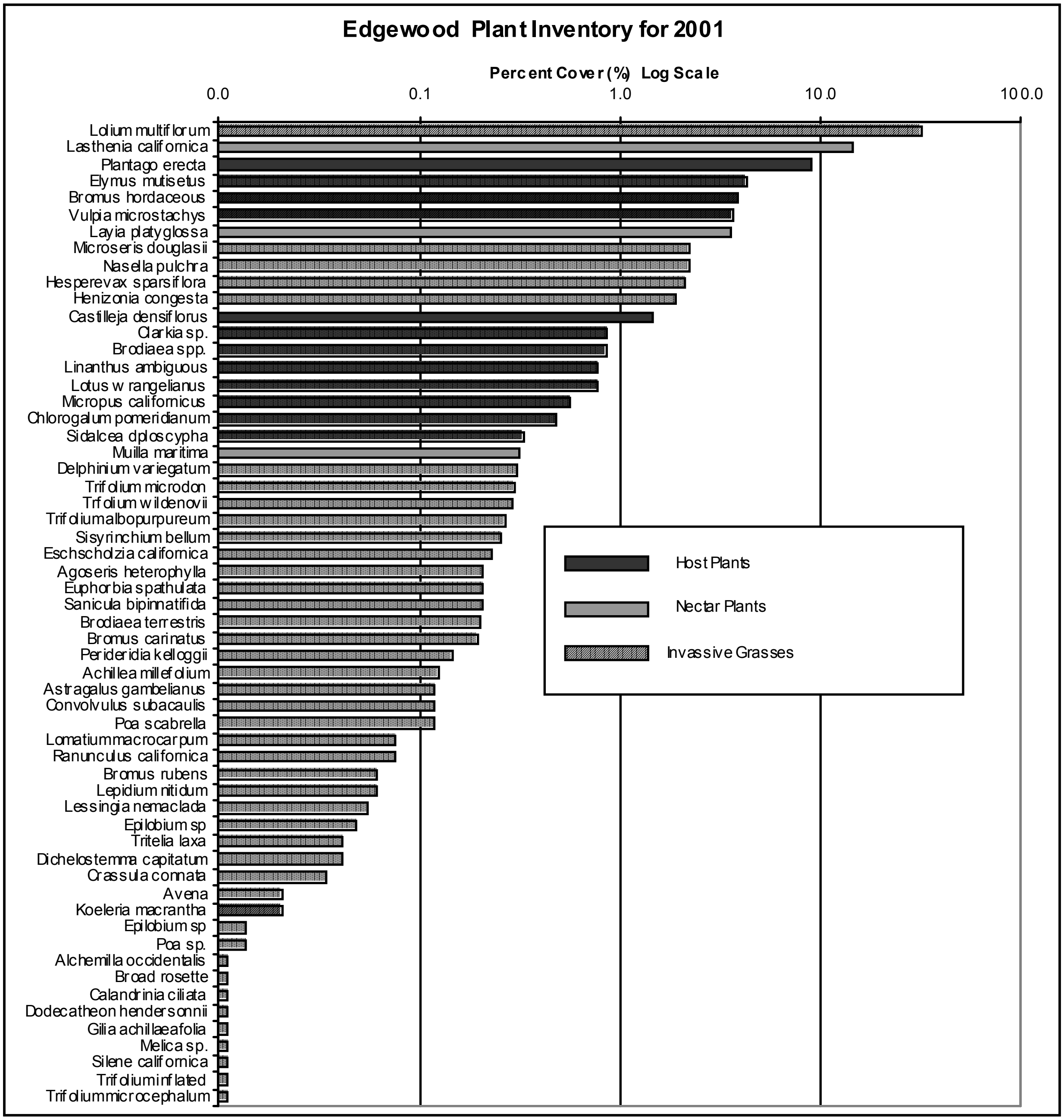
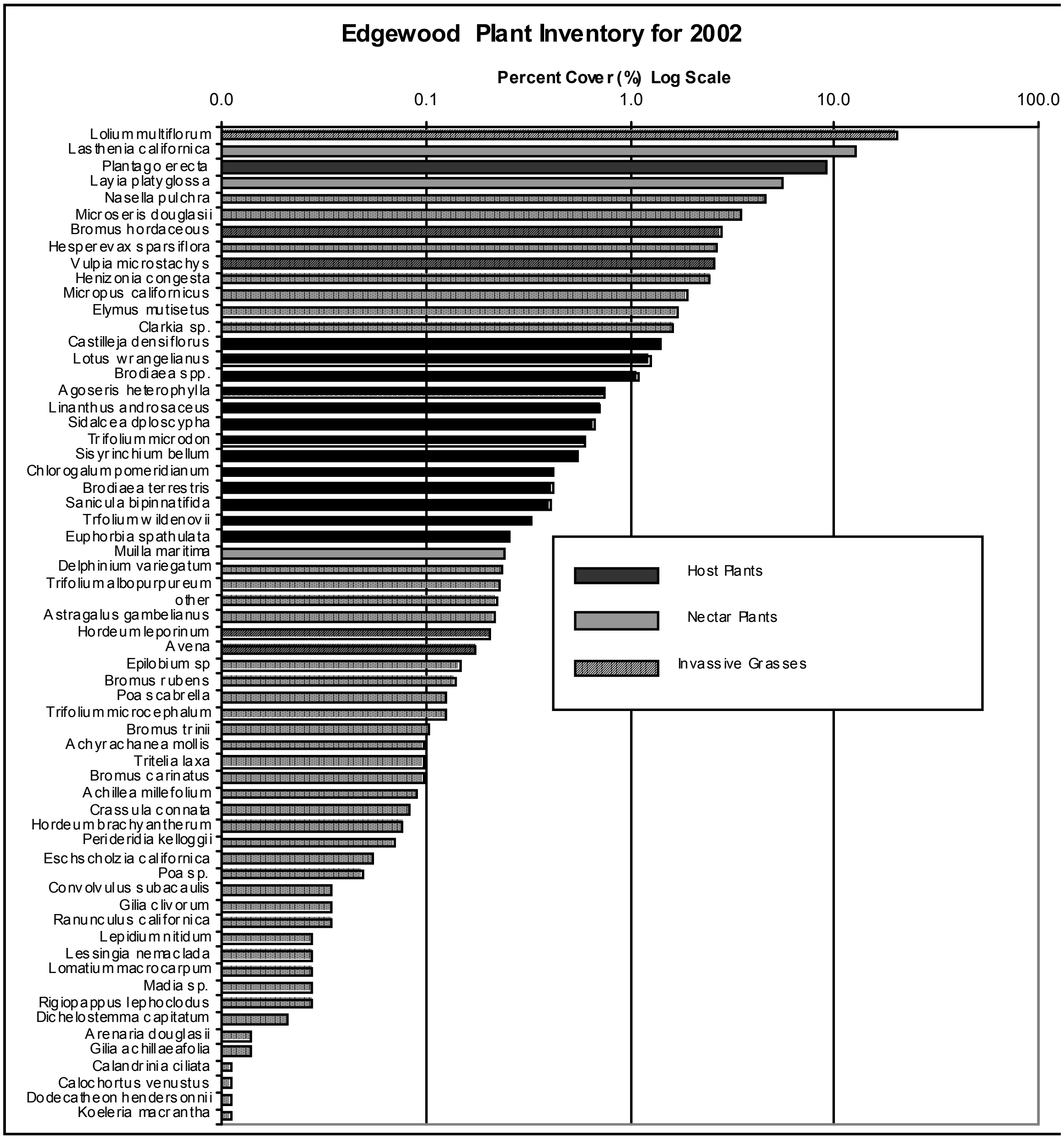

Edgewood Plant Inventory for 2001
Percent Cover (%) Log Scale
0.0
0.1
1.0
10.0
100.0
Lolium multiflorum
Lasthenia californica
Plantago erecta
Elymus mutisetus
Bromus hordaceous
Vulpia microstachys
Layia platyglossa
Microseris douglasii
Nasella pulchra
Hesperevax sparsiflora
Henizonia congesta
Castilleja densiflorus
Clarkia sp.
Brodiaea spp.
Linanthus ambiguous
Lotus wrangelianus
Micropus californicus
Chlorogalum pomeridianum
Sidalcea diploscypha
Muilla maritima
Delphinium variegatum
Trifolium microdon
Trifolium wildenovii
Trifoliumalbopurpureum
Sisyrinchium bellum
Eschscholzia californica
Agoseris heterophylla
Euphorbia spathulata
Sanicula bipinnatifida
Brodiaea terrestris
Bromus carinatus
Perideridia kelloggii
Achillea millefolium
Astragalus gambelianus
Convolvulus subacaulis
Poa scabrella
Lomatiummacrocarpum
Ranunculus californica
Bromus rubens
Lepidium nitidum
Lessingia nemaclada
Epilobium sp
Tritelia laxa
Dichelostemma capitatum
Crassula connata
Avena
Koeleria macrantha
Epilobium sp
Poa sp.
Alchemilla occidentalis
Broad rosette
Calandrinia ciliata
Dodecatheon hendersonnii
Gilia achillaeafolia
Melica sp.
Silene californica
Trifoliuminflated
Trifoliummicrocephalum
Host Plants
Nectar Plants
Invassive Grasses

Figure 4.2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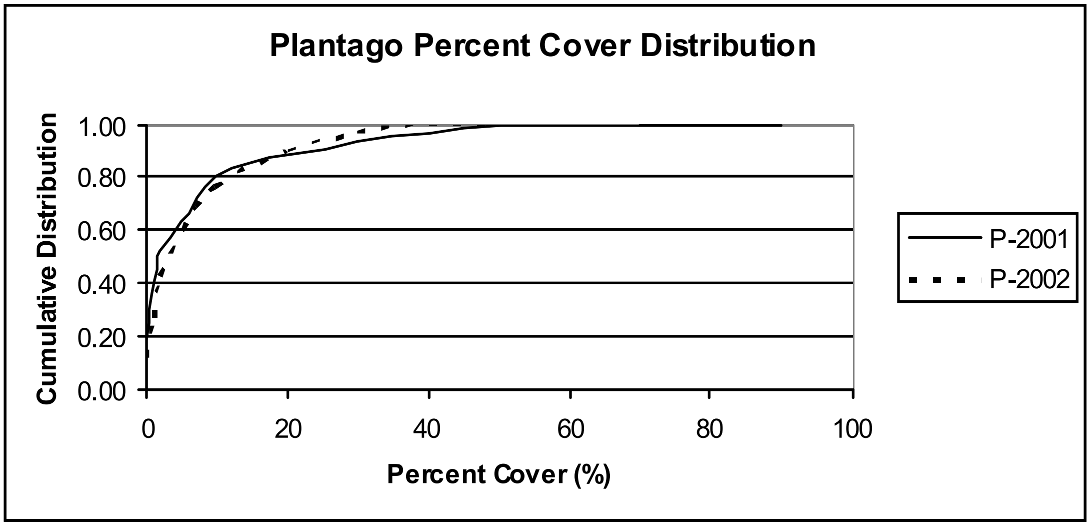
Nasella pulchra
Microseris douglasii
Bromus hordaceous
Hesperevax sparsiflora
Vulpia microstachys
Henizonia congesta
Micropus californicus
Elymus mutisetus
Clarkia sp.
Castilleja densiflorus
Lotus wrangelianus
Brodiaea spp.
Agoseris heterophylla
Linanthus androsaceus
Sidalcea dploscypha
Trifolium microdon
Sisyrinchium bellum
Chlorogalum pomeridianum
Brodiaea terrestris
Sanicula bipinnatifida
Trfolium wildenovii
Euphorbia spathulata
Muilla maritima
Delphinium variegatum
Trifolium albopurpureum
other
Astragalus gambelianus
Hordeum leporinum
Avena
Epilobium sp
Bromus rubens
Poa scabrella
Trifolium microcephalum
Bromus trinii
Achyrachanea mollis
Tritelia laxa
Bromus carinatus
Achillea millefolium
Crassula connata
Hordeum brachyantherum
Perideridia kelloggii
Eschscholzia californica
Poa sp.
Convolvulus subacaulis
Gilia clivorum
Ranunculus californica
Lepidium nitidum
Lessingia nemaclada
Lomatium macrocarpum
Madia sp.
Rigiopappus lephoclodus
Dichelostemma capitatum
Arenaria douglasii
Gilia achillaeafolia
Calandrinia ciliata
Calochortus venustus
Dodecatheon hendersonnii
Koeleria macrantha
Host Plants
Nectar Plants
Invassive Grasses

Figure 4.3 Cumulative Distributions



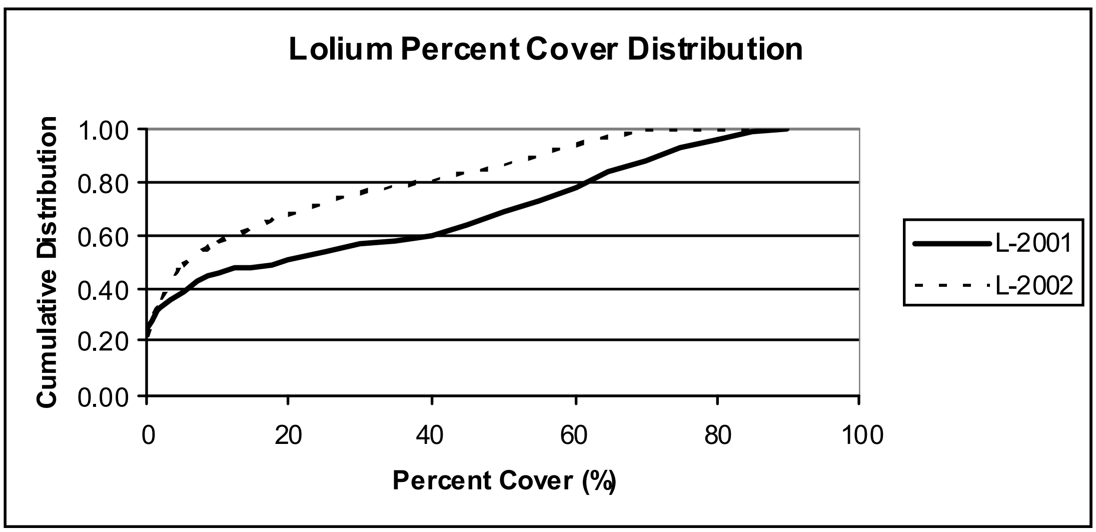


Figure 4.4 Monthly Precipitation

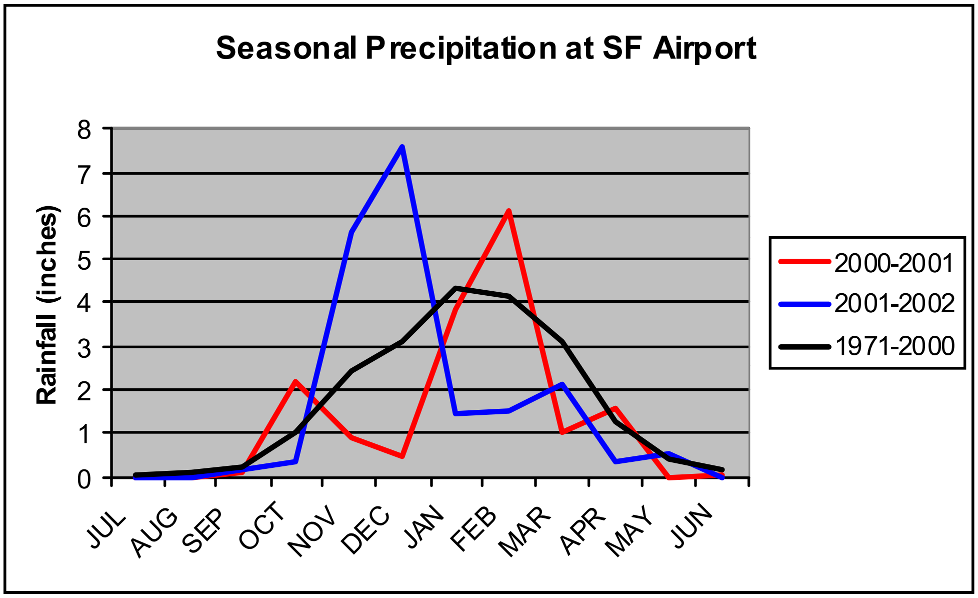
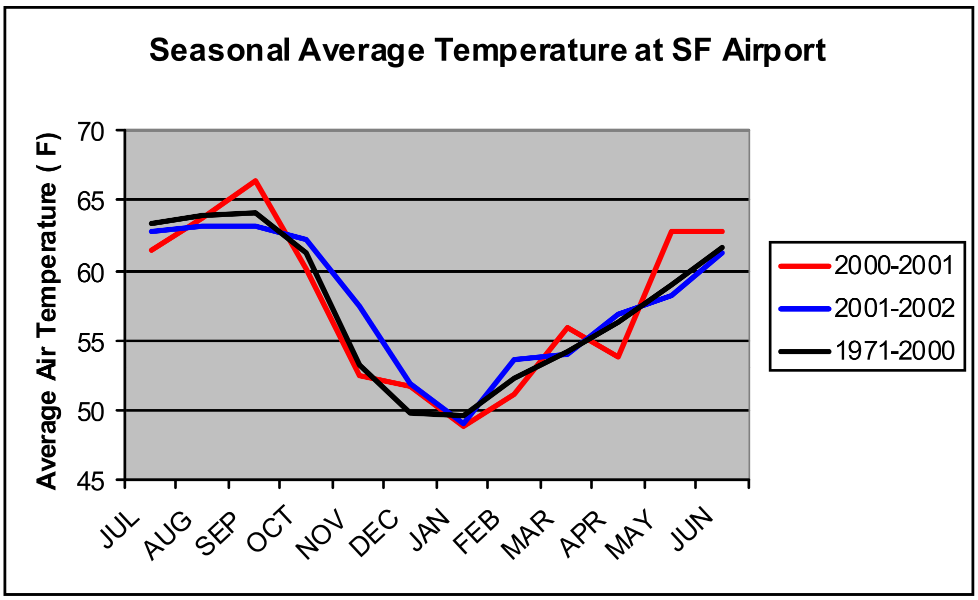
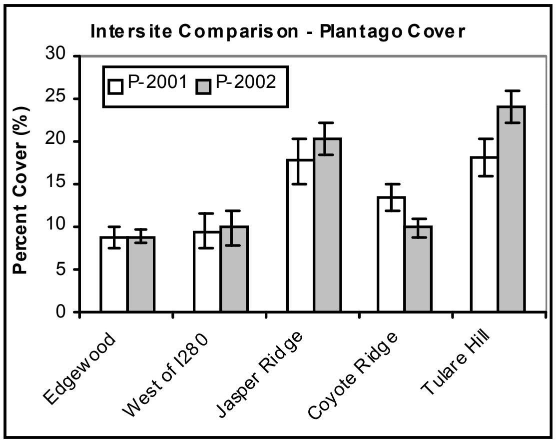


Figure 4.5 Monthly Temperatures



Host and Nectar Plants

Figure 4.6



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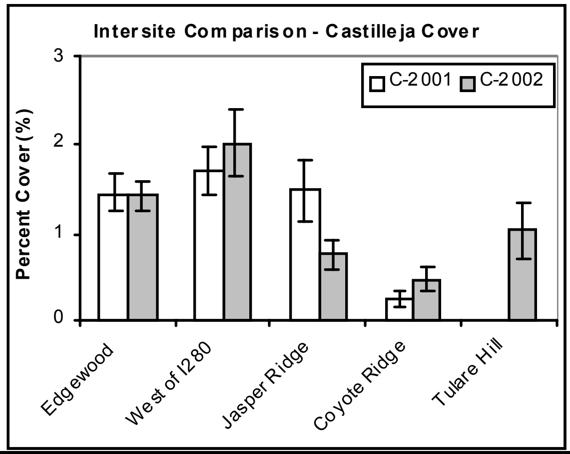

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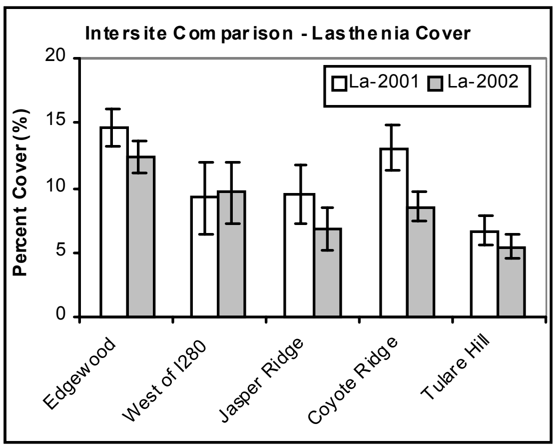

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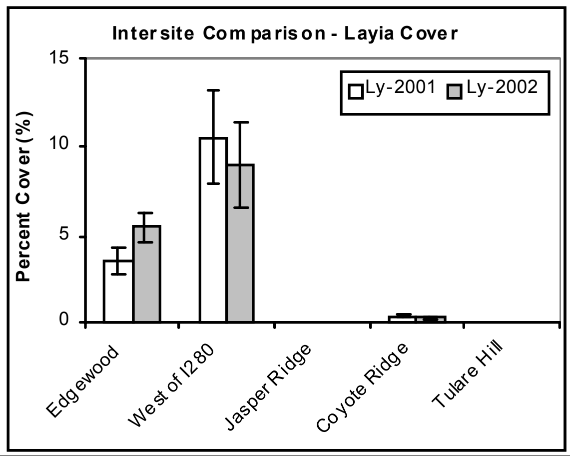

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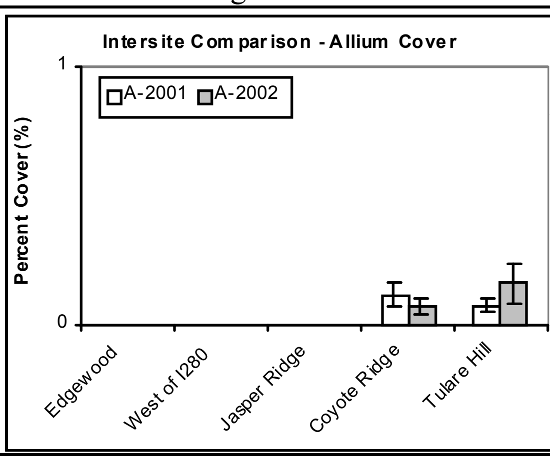

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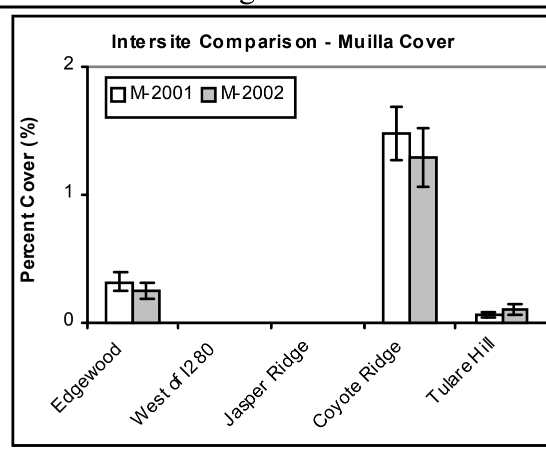
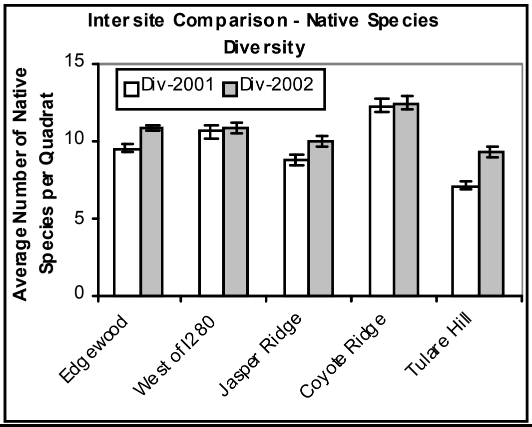


Grasses

Figure 4.12



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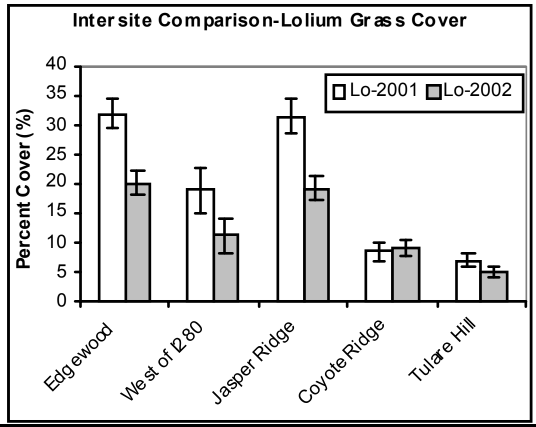

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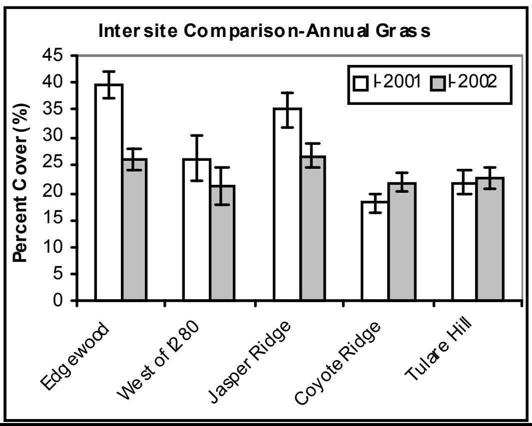

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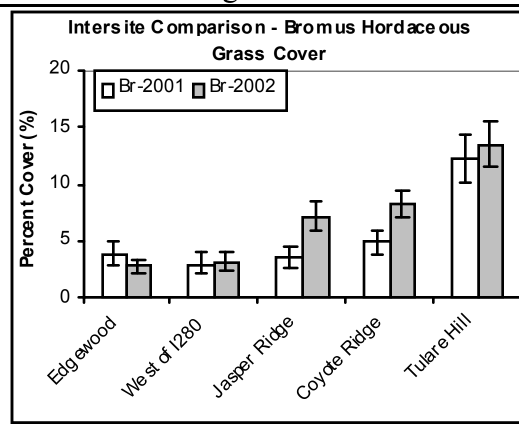

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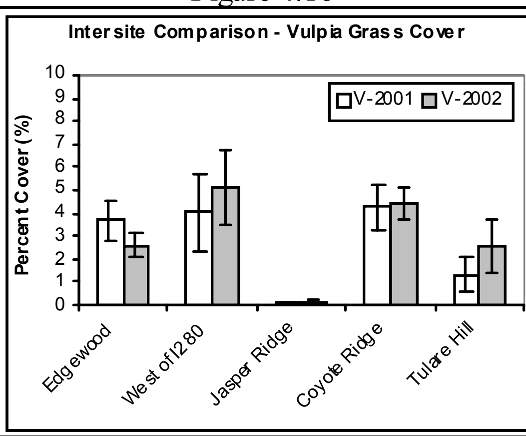


Figure 4.17

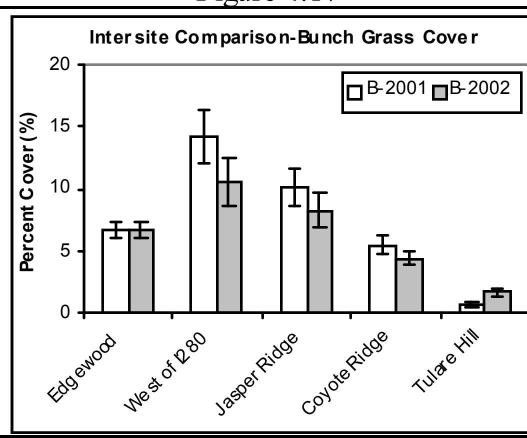


Photo 4.1 Transect in high quality habitat

David Luth and Toni Corelli in background. High quality *Plantago* habitat with 23% cover. Note the deeper soils a few meters out where introduced grasses dominate. The main introduced grass here is *Bromus hordaceous* at 8% cover. *Lolium* cover only 3.7%

Photo 4.2 Transect in high forb, low *Plantago* cover

Transect on thin soils close to Highway 280. *Plantago* cover 4% despite high forb cover, and *Lolium* cover of 27%.

Photo 4.3 Transect in high grass, low *Plantago* cover

Transect on thin soils close to Highway 280. *Plantago* cover 2.8% and *Lolium* cover of 40%.

Photo 4.4 Typical thatch layer in degraded habitat

Section 5: Grass invasions patterns: nitrogen fertilization from Highway 280?

This analysis considers three factors that are hypothesized to affect the abundance of *Lolium* and *Plantago* at Edgewood. Soil depth has a strong effect on *Lolium* cover and biomass at other serpentine sites (Huenneke et al. 1990). Ungrazed sites in South San Jose, where nitrogen deposition rates are on the order of 10 kg-N ha^{-1} yr^{-1}, convert rapidly to dense swards of *Lolium* and other invasive grasses (Weiss 1999). At Edgewood, traffic on Highway 280 may be emitting substantial amounts of NO_x that can dry deposit downwind of the source. Calculations based on traffic loads and emission factors estimate total NO_x production per year and a wind rose demonstrates strong prevailing NW winds except for mid-winter (Fig. 5.1). If the traffic emissions are affecting the grassland, one would expect to see the following pattern: *Lolium* cover will be higher downwind of the freeway as opposed to upwind, and will be higher closer to the freeway than further away. Soil depth will have a significant effect, but the effects of the freeway should be apparent on shallower soils.

17 transects were east (downwind) and 4 were west (upwind) of the roadway, ranging 25-540 meters from the roadway centerline. Every 5 meters, cover of all plant species was visually estimated in a 0.25 m^2 quadrat, and four soil depths measured. Multiple linear regression tested effects of mean soil depth, roadway distance, and direction against log-transformed cover of *Plantago* and *Lolium* (Table 5.1).

Emission calculations for Highway 280 used data from Caltrans and California Air Resources Board (CARB). Traffic has held steady at about 100,000 vehicles/day for the past 5 years. Low and high estimates are calculated based on vehicle speeds and traffic mix. The freeway frontage through the Preserve is approximately 1 kilometer long, so estimates will be in metric tons of NO_x per km per year (mtons-NO_x km^{-1} $year^{-1}$).

All data are consistent with the hypothesis that short-range N-deposition from vehicle emissions appears to be effectively fertilizing the grassland, allowing *Lolium* to invade and degrade the butterfly habitat. As hypothesized above, *Plantago* cover increased with roadway distance, decreased with deeper soils, and was higher upwind than downwind (Table 5.1). *Lolium* cover followed the opposite pattern – decreased with roadway distance, increased on deeper soils, and was lower upwind.

The range of potential NO_x emissions from 280 can be bracketed. 100,000 vehicles passed the site daily over recent years. Traffic speed has a huge effect on NOx emissions (Fig. 5.2). A low estimate is 15.1 mtons-NO_x km^{-1} $year^{-1}$ if traffic is treated as cars going at moderate speeds (20-45 mph),. The fleet average at 65 mph (104 kph) provides a high estimate of 58 metric tons-NO_x km^{-1} $year^{-1}$ Traffic on 280 is primarily automobiles and light trucks, with about 10% heavy trucks. Heavy trucks have high NO_x emissions, but are a lower proportion of traffic on 280 than on other major freeways. Therefore, overall fleet averages slightly overestimate NO_x emissions. Small differences in vehicle mix are likely swamped by the effect of traffic speeds (Fig. 5.2) – average speeds regularly exceed 100 kph (70 mph), in the zone where NO_x emissions are rapidly increasing with speed. During morning rush hour when speeds drop to 30-50 kph (20-30 mph) or slower, NO_x emissions may be lower than when the freeway is just at or below capacity.

Prevailing WNW winds (Fig. 5.1) blow tailpipe level NO_x-emissions into adjacent grassland, where some fraction dry-deposits on plants and soils, with higher deposition expected closer to the roadway where concentrations are highest. Dry deposition is an extremely complicated process, but with all else (surface composition, plant cover, and wetness) being equal, deposition rates are a linear function of concentrations. Observations from passive monitoring of NOx at Edgewood will establish aerial NOx concentrations just east and west of the freeway and 400 m downwind, and a range of absolute deposition values can then be developed. Dispersion modeling from a line source is also possible using EPA approved models such as CALINE.

Extensive work has been done on nutrient limitations in local serpentine grasslands (reviewed by Weiss 1999). *Lolium* abundance and biomass is strongly nitrogen limited in serpentine soils, especially on shallow soils (< 20 cm) that normally support dense stands of *Plantago* and other annual forbs. *Plantago* stands on shallow soils may have high cover, but rapidly senesce. Plants on deeper soils tend to grow larger and senesce later than the small plants on shallow (<10 cm) soils, and provide much better prediapause larval habitat than shallow soils. The progressive restriction of *Plantago* to shallower soils nearer the freeway creates unfavorable timing for the butterfly over those areas of the habitat.

Edgewood also lies in the wetter part of the range of the Bay checkerspot (Murphy and Weiss 1988a). Wetter years appear to favor annual grass in serpentine grasslands at Jasper Ridge (Hobbs and Mooney 1995). The vigorous invasion of grass at Edgewood following 1997-98, and a similar response to 1982-83 El Nino rains, qualitatively corroborate such a relationship. However, the overall relationship between grass growth and weather has not been analyzed in detail, and is likely complex, depending on seasonal distribution of rainfall, temperature, and amount of dead standing biomass and thatch.. Additive effects of increased moisture and elevated N are likely and have been observed in experiments at Jasper Ridge Biological Preserve (N. Chiariello, pers. com).

Emissions from Highway 280 will continue to deposit on serpentine grasslands for many years to come, since fleet NO_x emissions are expected to decrease only incrementally over the next decade. Absolute measurement of N-deposition are difficult at best, but the passive monitoring stations in place may provide reasonable estimates. The ultimate needs for ongoing habitat restoration and management may depend on how rapidly N-deposition (at whatever absolute levels are present at Edgewood) interacts with the pattern of wet and dry years, and promotes the rebound of *Lolium* following restoration treatments.

Samples of raked cuttings in 0.5 x 0.5 m^2 in the 2001 mow plots contained 100 g of dry biomass/m^2 (Table 5.2). The mean N-content of foliage was 0.8%. Therefore, 8 kg-N ha^{-1} of nitrogen were removed by raking. In 2002, all rakings from three 337.5 m^2

plots were weighed, and a slightly lower figure of 5.8 kg-N ha^{-1} was obtained (Table 5.3). These plots were in lower biomass areas of the habitat than the 2001 plots. These figures are about the same order of magnitude as estimated N-deposition in Santa Clara County (8-10 kg-N ha^{-1} yr^{-1}). Removal of readily available N from the grassland may be an advantage of raking over longer time periods (it did not have a significant effect on plant composition from 2001 to 2002), but raking is expensive unless a mechanical method is used.

Table 5.1. Regression coefficients and LS means.

2001	Log_{10} Plantago	Log_{10} Lolium
Distance	0.0015/m	-0.0022/m
Soil Depth	-0.012/cm	0.017/cm
East (LS mean)	0.54	1.29
West (LS mean)	1.02	0.46

All effects p <0.001.

Table 5.2. Biomass and N-content 2001 Mow plots

2001	Mean	S.E.
Biomass	100	0.13
N-content %	0.78	0.02
Kg-N/ha	7.8	0.2
N-	1.02	0.46

Table 5.3. Biomass and N-content 2002 Mow-Rake plots

Plot	Area m^2	Kilograms	Kg/m^2	Kg/Hectare	kg-N/ha	lbs/acre	Lbs-N/acre
M7-M32	337.5	15	0.044	444	3.6	396	3.2
M29-M30	337.5	41.4	0.123	1226	9.8	1091	8.7
M2-M31	337.5	16.8	0.050	498	4.0	444	3.5
Average	337.5	24.4	0.072	722.8	5.8	643.5	5.1

Fig. 5.1 San Francisco Airport
Wind Direction Distribution (all speeds)

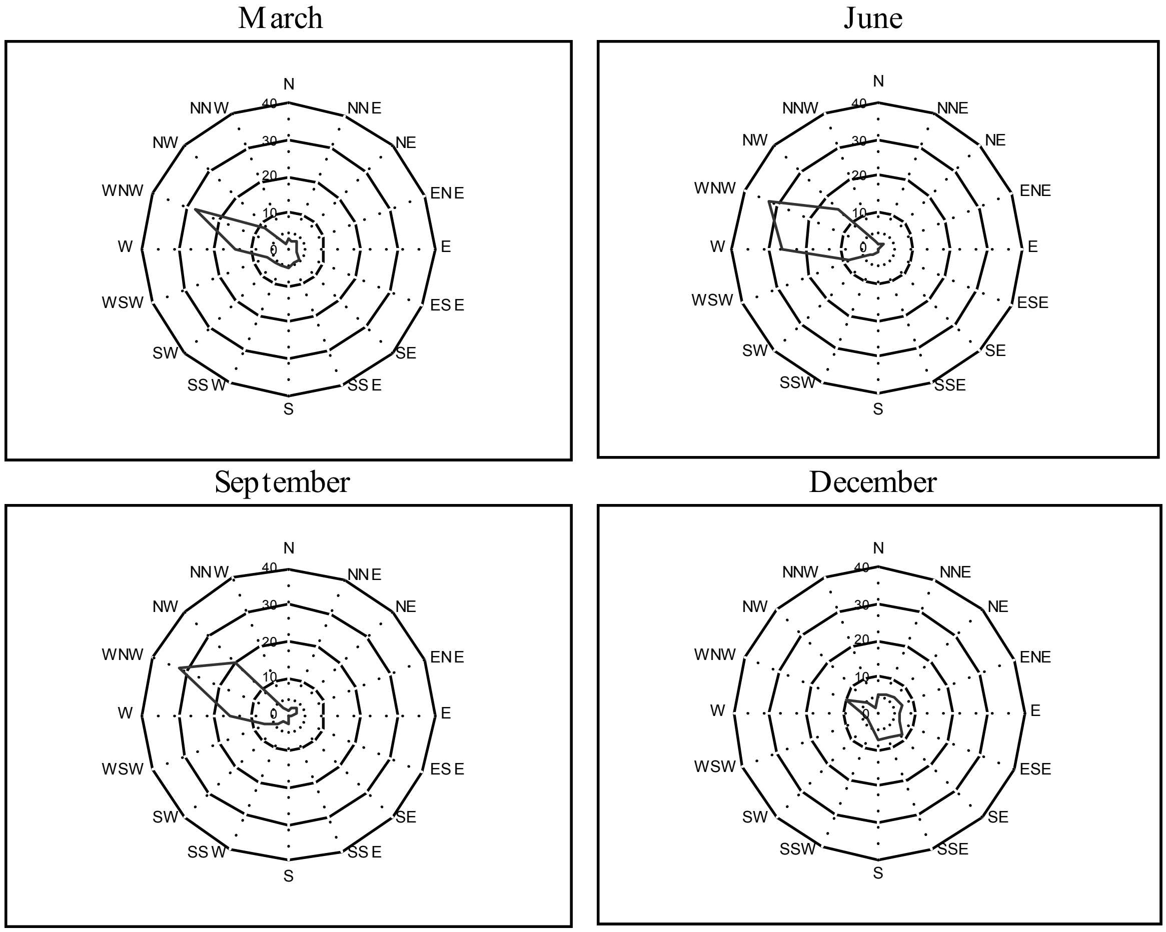
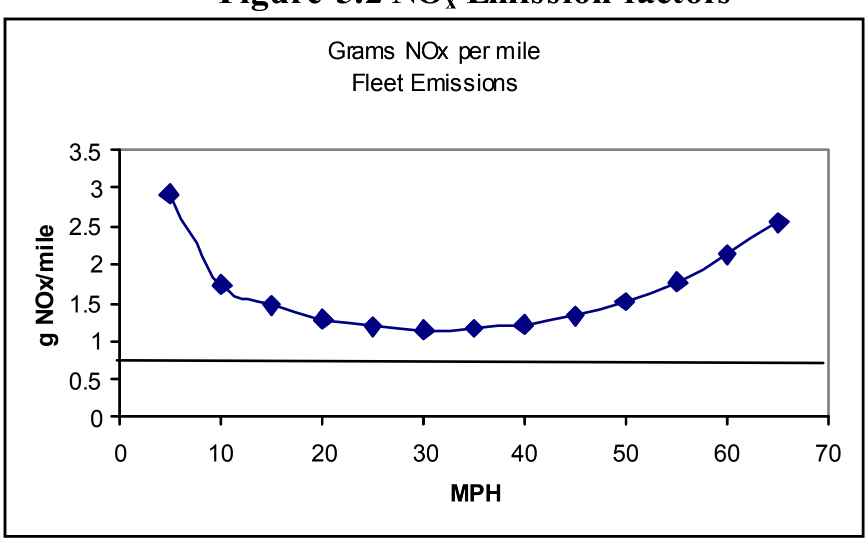


Figure 5.2 NO_x Emission factors



Section 6: Experimental treatments

Small-scale experimental treatments are an essential step for any restoration project. Testing multiple factors to identify biologically and cost-effective methods rapidly, and conversely eliminate ineffective treatments, requires some degree of statistical sophistication.

The quadrat methodology allows for repeated measurements of plant cover at known locations, a very effective experimental design. The high degree of natural variability in serpentine grasslands is both an advantage and disadvantage. High levels of fine-scale variability in soil depth, gopher disturbance make for a high degree of independence among samples 5 meters apart, so that the number of effective replicates is large. However, the interannual variability driven by weather and gopher disturbance is potentially very high, so a high degree of replication is necessary.

Experimental blocks were set up in anticipation of mowing, mowing and raking, goat grazing, and fire treatments (Map 6.1). Experimental blocks were parallel transects 10 meter apart, so that a total of 20 – 40 quadrats were available for treatments and controls in various blocks. Two 40 quadrat blocks were assigned to fire treatments, two 20 quadrat blocks to grazing, and two 20 quadrat blocks to mowing, raking, seeding and local disturbance. Internal controls (untreated) in each block were set up.

Planned treatments completed in 2001 and assessed in 2002 were springtime mowing, raking, and fall seeding with *Plantago*. The first year effects of light goat grazing could also be examined. Heavy goat grazing in March 2002 will not be evaluated until Spring 2003. Prescribed fires were not executed for various reasons (see below). Fall mowing was tested using comparisons of fall cut firebreaks versus adjacent uncut burn blocks.

Mowing/Raking/Seeding

On May 5 2001, ranger Rick Munz cut the grassland in several blocks using a gas powered string cutter (Photo 6.1). Most forbs, including *Plantago* and *Castilleja* were senescent by this date, but *Lolium* was still mostly green with few or no ripened seeds. The vegetation was cut close to the soil surface, especially to break up the duff and thatch layers. Small rocks were flung up to 5 meters, and duff was dispersed over a scale of 1 meter. These areas can be seen on both aerial photographs as the small blocks near the Eucalyptus trees (Maps 1.1 and 3.1, Map 6.1). One week later, duff samples were collected in 0.5 x 0.5 m^2 quadrats adjacent to plant monitoring quadrats to estimate dry biomass and nitrogen and phosphorous content. In early summer, two of the blocks were raked of the duff, which was disposed beneath the *Eucalyptus* trees. *Plantago* was seeded (400 seeds/m^2) in half of the monitoring quadrats (randomly assigned within blocks) in November 2001 following germination of many species, and 10 quadrats (randomly assigned within blocks) were disturbed by surface raking prior to seeding. Table 6.1 shows sample size of experimental treatments. Control plots included numerous quadrats within the experimental area that were not treated (i.e. unburned fire transects) as well as local controls within each block.

Goat Grazing

In March 2002, a herd of 48 goats was brought onsite by Sycamore Farms (Photo 6.2). Electric fences were set up around four 15 x 20 meter plots and grazed for 24 hours, which largely stripped the vegetation from the entire plot (Photo 6.7). One unused fire plot (20 x 30 meters) was grazed for 24 hours (half the intensity). Results from the heavy grazing will not be apparent until 2003, but preliminary analysis of the lighter grazing is presented below.

Prescribed Fire

All requisite permits for prescribed burning were obtained, and contacts with CDF (Mike Gagarin) included a site visit in September 2001. Plots were laid out and firebreaks cut with a string cutter. However, the burn was not executed. A spring burn scheduled for May 22, 2002 was cancelled by late season rain, and a rescheduled June 5 date was cancelled by a directive from State CDF. A fall burn in 2002 does not appear feasible. As mentioned above, these unburned plots were used as additional control plots.

Experiment Analysis

Statistical analysis for hostplants, nectar sources, annual grasses, and select other species was done by repeated measures ANOVA, testing across mowing, with raking and disturbance nested within mowing. Treatment was crossed with seeding treatment for analysis of *Plantago* response. All plant data were log transformed ($\log_{10}$ [cover +1]) to normalize the distributions. The analysis effectively compares the difference in a particular species cover in each quadrat between the two years, and is also known as a Before-After Control-Impact design (BACI). Each quadrat was treated as an individual replicate following extensive testing for block effects and spatial dependence, and no significant block effects, block by treatment interactions, or spatial dependence was detected in either initial conditions or effects. This analysis confirms that local changes in soil depth and disturbance dominate plant variability on fine-spatial scales of meters or less and that sample quadrats can be treated as independent for statistical purposes. The responses of hostplants, nectar sources, annual grasses, and several late-season forbs were also examined, along with changes in overall native species richness. Statistical analysis was done in JMP IN 4.0 (SAS Institute).

A fall mowing treatment was tested by comparing firebreaks string cut in Fall 2001 with undisturbed areas in the adjacent unburned burn blocks acting as controls. Because no 2001 transects were placed in the firebreaks, the response was tested by comparing *Plantago* and *Lolium* in 20 quadrats (2 transects) in the firebreaks with the 40 quadrats (4 transects) within the unburned area using 2002 plant cover data. No seeding was done in these transects.

Results

Photographs of the mow line in April 2002 show a visible difference in plant community (Photos 6.3 and 6.4). Outside the mow line, there is much standing dead biomass from 2001 (foreground of Photo 6.3, and right side of Photo 6.4). The plant community within the mowed area was diverse and had a high proportion of native species, minimal duff, and little thatch (Photo 6.5).

The full statistical treatment, with output tables from JMP IN are presented in Appendix A (provided in electronic form on CD). A summary table provides the results of tests for significant effects (Table 6.2) of treatments. Mowing was the only strong individual factor identified, Raking had no additional effect, nor did seeding have a significant effect on *Plantago* cover, and no interaction terms were significant.

Because the raking and seeding did not have significant effects on any species, these factors were lumped to summarize the overall effects of mowing on key species (Fig. 6.1). *Plantago* increased from 3 to 9% cover in mowed quadrats, compared with no change in control quadrats. *Lolium* decreased from 50% to 15% in the mowed quadrats, and showed a lesser decrease from 50 to 40% in control plots. *Castilleja* cover was unaffected by mowing, maintaining about 1% cover in both years in mowed and unmowed plots. (not shown). *Lasthenia* increased from 4 to 8% cover.

Species richness in the mowed plots increased from an average of 7.8 to 11.3 species/quadrat, compared with a nominal increase in the control plots. The reduction in Lolium and thatch allowed for much higher forb densities, and the wildflower display in the mowed plots was much more intense than in the adjacent unmowed areas (Photo 6.4)

The mowing also provided a qualitative improvement in hostplant resources. Individual *Plantago* were very robust in the mowed plots, with multiple flower heads and high seed production, and remained green relatively late into early May. *Plantago* in untreated plots was largely senescent by mid-April. Individual *Castilleja* were also more robust, and remained green longer than in adjacent umowed areas.

Other species examined showed no detectable effects. Two mid-season annuals, *Clarkia rubicunda* and *Sidalcea diploscypha* were flowering at the time of mowing. Both of these species were present in the mow plots in 2002 in similar densities to 2001.

Perennials are expected to be able to recover from one-time mowing. The bulb-forming *Brodiaea*, *Tritelia*, and *Dichelostemma* species were all present throughout the mowed plots in 2002. Bunchgrass cover also did not change following mowing.

When mowed with a string-cutter, many *Lolium* that have not yet ripened seed were prevented from seeding. The duff and thatch layer were broken up, and ripe seeds of forbs were scattered up to a few meters across the plots.

Cover of key plant species in the fall mow transects did not differ significantly from the adjacent undisturbed habitats. Fall mowing appears to be ineffective as a management technique

Raking

Raking had no detectable effect on any species in 2001. Raking removed approximately 100 g of dry biomass/m^2 with a nitrogen content of 0.78%. It also redistributed seeds and further disturbed the thatch layer. It appears that unraked cut material largely decomposed *in situ*. However, the long-term effects of raking and removing readily available nitrogen may be a positive benefit, so the fate of raked versus unraked plots will be followed for several years.

Disturbance

Small-scale disturbance (raking the soil surface in November 2001 following germination) had been included in case simply mowing was not effective. Because the results showed that mowing without disturbance was highly effective, the disturbance treatment has been dropped from consideration.

Goat Grazing

The heavy goat grazing effectively stripped almost all vegetation from the plots (Photo 6.6). *Plantago* was among the last species to be eaten by the goats. Bunchgrasses were grazed, but resprouted and produced heavy seed set in May. As mentioned above, the results of the heavy goat grazing will not be known until Spring 2003. The light goat grazing left more live plant material behind (Photo 6.7) and did not have statistically significant effects on key plant species.

The deposition of goat pellets (feces) was of some concern, given the appearance of the heavily grazed goat plots. All goat pellets from 0.5 x 0.5 m^2 quadrats adjacent to plant sample quadrats were collected and weighed (Table 6.3). The total amount deposited was 40 g/m^2, with some quadrats having none, and some upward of 120 g/m^2.

It is important to note that goat feces are lower in nitrogen than the vegetation consumed, and that feces represent a very local redistribution of nutrients. More nitrogen is probably deposited by urine, which was not measured. The effects of high density goat droppings will be noted in 2003, when the quadrats are resampled for plant cover.

Phase 2 Experiments

In order to solidify the conclusions that mowing is an effective treatment, and further test raking and seeding, 6 more 337 m^2 blocks were mowed between May 8 and May 12, 2002 (see below Map 10.1).. Each plot contains 8 quadrats, and 8 control quadrats are interspersed with each pair of blocks. One of each pair was randomly selected for raking. Rakings were weighed after air drying, and nitrogen contents from 2001 were used to estimate total N removed with the rakings (see above, Table 5.3). Half of these quadrats, both control and mowed, will be seeded with 100 Plantago seeds (rate = 400/m^2). Results from these experiments will be assessed in Spring 2003.

Table 6.1 # quadrats in each treatment

Treatment	Total	No Seed	Seed
Mow	11	6	5
Mow-Rake	11	6	5
Mow-Disturb	10	5	5
Goat graze light	16	16	0
Control	72	72	4

Table 6.2 Species responses

Species	Mow	Rake	Seed	Disturb	Goats
Plantago erecta	(+)***	0	0	0	0
Castilleja densiflorus	0	0	0	0	0
Lasthenia californica	(+)*	0	0	(-)**	0
Layia platyglossa	(+)*	0	0	0	0
Lomatium sp.	nd	nd	nd	nd	nd
Muilla maritima	nd	nd	nd	nd	nd
Lolium multiflorum	(-)***	0	0	0	0
Bromus hordaceous	(-)*	0	0	0	0
Clarkia rubicunda	0	0	0	0	0
Sidalcea diploscypha	0	0	0	0	0
Brodiaea sp.	0	0	0	0	0
Bunchgrass	0	0	0	0	0
Species richness	(+)**	0	0	0	0

Table 6.2 (+) denotes increase, (-) denoted decrease. 0 denotes No Change. nd – not enough data to draw conclusions. P values denoted by asterisks -*** p< 0.0001, ** p<0.01, * p <0.05

Table 6.3 Goat droppings by area grazed

Grazing Area	Grams/m^2
Block 21-22A	47.5
Block 21-22B	16.6
Block 23-24A	46.9
Block 23-24B	49.1
Total Area	40.0

Figure 6.1 Mowing (aggregated) results

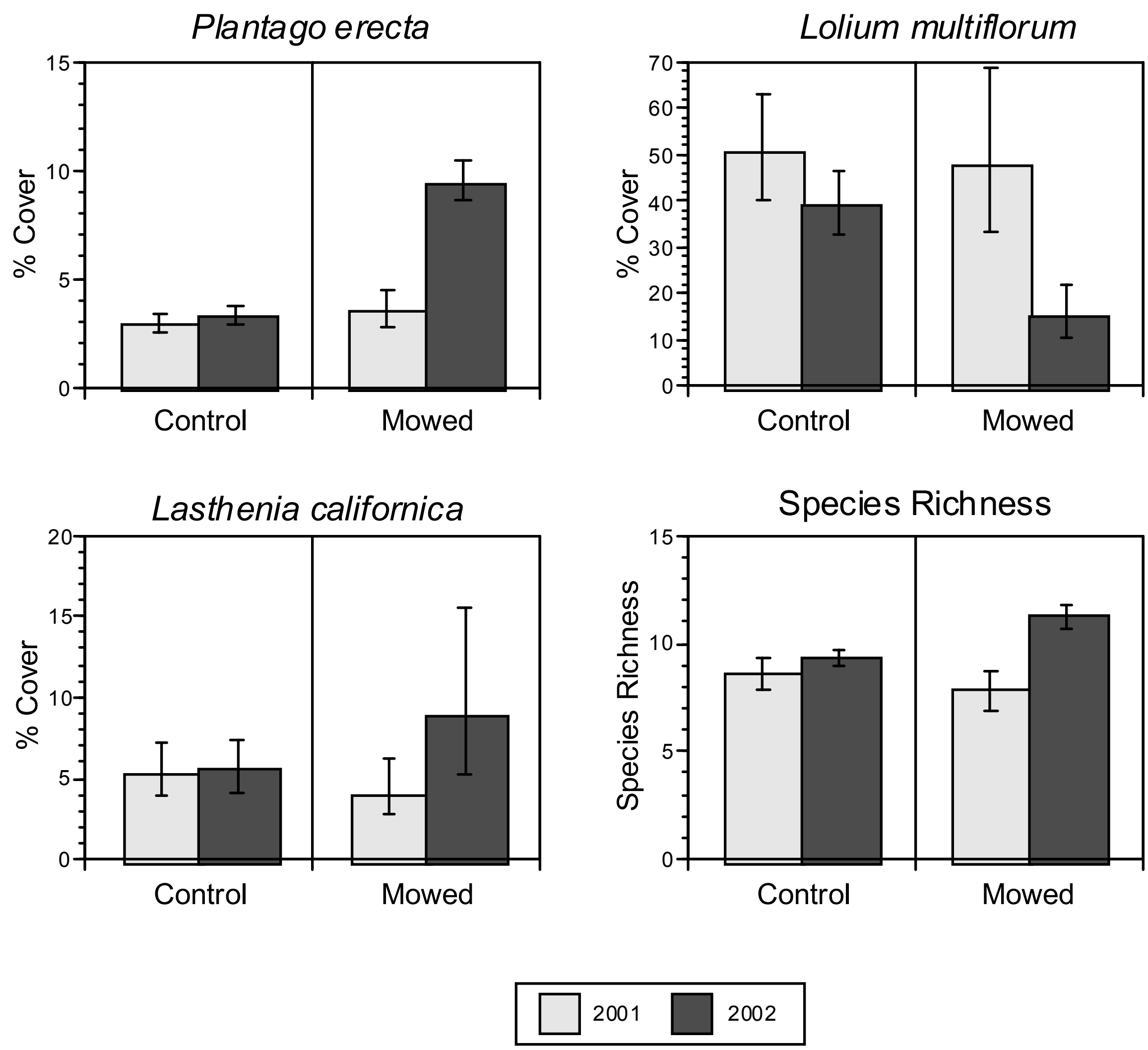


Figure 6.1. Significant ($p < 0.001$) responses of key plant species to mowing treatments. Error bars are 95% confidence intervals. No other species showed significant changes in response to mowing.

Map 6.1 Experimental Blocks

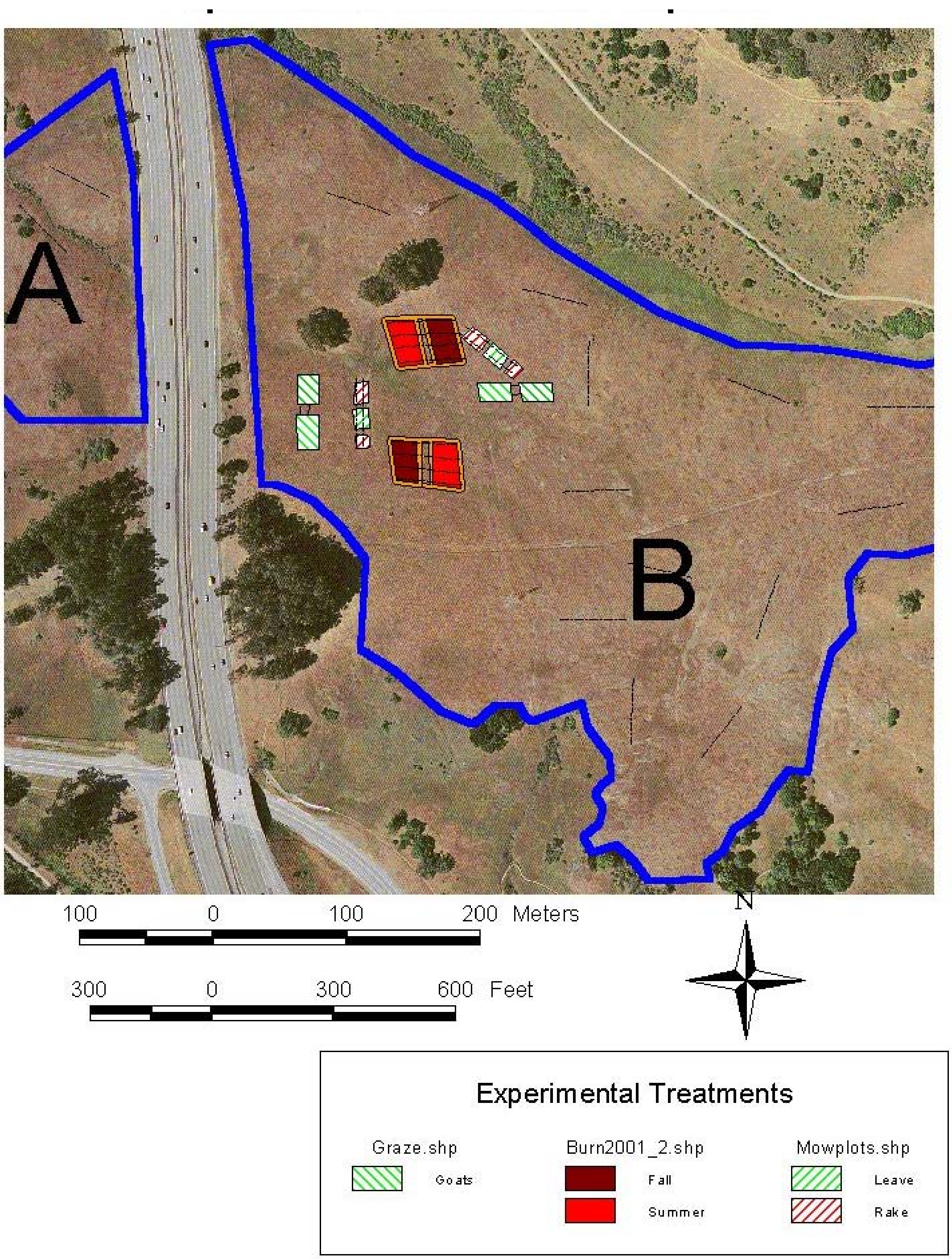


Photo 6.1 String-cutting by Park Staff May 8, 2002

Photo 6.2 Goat Pen March 2002

Photo 6.3 Mow line marked on tape

Photo 6.4 Right mowed, Left umowed

Photo 6.5 High native species cover/diversity in mowed plot

Photo 6.6 Robust and dense *Plantago* in mow plots

Photo 6.7 Effects of heavy goat grazing

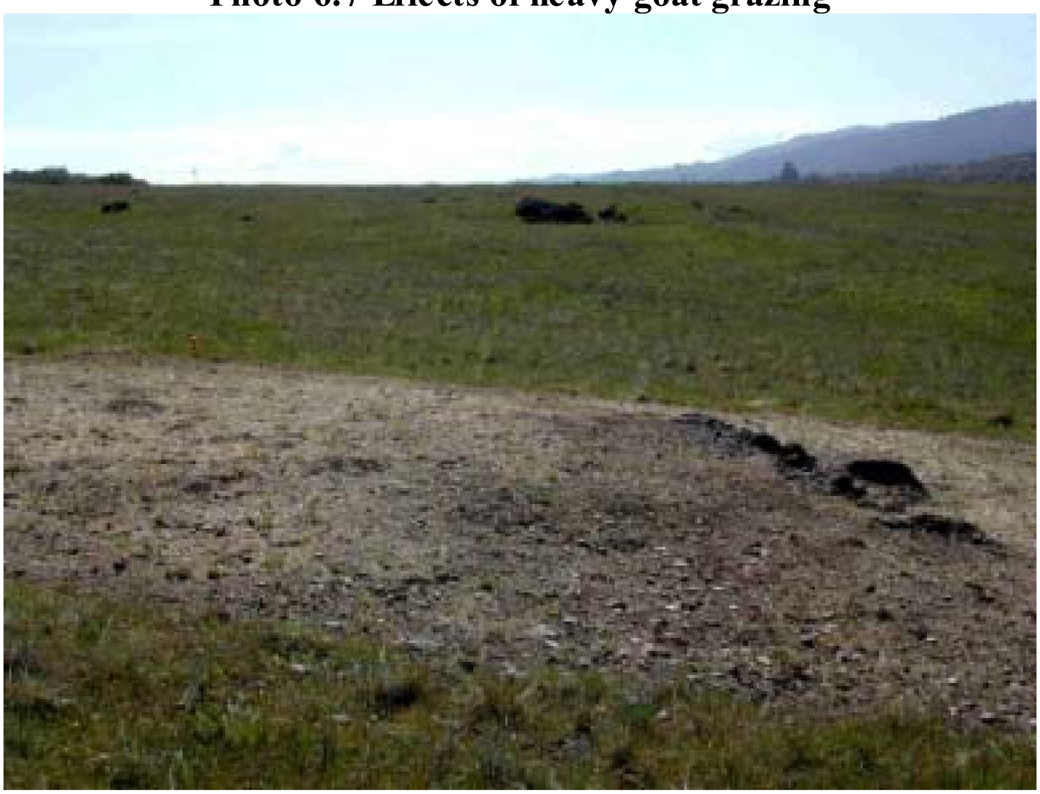


Photo 6.8 Effects of lighter grazing

Section 7. Plantago Seed Propagation

In April-May 2001, more than 15,000 *Plantago erecta* seeds were collected from grasslands within Edgewood Park. Some were used for seeding the experimental plots, and more than 6000 were used to start a seed farm at the ranger station. Seeds were planted in numerous flats and were grown in winter 2002. under outside conditions, some in the ground and some in flats in a screen house structure. The ranger station site is actually quite cool and shady in the winter compared with the open serpentine grasslands, and plants grew slowly for many months. Entire plants were harvested in late May 2002. Each individual plant was far more robust 15-30 cm (6-12 in) than those on the serpentine (2-3 in or less), and produced multiple flower stalks. A total of 1.7 kg (3.7 lbs) of Plantago biomass was harvested. Based on 171 seeds/gram of dry biomass, the seed harvest for 2002 was 287,000 seeds. A small portion of seeds will be used to further test seeding in the 2002 mow plots.

Producing seed for mass-scale reseeding is possible with one more growing season for seed production. At 400 seeds/sq meter, the seeds produced in 2002 are sufficient to seed in approximately 0.07 ha (0.8 acre). Production would have to increase by a scale of 5-10 to provide enough seed to treat multi-acre sites. It might be possible to grow substantially more individual plants in the plots and screen house at the ranger station, now that procedures are well-worked out.

Commercial seed companies such as Pacific Seed will grow out seeds for production. If seed production/plant remains at 180 seeds, there is sufficient seed in hand (>200,000 seeds) to grow enough of a crop to seed 10 ha at 400 seeds/sq meter. Such a grow out could be done during one season and provide seed for several years of restoration. Costs would have to be worked out with the seed company.

Table 7.1

# seeds/gram dry whole plant biomass	171 ± 13	
Dry plant biomass 2002	1.684 kg	3.7 lbs
Total number of seeds 2002	287,000 ± 20,000	
To be used in seeding experiments 2002	7200	72 quadrats X 100 seeds

Section 8. Bay checkerspot butterfly reintroduction options

The Bay checkerspot butterfly is likely to be completely extinct at Edgewood in the next year or two, if not already as of 2002. Healthy populations exist in Santa Clara County and are a potential source of individuals for reintroducing the butterfly into Edgewood Natural Preserve. The following principles are an initial attempt to guide reintroduction efforts, and are open to refinement and additions as the process proceeds.

1) The habitat at Edgewood represents the best chance for a healthy Bay checkerspot butterfly population in the San Francisco Peninsula.
2) Principles of adaptive management will be necessary, with monitoring and yearly planning essential components.
3) The population is at or near complete extinction in 2002. Rapid recovery to hundreds or thousands of individuals is extremely unlikely if nothing is done. Confirmation of extinction will take 2-3 additional years, because the population may persist at extremely low numbers before complete extinction.
4) Healthy populations in Santa Clara County with hundreds of thousands of larvae and adults in 2002 are a ready source population for reintroduction material. Removal of hundreds or even thousands of individuals from the center of these dense populations will have little impact, if the populations remain at high levels. Even at the lowest population sizes observed at Kirby canyon (25,000 larvae), hundreds of individuals could be removed for transplantation.
5) Captive rearing is expensive, and success is uncertain. If the Edgewood population were to rebound substantially on its own, only then could captive rearing be considered. There would still be danger of a genetic bottleneck, which must be weighed against the potential genetic uniqueness of remaining Edgewood butterflies.
6) Introducing butterflies into poor quality habitat as currently exists at Edgewood is likely a wasted effort. Substantial areas of EWB should be treated before reintroduction.
7) Introduction of butterflies into the smaller subareas should be considered in conjunction with reintroduction into EWB, and local restoration needs assessed. However, the main effort should be directed at EWB.
8) Coordination with reintroduction at Jasper Ridge Biological Preserve should be pursued, but reintroduction to Edgewood should not be dependent on the ability to reintroduce butterflies elsewhere.
9) All activities will require permits from USFWS. If continued restoration activities are needed following reintroduction, then there is potential for take of individual Bay checkerspot eggs, larvae, pupae, or adults, depending on the timing of treatments.
10) Maximal amounts of scientific information should be derived from the reintroduction attempt, but such studies should minimize risks to reintroduction success.
11) Postdiapause larvae and adults are the two best stages for reintroduction because they are easiest to collect and handle. The advantages of using larvae are: a) larvae would finish their development and pupate on site, and emerge according

to natural phenology; b) it would be possible to start the population with a mix of early and late developing larvae so as to spread risks of early hostplant senescence and late season rains; c) a full complement of parasitoids would likely accompany a significant infusion of postdiapause larvae, so that all components of the food web would be present. The disadvantages of using postdiapause larvae include: a) a potential 50% or greater mortality rate from parasitoids, pupal predation, and disease; b) inability to get genetic information on larvae with current technology.

12) The advantages of using adult butterflies include: a) easy capture and handling; b) ability to gain genetic information from legs; c) release into habitat is straightforward, and releases could be timed to spread risks of inclement weather. Disadvantages of releasing adult butterflies include: a) female butterflies will already have laid some portion of their egg production, so effective propagule size will be lower than an equivalent number of larvae; b) no parasitoids will be present; c) poor weather immediately following releases may cause high mortality.
13) Transporting pupae, eggs, or prediapause larvae is more logistically difficult than transporting postdiapause larvae or adults and does not appear to have any special advantages.
14) The initial releases should be in the hundreds of individuals. This number will ensure a high amount of genetic diversity and opportunity to survive a string of poor post-reintroduction years.

These principles are open for discussion and may form the basis for a more formal reintroduction plan and proposal. Money for planning the reintroduction may be pursued through Section 6 recovery funds from USFWS, or other sources as identified.

Section 9. Potential conflicts with other species

Restoration activities, whether mowing, grazing, fire, etc. could have impacts on other species. Location and timing determine the level of impact on particular species. The locations of protected plant species in Edgewood Preserve are well-mapped, were and avoided in present experiments, and will continue to be avoided. Only one protected plant species exists in the proposed restoration areas close to Highway 280 (a small population of *Pentachatea bellidiflora* on extremely shallow soils), and can be easily avoided.

Mowing increased native species cover and diversity by reducing *Lolium* cover and scattering seeds. Perennials such as Brodiaeas, bunchgrasses, and *Lomatium spp.* can resprout the following year and should be relatively unaffected. Mid-season blooming native annuals such as *Clarkia rubicunda* and *Sidalcea diploscypha* are the most sensitive to mowing at that time. These species persisted from 2001 to 2002 in mowed areas, but the interspersion of mowed and unmowed areas within the mow blocks should allow for persistence of these species.

Potential impacts on grassland-nesting birds, particularly Western Meadowlarks, was brought up as an issue by Lee Franks. Several meetings and field trips , Field observations by Lee Franks and SBW and DCL indicated that mowing in 2002 was during territorial set up, but prior to actual nesting activities. Meadowlarks were observed post-mowing around all the 2002 mow plots. At this point there does not seem to be an irreconcilable conflict between mid-spring mowing and nesting meadowlarks.

Section 10. Management Options and Recommendations

This section assesses the restoration experiments so far, and lays out management options and recommendations, including a 3-4 year plan for restoration. An adaptive management framework is necessary, because of unpredictable yearly weather, variable ecological conditions, and changing socio-political circumstances, and other unanticipated factors.

Adaptive management provides for careful monitoring of activities and their results in a scientifically defensible manner.

Mowing is an effective method for habitat restoration in serpentine grassland. It increased *Plantago* cover by a factor of 3, and reduced *Lolium* cover by an factor of three. Species diversity increased, due to increased cover of native species. Mowing with string-cutters has the following advantages:

1) Can be timed precisely to maximize reduction in *Lolium* and minimize impacts on desired forbs that have already senesced. This window lasts 1-2 weeks, and will vary according to yearly weather. There will be 1-2 weeks notice for scheduling purposes, but some flexibility at the last minute will be necessary

2) uses equipment and staff already available to San Mateo County Parks;

3) it can be contracted out depending on costs (see below);

4) treatment areas can be precisely delineated;

5) it is possible to be selective within treatment areas so that concentrations of desirable plants can be avoided.

Time and costs for mowing by string-cutting were calculated from experiences in 2002. In 2002, 3 areas were chosen for mowing (Map 10.1). Each area had 2 plant transects across the mow plots to evaluate the plant species changes from 2002 to 2003. Each area had two mow plots with a control area in between, similar to the mowing pattern in 2001. Each mow plot was approximately 22.5 meters by 15 meters and the total area mowed in 2002 was ½ acre. The mowing was completed between May 8th and May 12th after a majority of the native forbs had set seed but before the invasive grasses had set seed. This timing is critical to reduce the seed success rate for the invasive grasses, and minimizing negative impacts on native annual forbs.

The mowing process was done by the park staff using string cutters. String cutters are the most appropriate tool given the rocky nature of the serpentine soils and the need to cut close to the ground to eliminate re-growth and disturb the duff layer. Time studies were done during the string cutting process to determine the level of effort and cost associated with this type of habitat treatment. The mowing rate depended mostly on equipment reliability. In one 45-minute period, there were no string changes needed. In another 1-hour period, 3 string changes were needed due to equipment failure. A reasonable average mowing rate of 18 person hours per acre was calculated from this time study (Table 10.1).

Shelter Belt, a commercial landscape company, has quoted $1000/acre maximum for string cutting in open grasslands. This seems reasonably consistent with our string cutting rate calculations from Spring 2002. Costs might be reduced if another technology can be found, including a flail mower or similar equipment, that can work in rocky serpentine grasslands. "Touch up" work with string cutters could supplement mowing to reach rockier areas, or close to sensitive plants, if those areas needed treatment.

A sample mowing rotation is presented in Map 10.1 This preliminary map is subject to modification. EWB is divided into 6 subunits, one of which is the currently high quality area of about 8 acres. Assuming that 25 acres are in need of restoration treatment, each of the other subunits is about 5 acres. For example, a 3 year rotation, 1/3 (1.67 acres) of each subunit (except for the currently high quality 8 acres) would be treated, for a total of 8.33 acres each year (Table 10.2). For a four-year rotation, 6.25 acres would need treatment each year, and so on.

These acreages are feasible for a work crew of several people over a week. The exact fine-scale pattern of mowing could be in strips or larger blocks. It may be important to avoid a "checkerboard" pattern, i.e. blend the mowed subunits into the landscape by creating natural looking irregular boundaries among subunits. The main tradeoff involved is the effort in flagging/marking sub-subunits – finer scale units will require more markers and flagging. Narrower strips would allow for recolonization of mowed areas by plants that are adversely affected by mowing in any given year, but also might provide for increased grass seed from unmowed areas.

The number of years required between treatments will only be known as the existing experiments proceed. The increases in *Plantago* cover, vigor, and seed set should lead to high *Plantago* cover for at least 2 years – the first year response (as observed), and high cover from a large seed crop. It is possible that *Lolium* will rapidly reinvade, grow vigorously, and overtop the forbs within several years, especially if weather favors grass growth. The nitrogen deposition from Highway 280 will likely decline slowly over the next decade as fleet NO_x emissions are reduced as CARB and EPA standards tighten, but no major reduction in vehicle numbers are expected.

Adaptive management has already begun – the 2002 mowing was designed to further test the most promising techniques identified from the 2001 experiments. Implementation of mowing in 2003 will be done after the results of the 2002 mowing experiments are assessed. There will also be a second year of data from the 2001 mow plots. Fine tuning 2003 mowing in the context of these results will be possible.

Other methods considered

Goat grazing has not been fully evaluated, so its effectiveness is unknown. Qualitative observations, and the experimental results from the lower intensity goat grazing suggest several disadvantages of goat grazing. The intensive grazing necessary to reduce the duff and thatch layers appears extreme in the first year, and would not be appropriate for large areas. The lighter grazing did not appear to have positive effects the first year. Goats are also expensive – the 5 days of goat grazing cost $1500 which would be $2000/acre at the light grazing level. There would be some economy of scale with a larger herd and larger plots. Goats, however, are not as selective as other livestock such as cattle.

Cattle grazing is highly effective in maintaining serpentine grasslands in Santa Clara County. Cattle are highly selective on annual grass (more selective than goats). However, the ~25 acre area in need of restoration at Edgewood is small for an economical cattle operations – only 2-4 cows would reach typical stocking rates of 1 cow/10 acres or 1 cow/6 acres. Cattle require sturdy fencing and a constant water supply. A rough estimate of needed fence for the 25 acres needing restoration is 1.2 miles. Seasonal grazing with higher densities of cattle for a short-period is a possibility, but the effectiveness of cattle grazing in other sites may be dependent on grazing pressure through the whole season, from grass germination to senescence .

Sheep may be effective in restoring serpentine, but have the same problem as goats in that they are likely to be expensive. Sheep, like goats, can be effectively controlled by electric fencing. Sheep grazing in watershed areas for drinking water (such as Crystal Springs) is discouraged, primarily when the sheep are grazing up to the boundary of the reservoir and can directly contaminate surface water with feces that may carry diseases. It is unlikely that surface water contamination would occur during seasonal grazing at Edgewood, but the contamination issue would need to be addressed.

Prescribed fire may provide cost effective initial treatment if it can be executed, but in the absence of tests at Edgewood, its effectiveness at increasing *Plantago* cover and reducing *Lolium* cover is unknown. A spring burn, timed to when *Lolium* seeds have not yet dropped, could have similar effects to the spring mow. It also would be highly efficient at eliminating duff and thatch. A fall wildfire -- a fast moving head fire -- in Santa Teresa County Park in October 2001 was sampled using transect methods in Spring 2002. It should be noted that this is highly degraded serpentine grassland subject to high N-deposition without grazing for more than 20 years. The results indicated:

1) The fire was effective in removing thatch and duff, and increased bare soil surface area.
2) There was no increase in *Plantago* or nectar sources
3) There was not a substantial decrease in *Lolium* density, or increase in native species diversity.
4) Without follow-up, the habitat will likely return to a dense sward of *Lolium* with little habitat value for the Bay checkerspot butterfly.

Table 10.1 String Cutting Time Study

Time Study Analysis	Mowing Rate
Most Efficient Period (no string changes)	12 person-hours/acre
Least Efficient Period (3 string changes/hour)	25 person-hours/acre
Average String Cutting Rate	18person-hours/acre

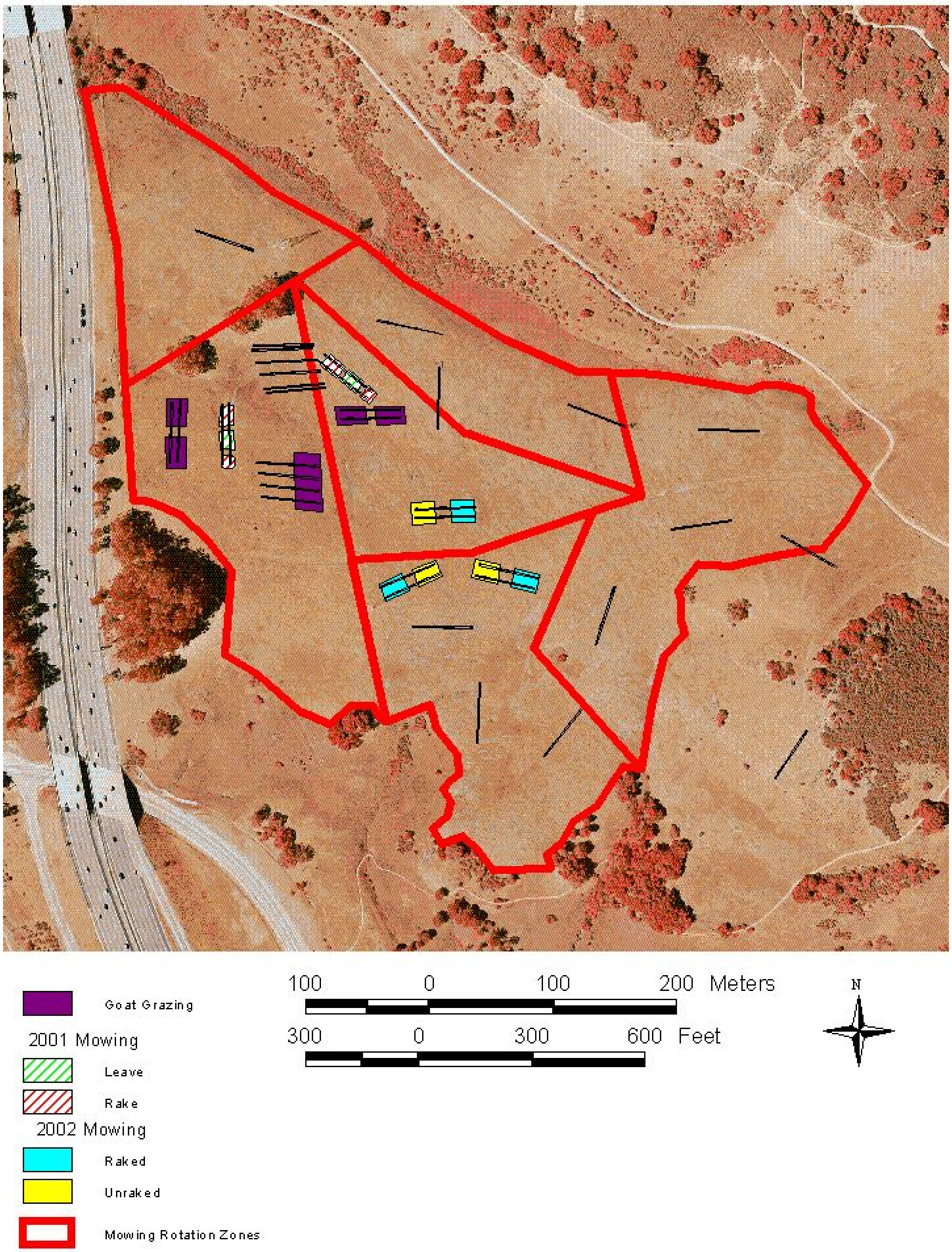
Table 10.2 Initial restoration acreage rotations

Rotation years	Acres out of 25	Block size	Hours Range	Cost *
2	12.5	2.5	144 – 300 hrs	$12,500
3	8.33	2.67	100 – 200 hrs	$8330
4	6.25	1.25	75 – 150 hrs	$6250
5	5	1	60 – 125 hrs	$5000

- cost range based on $1000 per acre maximum, can be refined by further studies and commercial quotes.

Map 10.1

Preliminary Management Rotation Zones



Section 11: Next Steps

Edgewood Natural Preserve should take the following steps to prepare for full scale habitat restoration and butterfly reintroduction to preserve the Bay Checkerspot population on the San Francisco Peninsula.

- Continue the existing experiments to evaluate the mowing and goat grazing activities from 2001 and 2002.
- Reconsider the practical and political aspects of using prescribed fire as a habitat management technique. If prescribed fire will still be under consideration, then prepare again for a Fall 2002 and/or Spring 2003 experimental fire.
- Plan for a set of mow areas in Spring 2003 totaling 5 to 9 acres.
- Evaluate and implement revisions required in the Master Plan of 1997 to accommodate the following activities:
    1. Larger scale mowing in Spring 2003 (5-8 acres) to begin implementation of an adaptive habitat restoration plan
    2. Long-term, proactive butterfly habitat management activities such as large scale mowing, grazing, prescribed fire, seed farming and seeding.
    3. Bay Checkerspot butterfly reintroduction
    4. Long-term habitat and butterfly monitoring activities
- In conjunction with the San Mateo Parks Foundation, seek funding sources to support these habitat management activities.

Acknowledgements

The financial support of the National Fish and Wildlife Foundation was the key component that allowed this project to proceed. San Mateo County Parks and Recreation staff, especially Ricardo Trejo, Dave Moore, and the Edgewood ranger staff, facilitated the project with their enthusiasm and professionalism. The Friends of Edgewood, California Native Plant Society, San Mateo County Parks and Recreation Foundation, and numerous concerned citizens and nature enthusiasts who support and participate in maintaining the unique biodiversity of Edgewood are deeply appreciated. Staff at the U.S. Fish and Wildlife Service, especially David Wright and Heather Bell, facilitated activities under the Recovery permit. Pamela Matson of Stanford University provided laboratory facilities and staff for the nitrogen content work. Sean Anderson of Stanford Center for Conservation Biology provided a sounding board for statistical analyses. And many thanks to Alan Launer and the generations of Stanford researchers who have worked at Edgewood over the decades as part of Paul Ehrlich's long-term study of checkerspot butterflies.

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Appendix A: Statistical analysis output for 2001-2002 Experiments

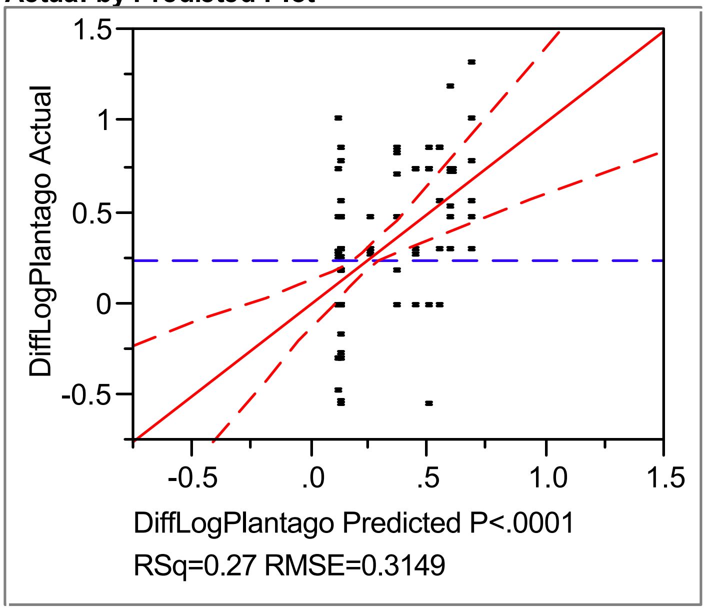
Provided in Electronic Form On CD

File: Appendix A Statistical analysis output.doc

Appendix A Statistical analysis output for 2001-2002 Experiments

A.1. Plantago erecta

Least Squares Fit
Response DiffLogPlantago
Whole Model
Actual by Predicted Plot



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	4.232972	0.846594	8.5356
Error	114	11.307015	0.099184	Prob > F
C. Total	119	15.539987		<.0001

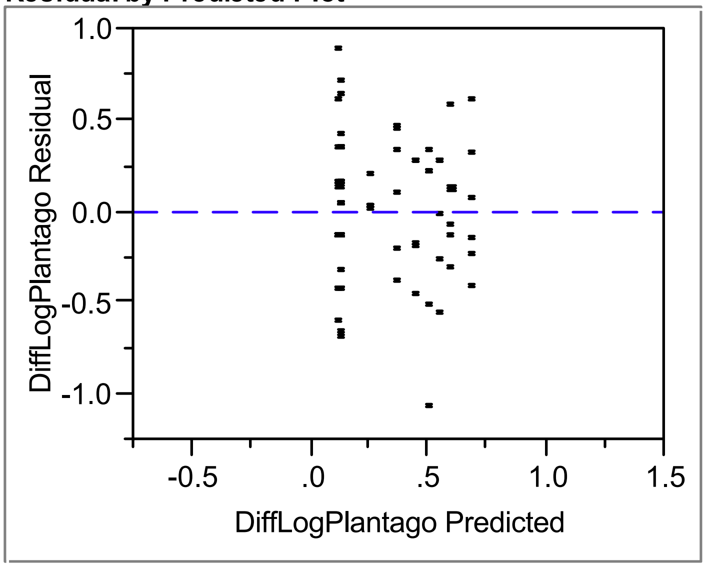
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.3877464	0.056698	6.84	<.0001
Mow 2[C]	-0.191917	0.044599	-4.30	<.0001
Mow 2[M]:Disturb[D]	0.0432709	0.068834	0.63	0.5309
GOAT[N]	0.0017894	0.043597	0.04	0.9673
Seed[N]	-0.06904	0.045973	-1.50	0.1359
Mow 2[M]:Rake[N]	-0.093724	0.067274	-1.39	0.1663

Effect Tests

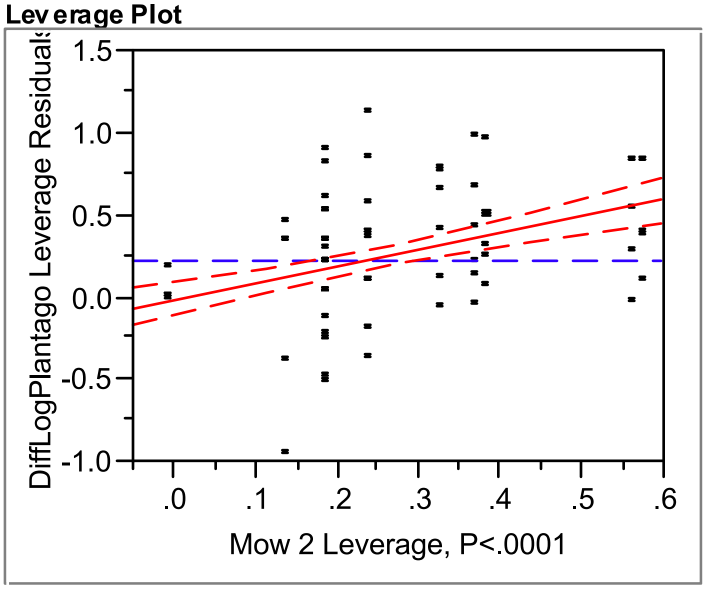
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mow 2	1	1	1.8365872	18.5169	<.0001
Disturb[Mow 2]	1	1	0.0391945	0.3952	0.5309
GOAT	1	1	0.0001671	0.0017	0.9673
Seed	1	1	0.2236897	2.2553	0.1359
Rake[Mow 2]	1	1	0.1925048	1.9409	0.1663

Residual by Predicted Plot



Mow 2

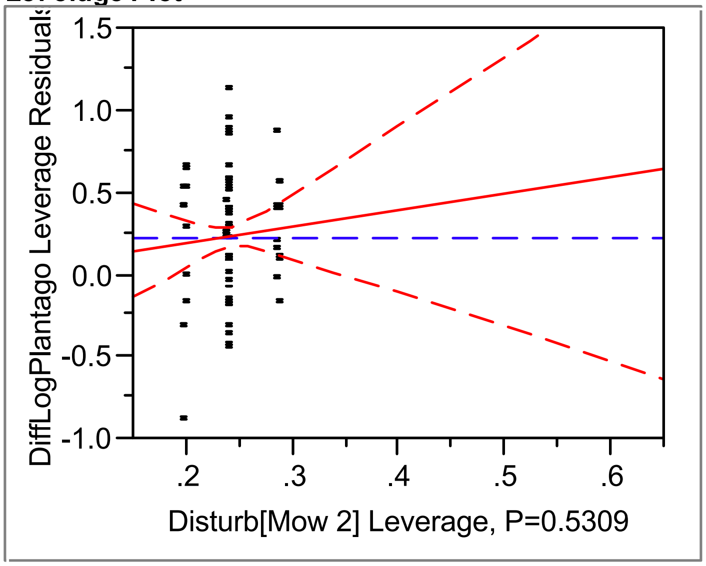
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
C	0.19582948	0.06147619	0.134205
M	0.57966328	0.08141351	0.535938

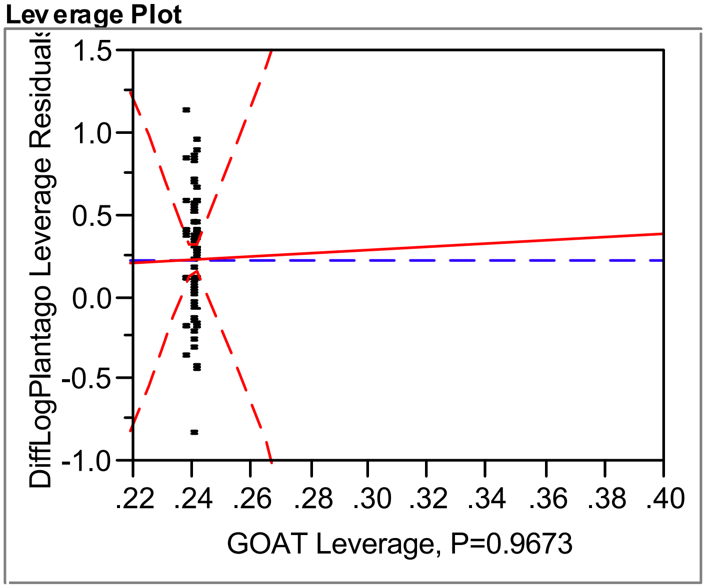
Disturb[Mow 2]
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	0.19582948	0.06147619
[M]D	0.62293419	0.12776385
[M]N	0.53639238	0.08005653

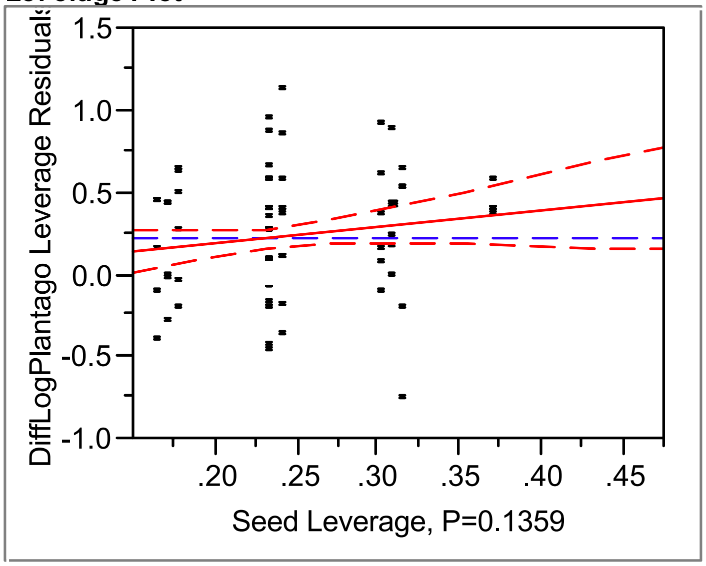
GOAT
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	0.38953582	0.04363156	0.259231
g1/2	0.38595694	0.09125181	0.125000

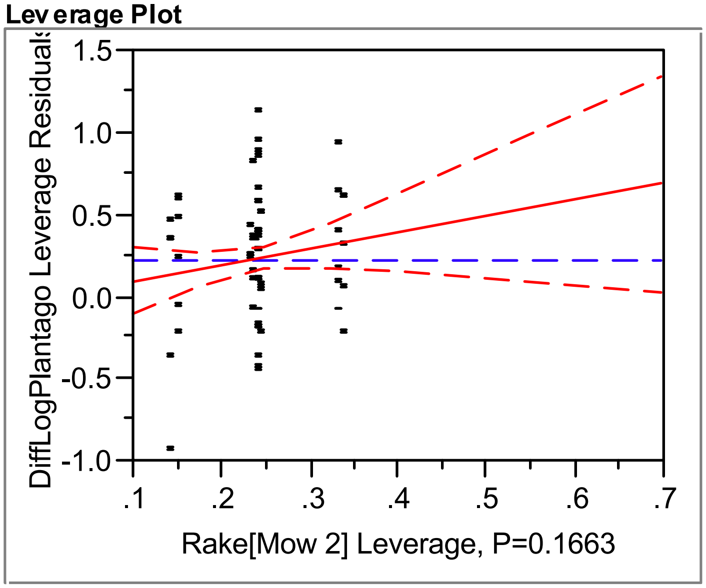
Seed
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	0.31870635	0.05753870	0.181200
S	0.45678641	0.08570610	0.542000

Rake[Mow 2]
Leverage Plot

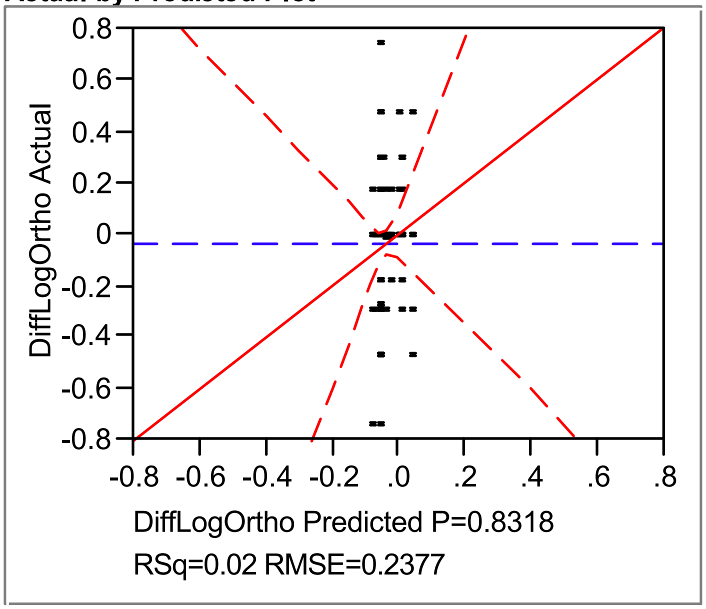


Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	0.19582948	0.06147619
[M]N	0.48593965	0.08154451
[M]R	0.67338692	0.12513394

A.2. Castilleja densiflorus

Response DiffLogOrtho
Whole Model
Actual by Predicted Plot



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	0.1195589	0.023912	0.4232
Error	114	6.4416154	0.056505	Prob > F
C. Total	119	6.5611743		0.8318

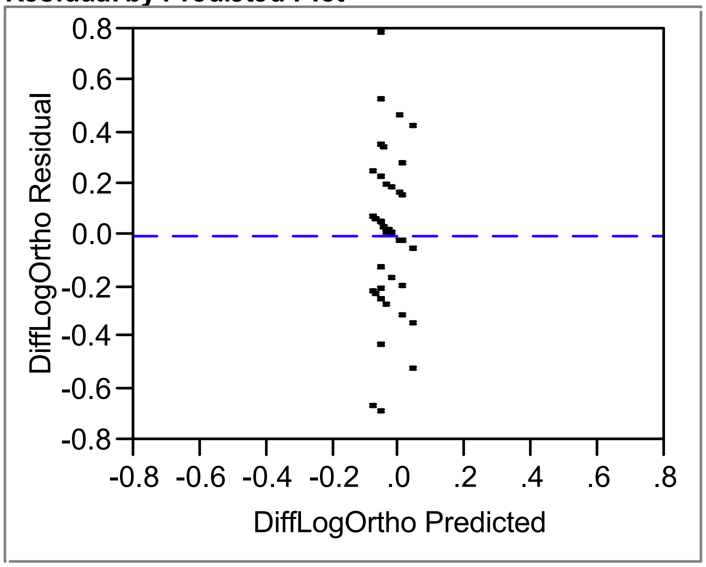
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.005557	0.042795	-0.13	0.8969
Mow 2[C]	0.0089771	0.033663	0.27	0.7902
Mow 2[M]:Disturb[D]	-0.038117	0.051955	-0.73	0.4647
GOAT[N]	-0.033223	0.032906	-1.01	0.3148
Seed[N]	-0.017829	0.034699	-0.51	0.6084
Mow 2[M]:Rake[N]	0.0432778	0.050778	0.85	0.3958

Effect Tests

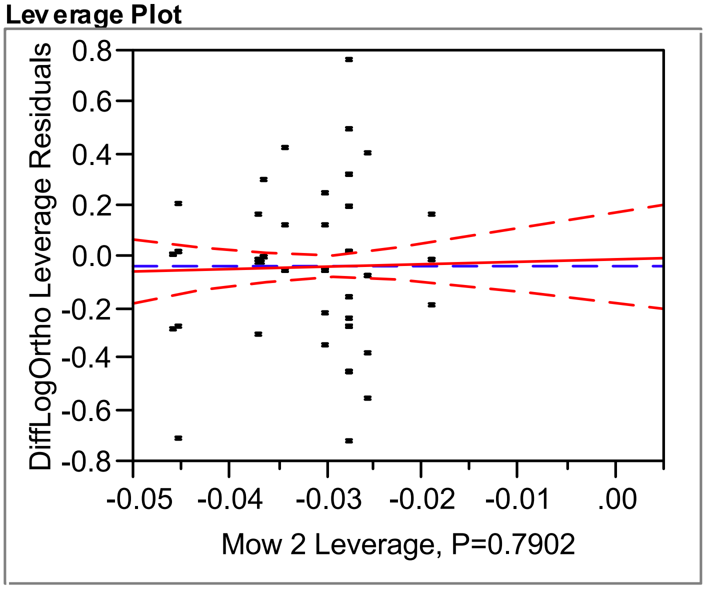
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mow 2	1	1	0.00401842	0.0711	0.7902
Disturb[Mow 2]	1	1	0.03041401	0.5382	0.4647
GOAT	1	1	0.05760040	1.0194	0.3148
Seed	1	1	0.01491769	0.2640	0.6084
Rake[Mow 2]	1	1	0.04104631	0.7264	0.3958

Residual by Predicted Plot



Mow 2

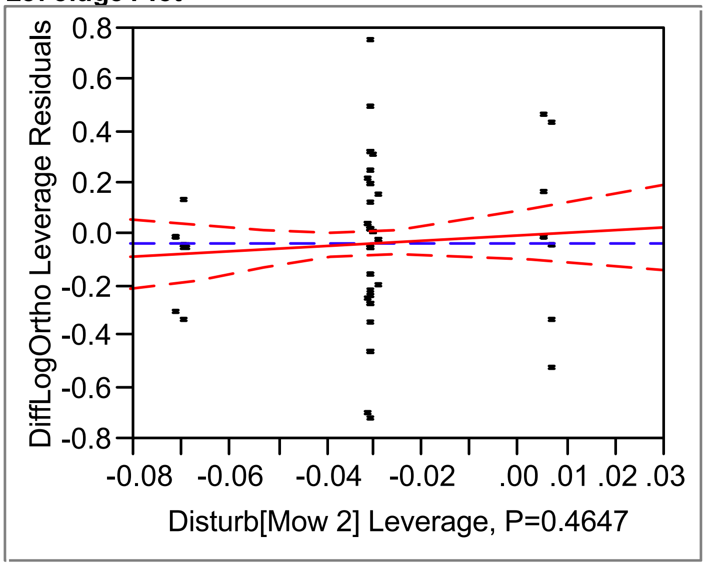
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
C	0.0034200	0.04640132	-0.03393
M	-0.0145341	0.06144972	-0.01994

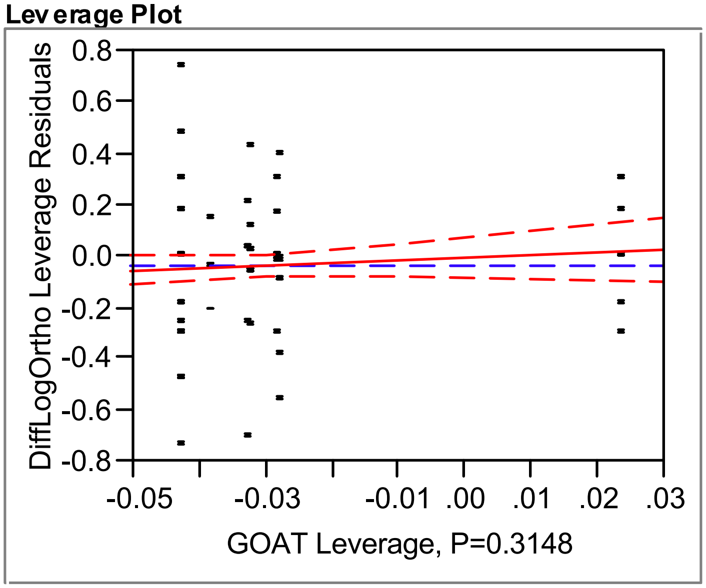
Disturb[Mow 2]
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	0.0034200	0.04640132
[M]D	-0.0526513	0.09643427
[M]N	0.0235830	0.06042549

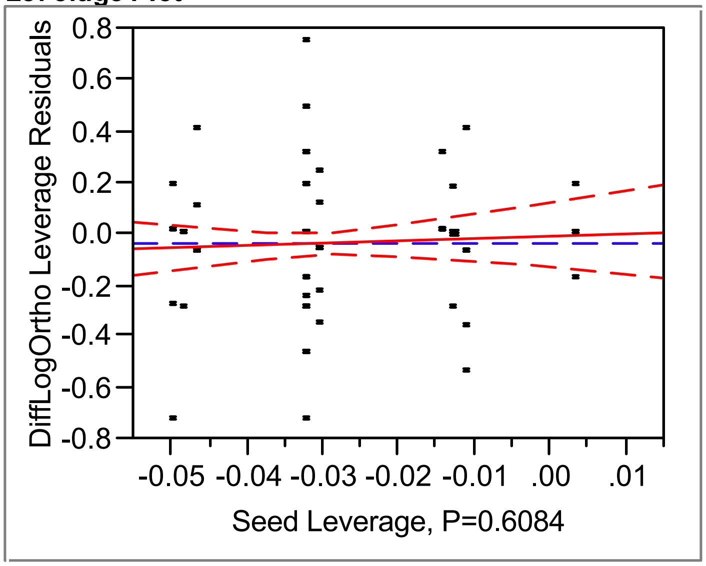
GOAT
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	-0.0387805	0.03293246	-0.03774
g1/2	0.0276664	0.06887552	0.01881

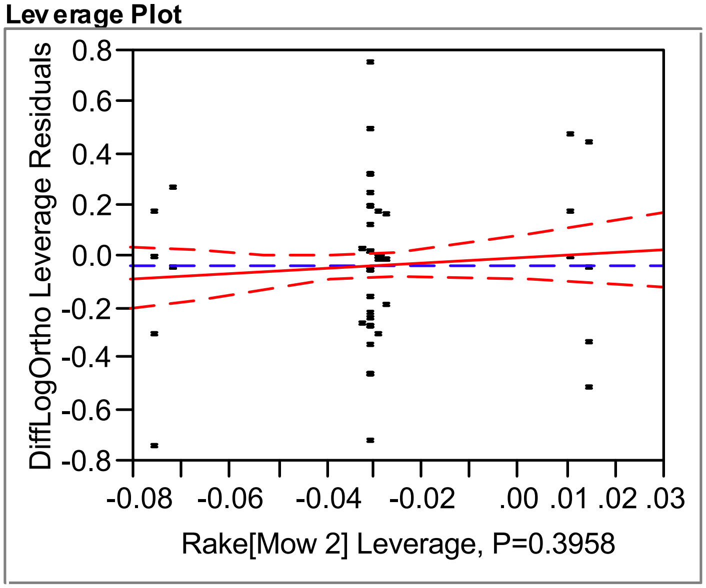
Seed
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	-0.0233861	0.04342936	-0.03499
S	0.0122720	0.06468970	-0.00625

Rake[Mow 2]
Leverage Plot

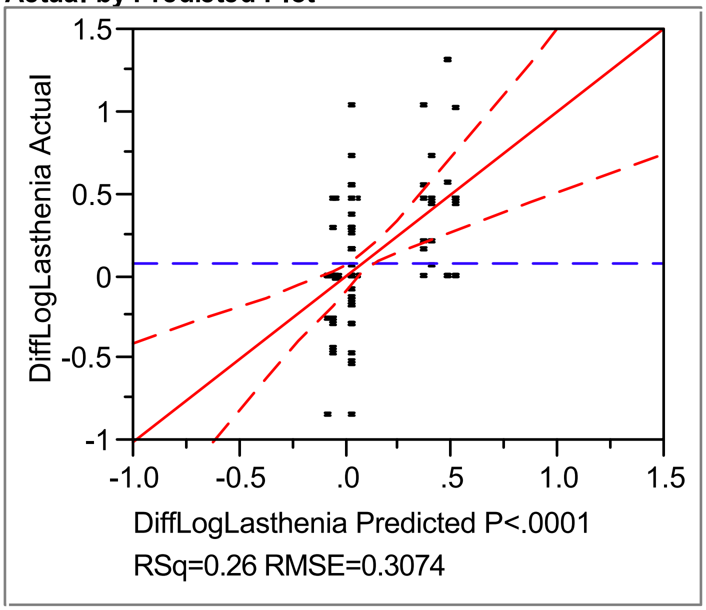


Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	0.0034200	0.04640132
[M]N	0.0287437	0.06154860
[M]R	-0.0578119	0.09444925

A.3. Lasthenia

Response DiffLogLasthenia
Whole Model
Actual by Predicted Plot



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	3.865199	0.773040	8.1816
Error	114	10.771272	0.094485	Prob > F
C. Total	119	14.636470		<.0001

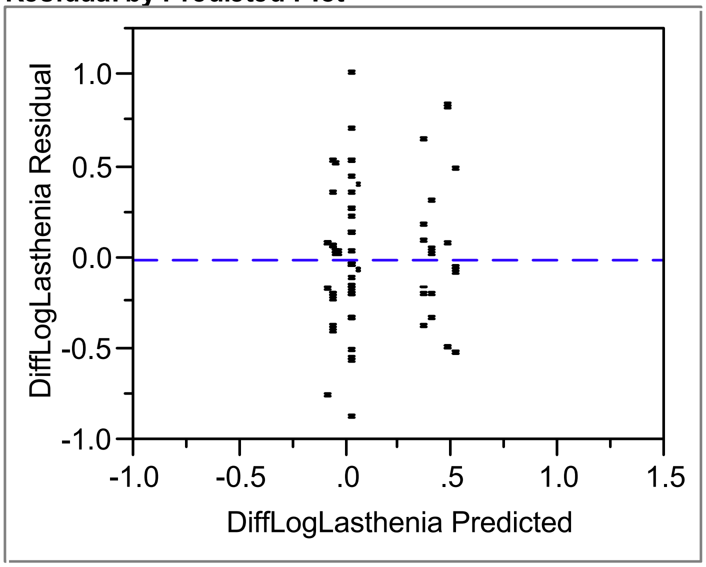
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0903484	0.055338	1.63	0.1053
Mow 2[C]	-0.085898	0.04353	-1.97	0.0509
Mow 2[M]:Disturb[D]	-0.234046	0.067184	-3.48	0.0007
GOAT[N]	0.0473112	0.042551	1.11	0.2685
Seed[N]	-0.018168	0.04487	-0.40	0.6863
Mow 2[M]:Rake[N]	-0.052633	0.065661	-0.80	0.4245

Effect Tests

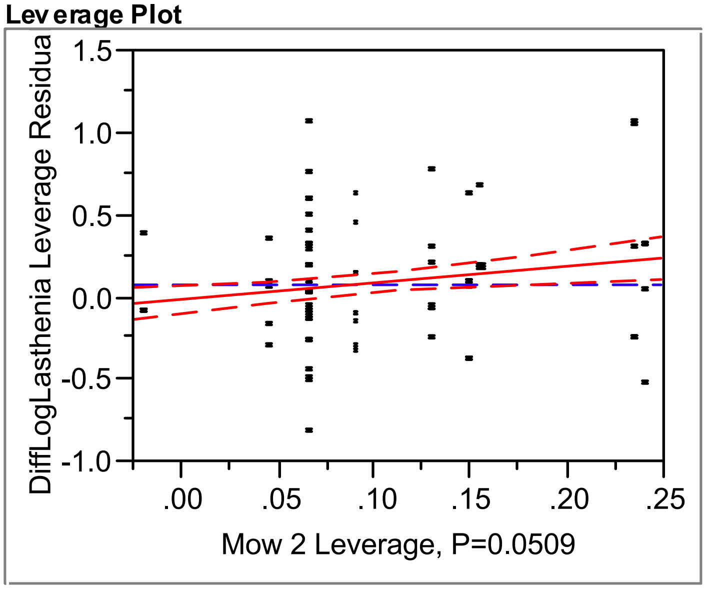
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mow 2	1	1	0.3679144	3.8939	0.0509
Disturb[Mow 2]	1	1	1.1466629	12.1359	0.0007
GOAT	1	1	0.1168059	1.2362	0.2685
Seed	1	1	0.0154900	0.1639	0.6863
Rake[Mow 2]	1	1	0.0607096	0.6425	0.4245

Residual by Predicted Plot



Mow 2

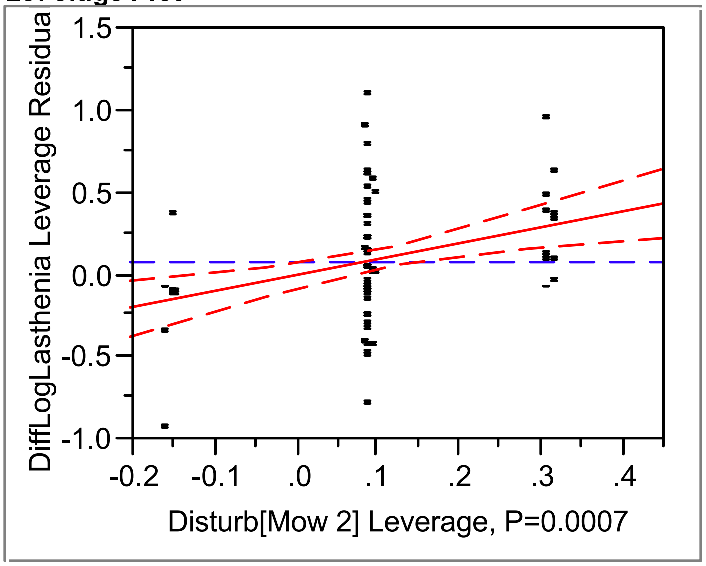
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
C	0.00445081	0.06000210	0.018042
M	0.17624594	0.07946136	0.294877

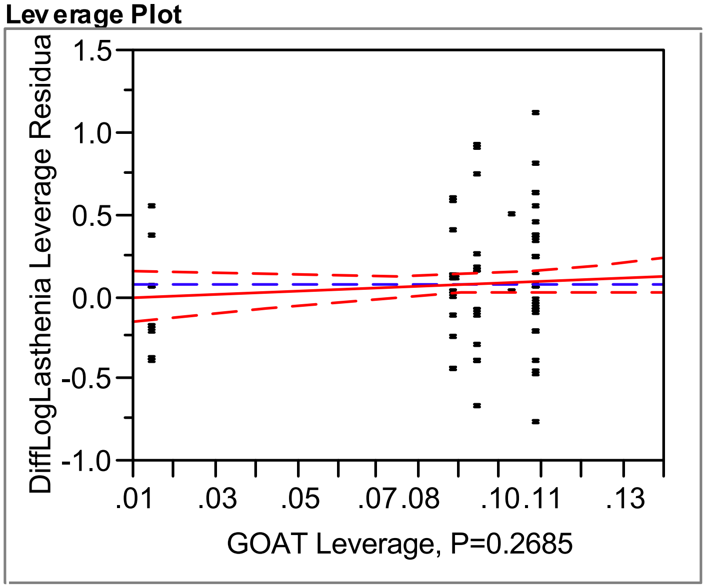
Disturb[Mow 2]
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	0.0044508	0.06000210
[M]D	-0.0578002	0.12470030
[M]N	0.4102920	0.07813691

GOAT
Leverage Plot

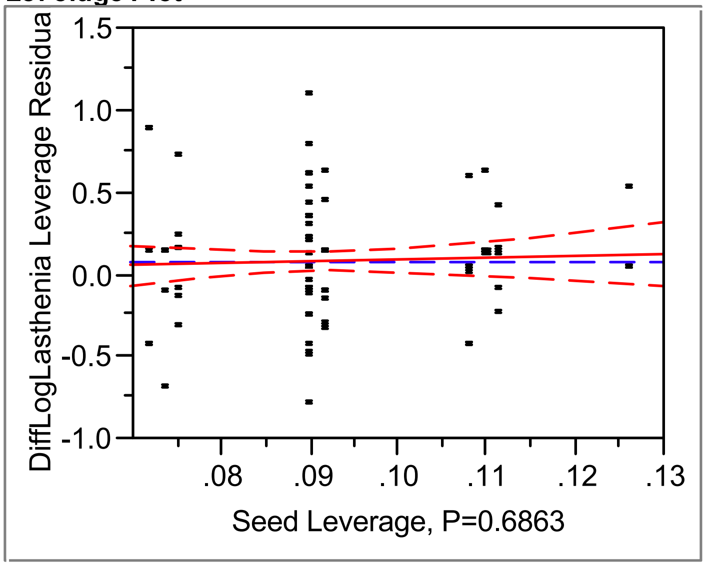


Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	0.13765958	0.04258535	0.11539
g1/2	0.04303717	0.08906375	-0.06103

Seed

Leverage Plot

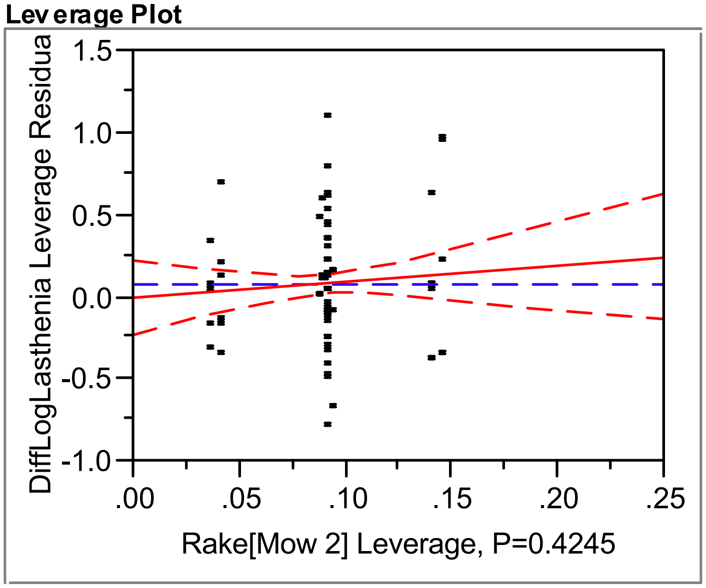


Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	0.07218053	0.05615902	0.056827
S	0.10851622	0.08365102	0.267053

Rake[Mow 2]

Leverage Plot

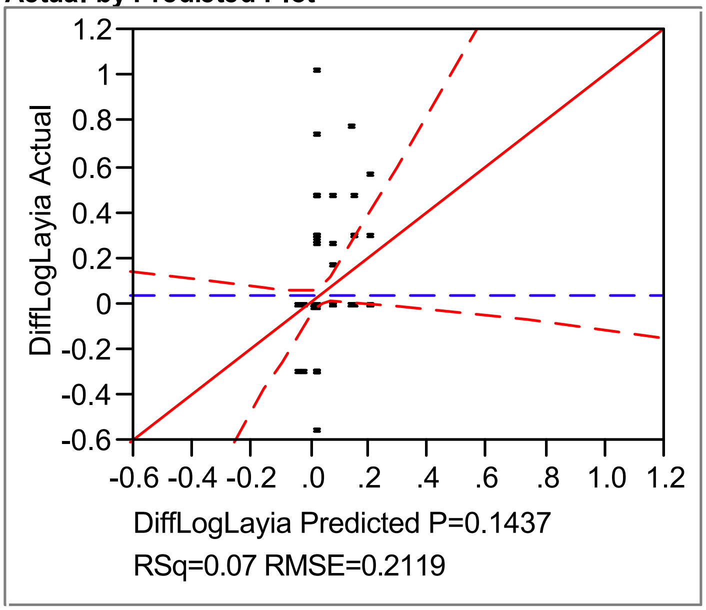


Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	0.00445081	0.06000210
[M]N	0.12361307	0.07958922
[M]R	0.22887882	0.12213345

A.4. Layia platyglossa

Response DiffLogLayia
Whole Model
Actual by Predicted Plot



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	0.3781856	0.075637	1.6852
Error	114	5.1165522	0.044882	Prob > F
C. Total	119	5.4947378		0.1437

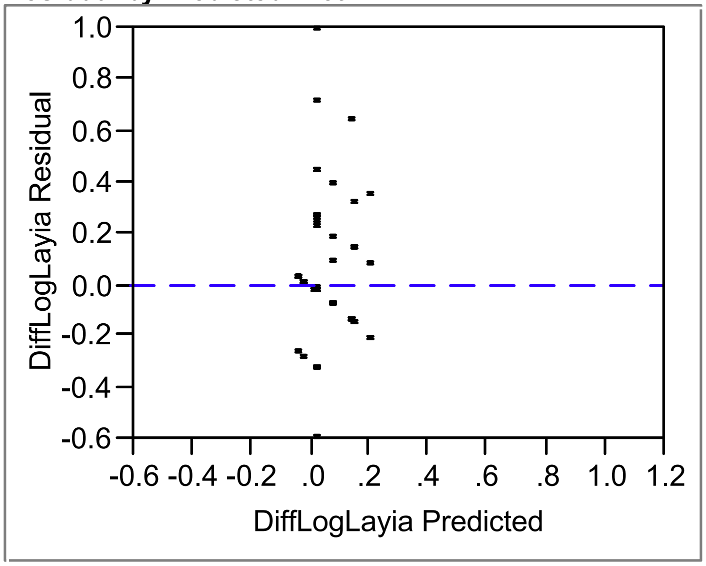
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.03177	0.03814	0.83	0.4066
Mow 2[C]	-0.0583	0.030002	-1.94	0.0545
Mow 2[M]:Disturb[D]	-0.030061	0.046304	-0.65	0.5175
GOAT[N]	0.0235946	0.029327	0.80	0.4228
Seed[N]	0.0313105	0.030925	1.01	0.3135
Mow 2[M]:Rake[N]	-0.035892	0.045255	-0.79	0.4294

Effect Tests

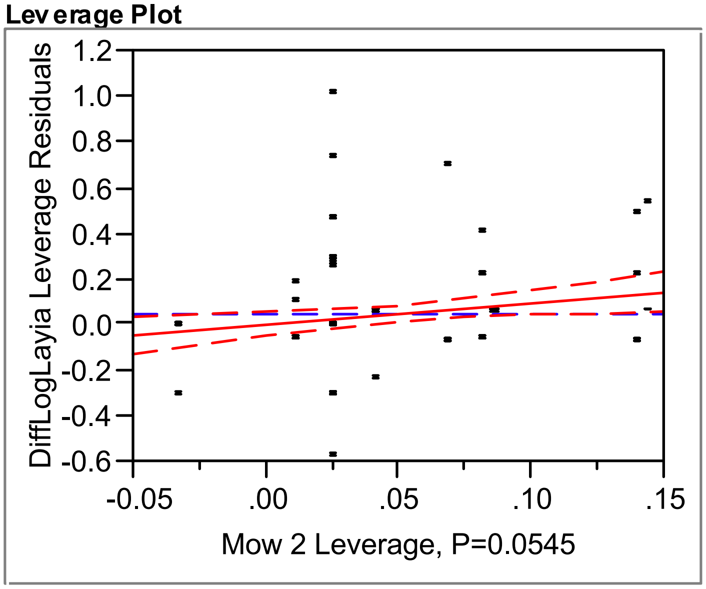
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mow 2	1	1	0.16948294	3.7762	0.0545
Disturb[Mow 2]	1	1	0.01891635	0.4215	0.5175
GOAT	1	1	0.02905101	0.6473	0.4228
Seed	1	1	0.04600688	1.0251	0.3135
Rake[Mow 2]	1	1	0.02823149	0.6290	0.4294

Residual by Predicted Plot



Mow 2

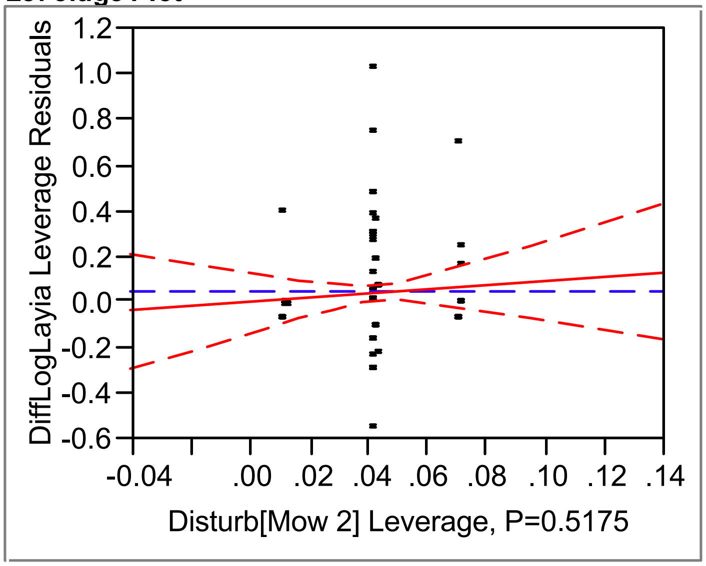
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
C	-0.0265302	0.04135439	0.016949
M	0.0900703	0.05476602	0.113721

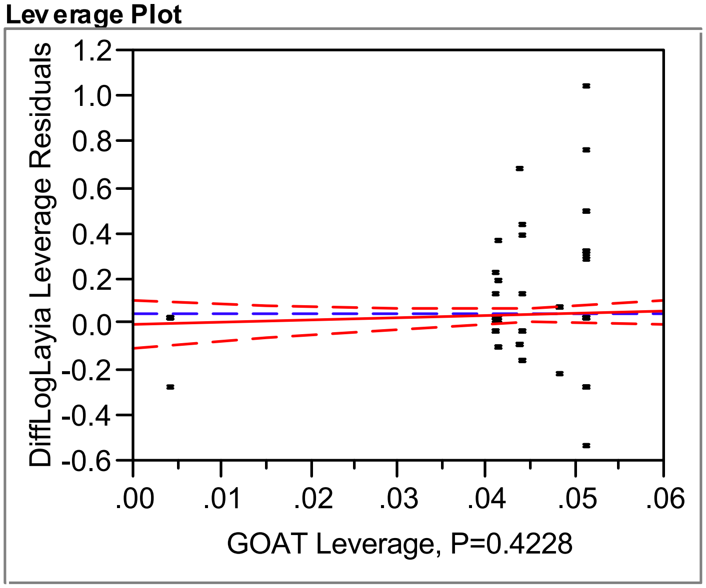
Disturb[Mow 2]
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	-0.0265302	0.04135439
[M]D	0.0600093	0.08594541
[M]N	0.1201312	0.05385319

GOAT
Leverage Plot

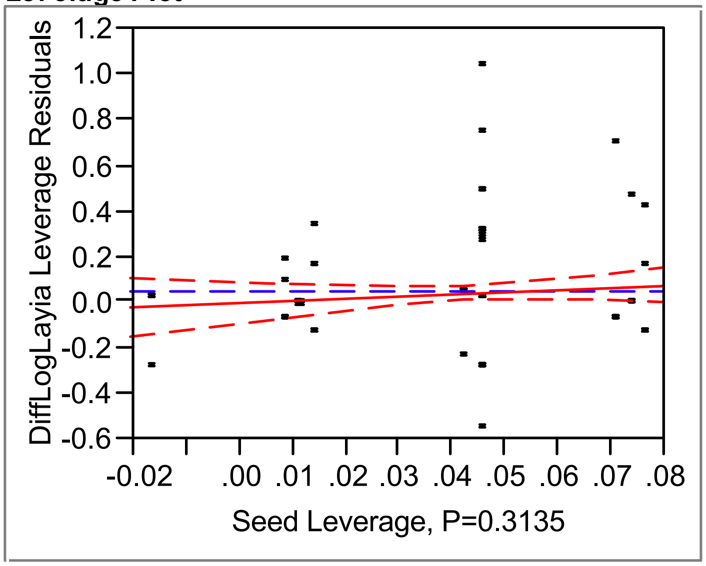


Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	0.05536459	0.02935050	0.05223
g1/2	0.00817542	0.06138414	-0.01881

Seed

Leverage Plot

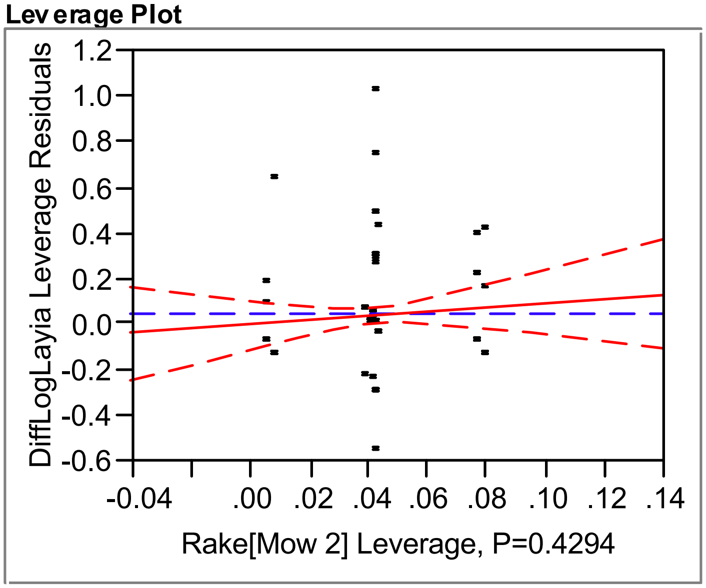


Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	0.06308046	0.03870568	0.039131
S	0.00045955	0.05765360	0.060874

Rake[Mow 2]

Leverage Plot

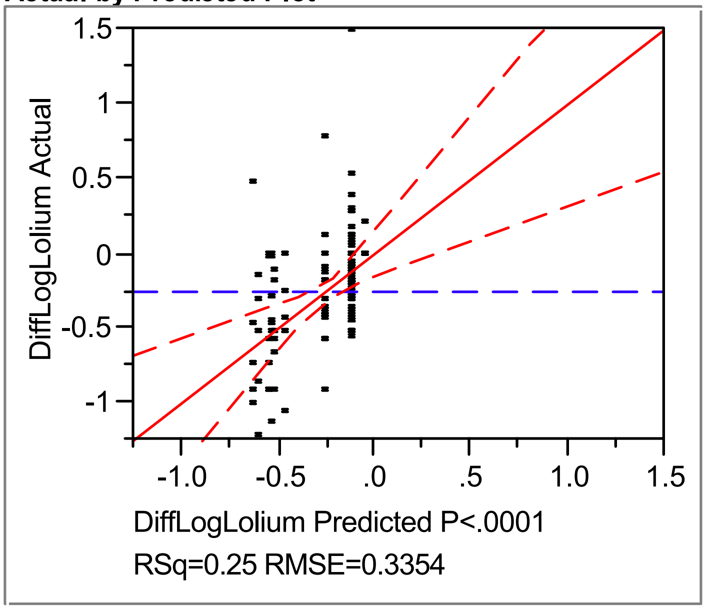


Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	-0.0265302	0.04135439
[M]N	0.0541785	0.05485415
[M]R	0.1259621	0.08417630

A.5. Lolium multiflorum

Response DiffLogLolium
Whole Model
Actual by Predicted Plot



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	4.306294	0.861259	7.6574
Error	114	12.821973	0.112473	Prob > F
C. Total	119	17.128267		<.0001

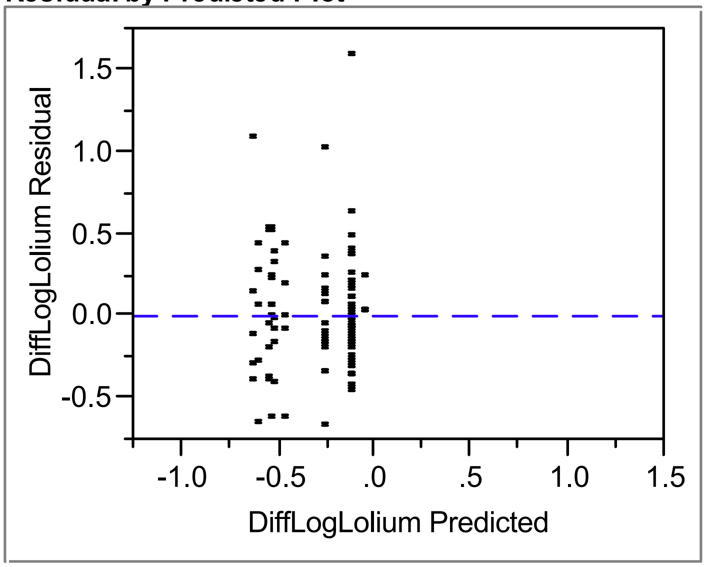
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.393076	0.060377	-6.51	<.0001
Mow 2[C]	0.2476746	0.047493	5.21	<.0001
Mow 2[M]:Disturb[D]	-0.045092	0.073301	-0.62	0.5397
GOAT[N]	0.0715677	0.046426	1.54	0.1260
Seed[N]	-0.038031	0.048956	-0.78	0.4389
Mow 2[M]:Rake[N]	0.0302755	0.07164	0.42	0.6734

Effect Tests

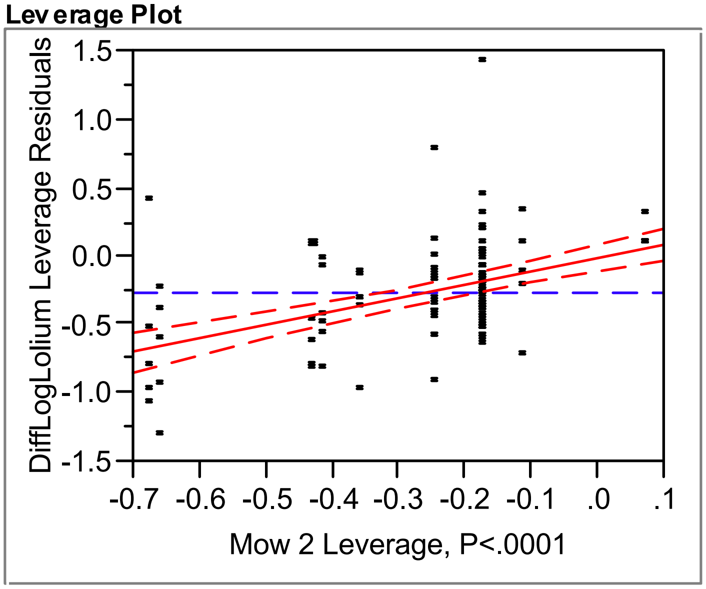
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mow 2	1	1	3.0587794	27.1956	<.0001
Disturb[Mow 2]	1	1	0.0425635	0.3784	0.5397
GOAT	1	1	0.2672831	2.3764	0.1260
Seed	1	1	0.0678750	0.6035	0.4389
Rake[Mow 2]	1	1	0.0200875	0.1786	0.6734

Residual by Predicted Plot



Mow 2

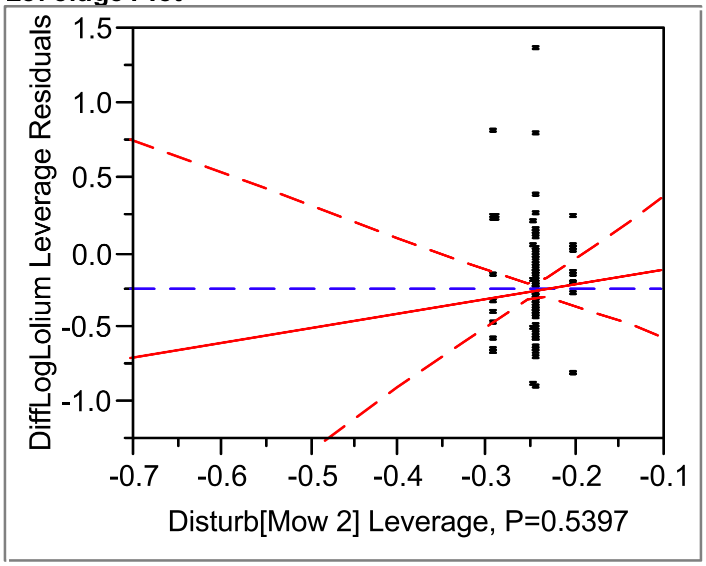
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
C	-0.1454017	0.06546518	-0.13443
M	-0.6407510	0.08669617	-0.54281

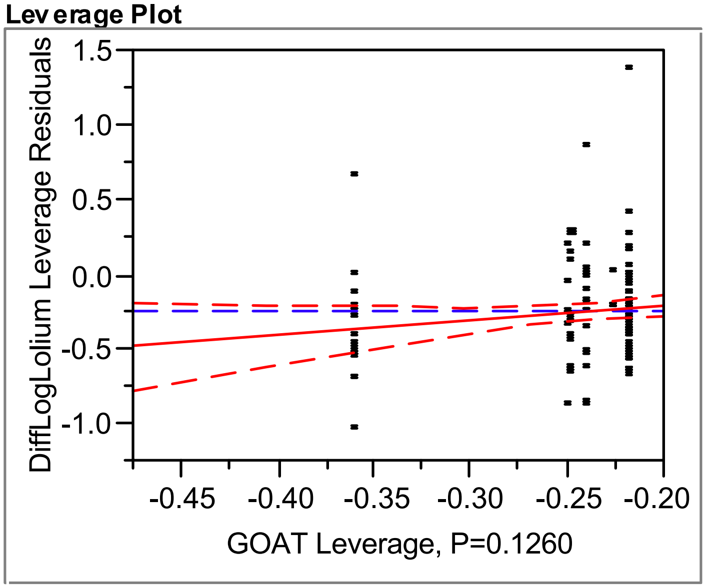
Disturb[Mow 2]
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	-0.1454017	0.06546518
[M]D	-0.6858433	0.13605403
[M]N	-0.5956587	0.08525114

GOAT
Leverage Plot

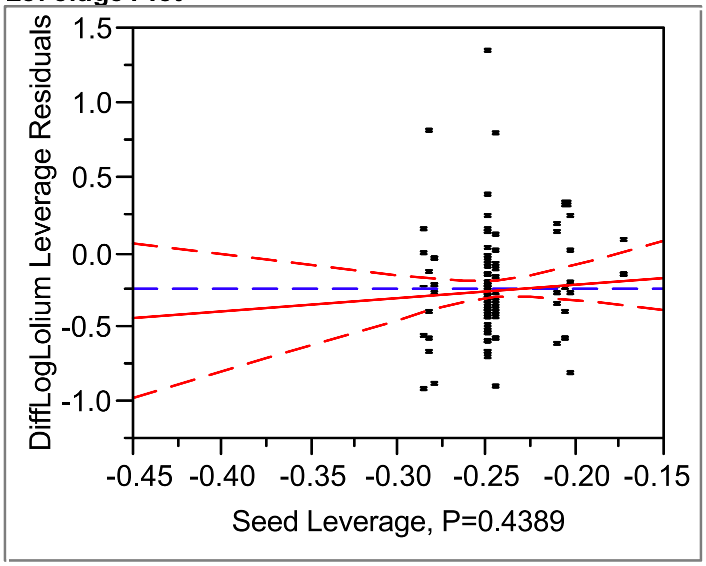


Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	-0.3215086	0.04646267	-0.24154
g1/2	-0.4646441	0.09717284	-0.25500

Seed

Leverage Plot

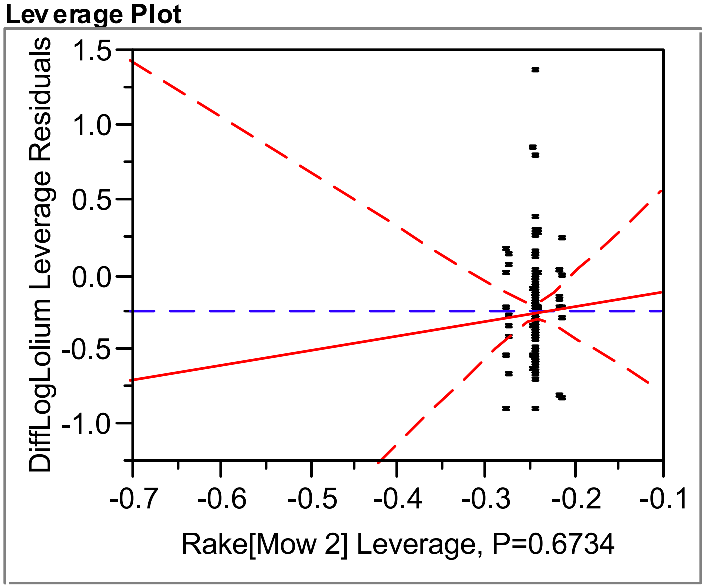


Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	-0.4311069	0.06127220	-0.20950
S	-0.3550458	0.09126730	-0.41250

Rake[Mow 2]

Leverage Plot

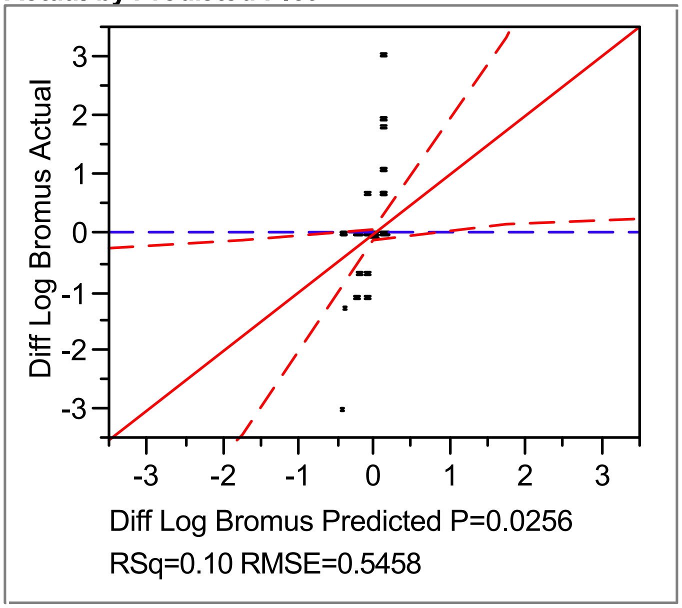


Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	-0.1454017	0.06546518
[M]N	-0.6104754	0.08683567
[M]R	-0.6710265	0.13325348

A.6. Bromus hordaceous

Response Diff Log Bromus
Whole Model
Actual by Predicted Plot



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	3.973334	0.794667	2.6676
Error	114	33.960627	0.297900	Prob > F
C. Total	119	37.933960		0.0256

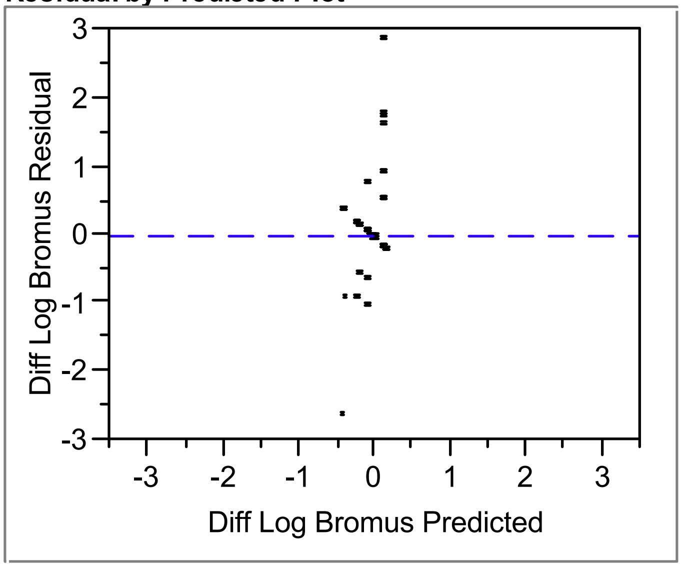
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.069425	0.098261	-0.71	0.4813
Mow 2[C]	0.131561	0.077293	1.70	0.0915
Mow 2[M]:Disturb[D]	0.1969097	0.119294	1.65	0.1016
GOAT[N]	0.1190065	0.075556	1.58	0.1180
Seed[N]	-0.011793	0.079673	-0.15	0.8826
Mow 2[M]:Rake[N]	-0.11493	0.116591	-0.99	0.3263

Effect Tests

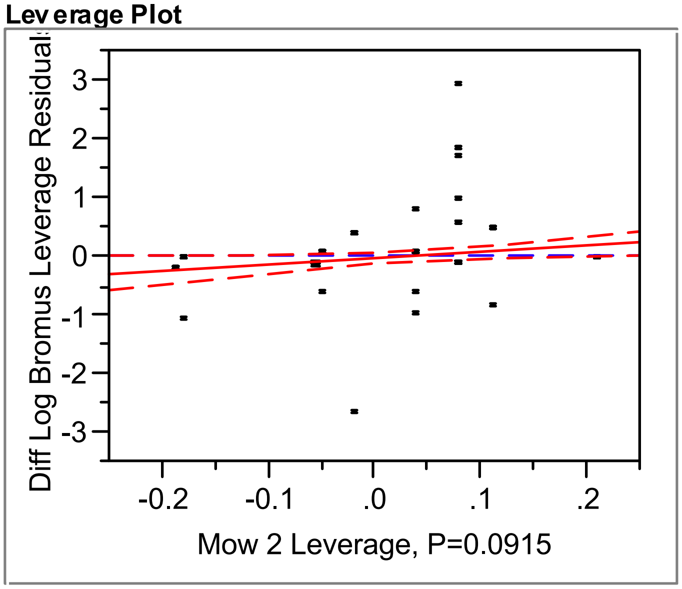
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mow 2	1	1	0.86305712	2.8971	0.0915
Disturb[Mow 2]	1	1	0.81164674	2.7246	0.1016
GOAT	1	1	0.73905744	2.4809	0.1180
Seed	1	1	0.00652628	0.0219	0.8826
Rake[Mow 2]	1	1	0.28947455	0.9717	0.3263

Residual by Predicted Plot



Mow 2

Leverage Plot

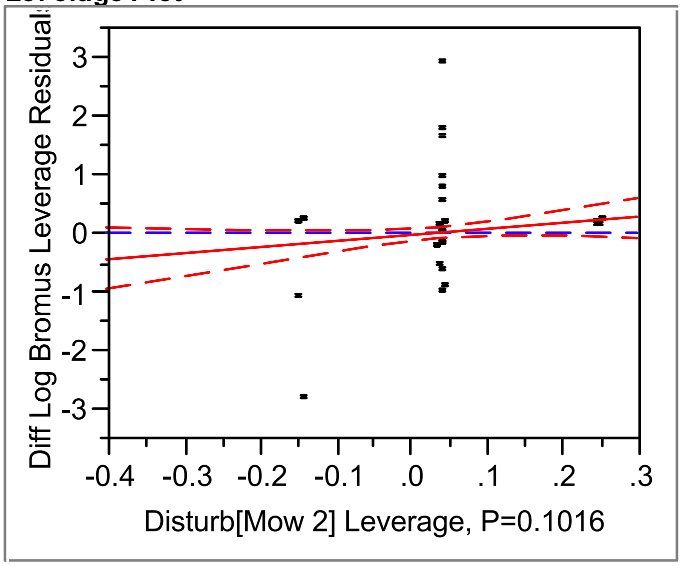


Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
C	0.0621359	0.10654199	0.12715
M	-0.2009862	0.14109458	-0.19174

Disturb[Mow 2]

Leverage Plot

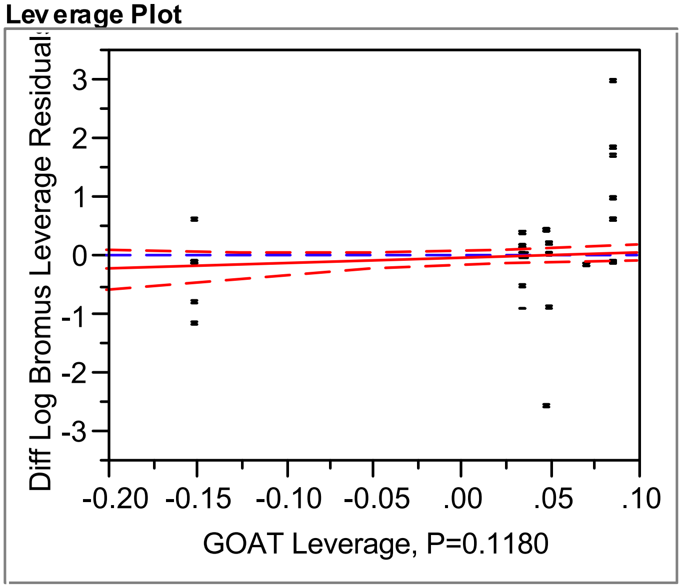


Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	0.0621359	0.10654199
[M]D	-0.0040765	0.22142255
[M]N	-0.3978958	0.13874285

GOAT

Leverage Plot

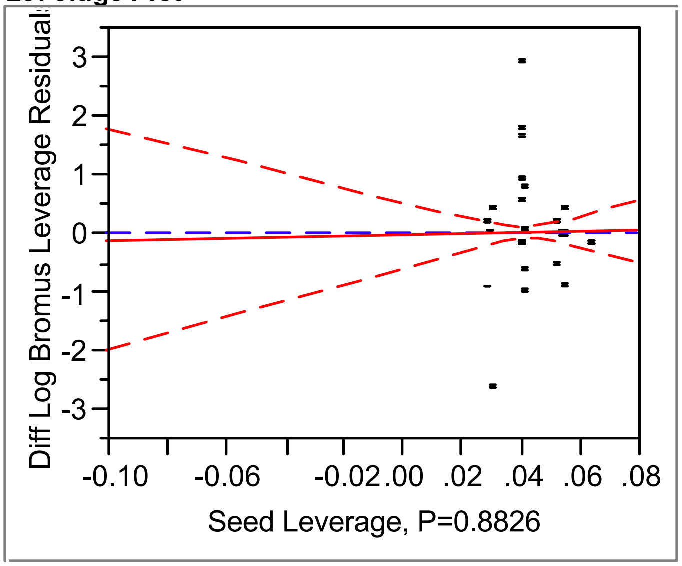


Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	0.0495814	0.07561616	0.05915
g1/2	-0.1884317	0.15814495	-0.06866

Seed

Leverage Plot

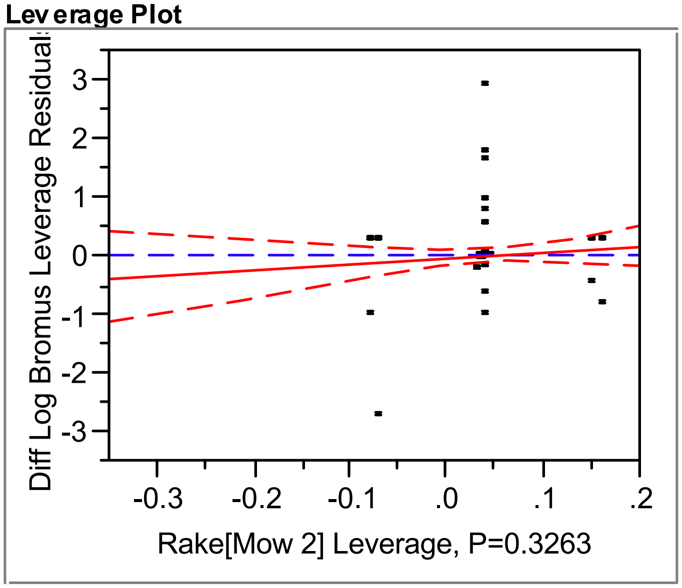


Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	-0.0812178	0.09971807	0.07046
S	-0.0576325	0.14853391	-0.09962

Rake[Mow 2]

Leverage Plot

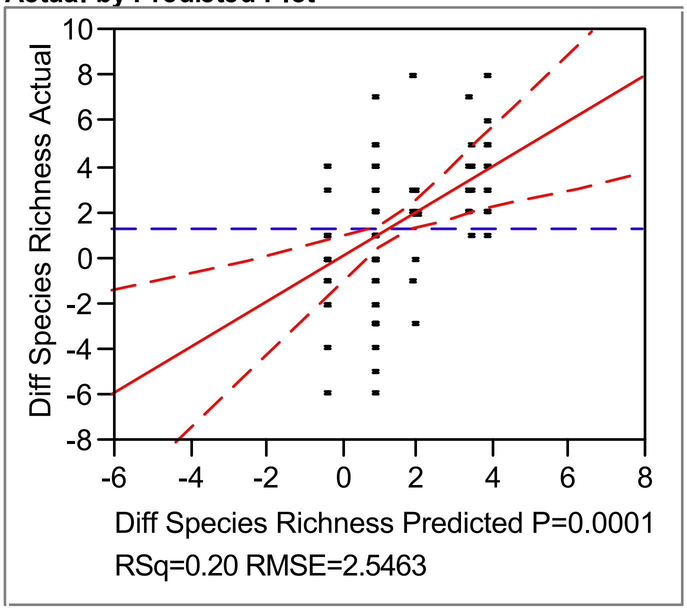


Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	0.0621359	0.10654199
[M]N	-0.3159162	0.14132162
[M]R	-0.0860561	0.21686476

A.7. Species Richness

Response Diff Species Richness
Whole Model
Actual by Predicted Plot



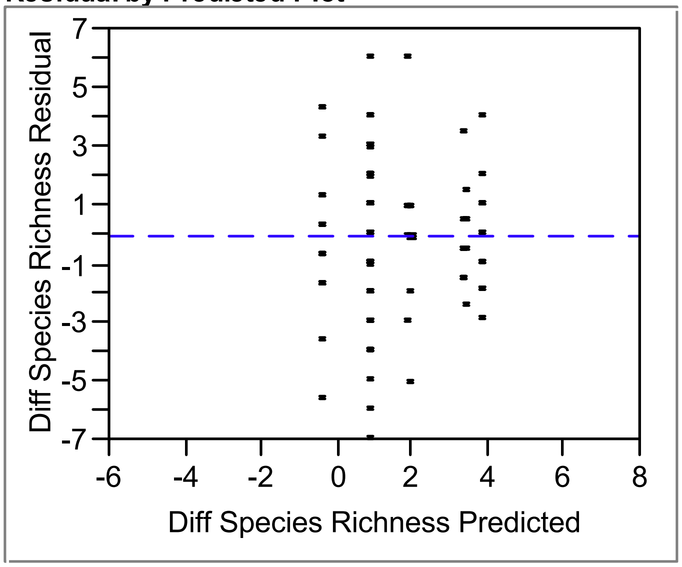
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.29984	0.458412	2.84	0.0054
Mow 2[C]	-0.995196	0.360595	-2.76	0.0067
Mow 2[M]:Disturb[D]	-0.728232	0.556539	-1.31	0.1933
GOAT[N]	0.6585504	0.352487	1.87	0.0643
Seed[N]	-0.021093	0.371698	-0.06	0.9548
Mow 2[M]:Rake[N]	-0.225355	0.543926	-0.41	0.6794

Effect Tests

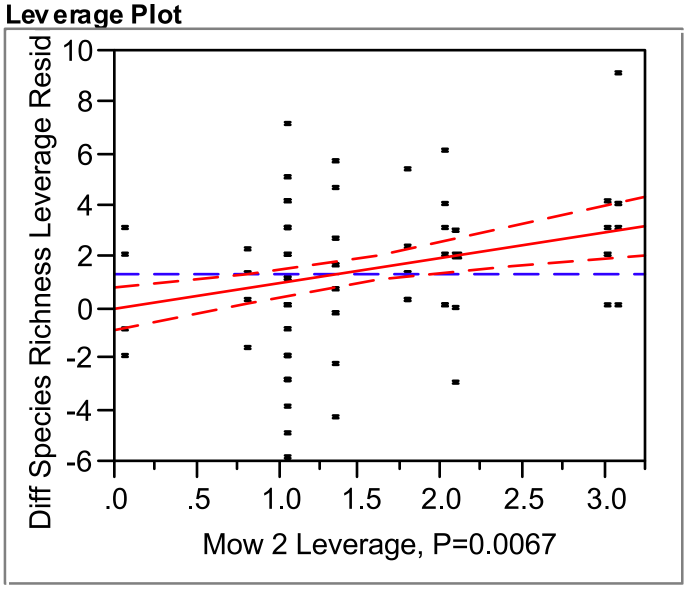
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mow 2	1	1	49.385854	7.6169	0.0067
Disturb[Mow 2]	1	1	11.101250	1.7122	0.1933
GOAT	1	1	22.631572	3.4905	0.0643
Seed	1	1	0.020880	0.0032	0.9548
Rake[Mow 2]	1	1	1.112957	0.1717	0.6794

Residual by Predicted Plot



Mow 2

Leverage Plot

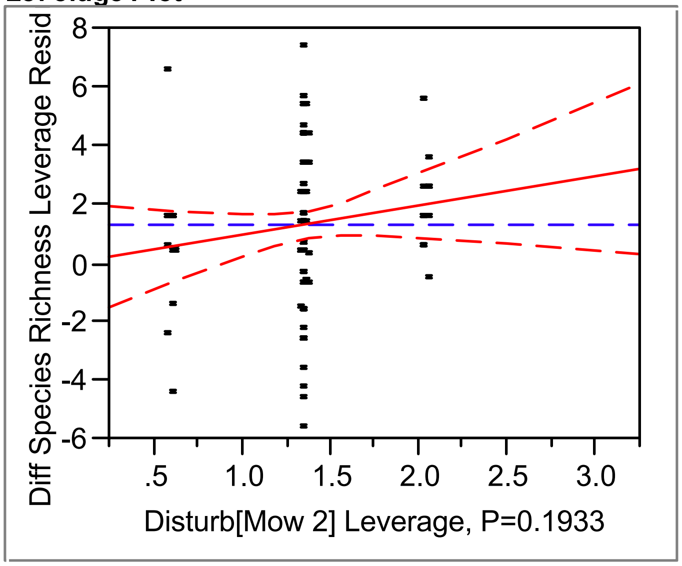


Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
C	0.3046438	0.49704676	0.70455
M	2.2950363	0.65824382	3.15625

Disturb[Mow 2]

Leverage Plot

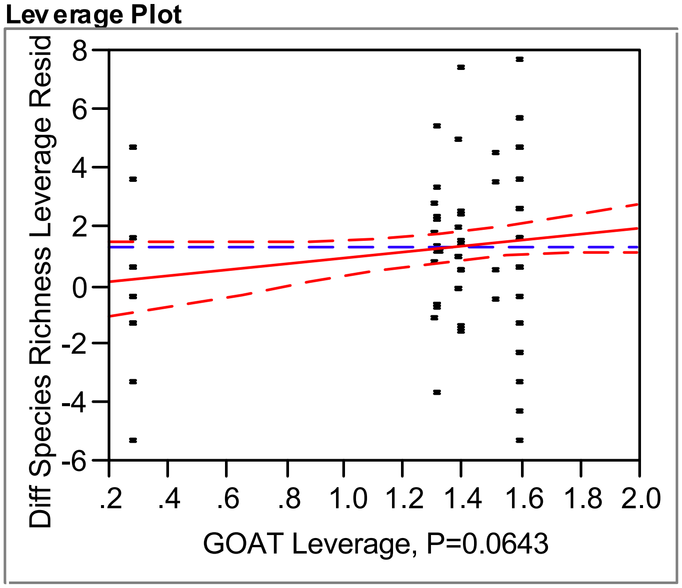


Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	0.3046438	0.4970468
[M]D	1.5668048	1.0329952
[M]N	3.0232678	0.6472724

GOAT

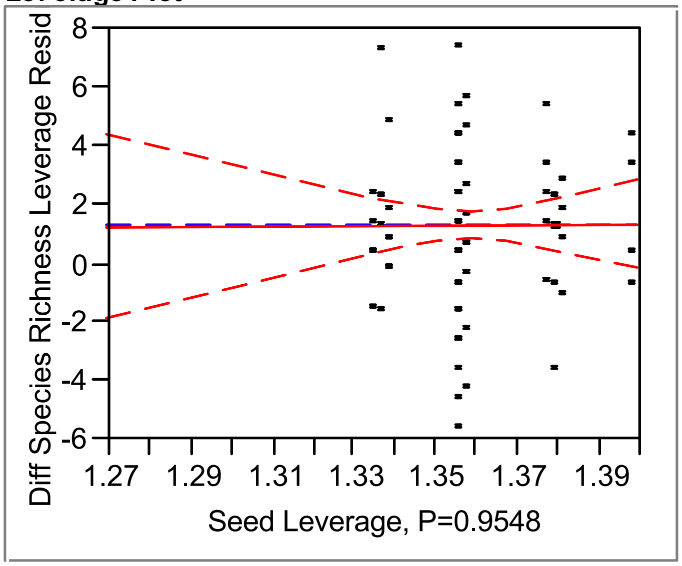
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	1.9583904	0.35276954	1.6250
g1/2	0.6412897	0.73778835	-0.3750

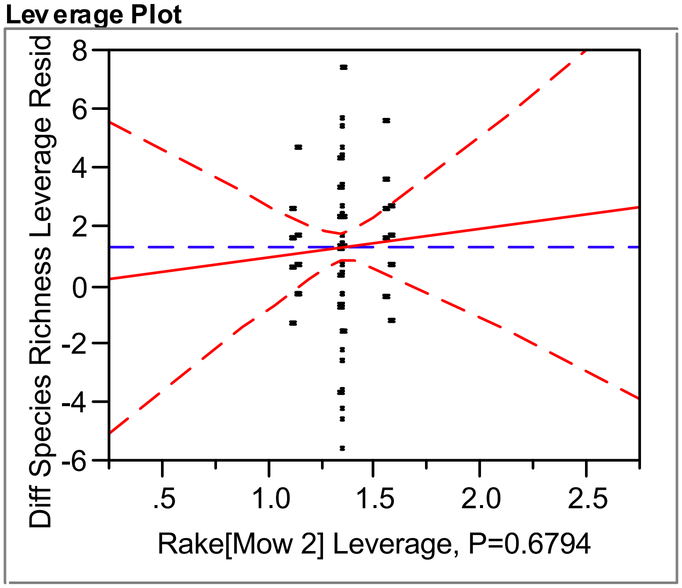
Seed
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
N	1.2787466	0.46521139	1.08000
S	1.3209335	0.69295027	2.75000

Rake[Mow 2]
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
[C]N	0.3046438	0.4970468
[M]N	2.0696812	0.6593030
[M]R	2.5203914	1.0117319