2002

Restoration of native grasslands after rooting by Feral pigs (SUS SCROFA)

Debie Ann Kinsey
San Jose State University

Follow this and additional works at: https://scholarworks.sjsu.edu/etd_theses

Recommended Citation

Kinsey, Debie Ann, "Restoration of native grasslands after rooting by Feral pigs (SUS SCROFA)" (2002). *Master's Theses*. 2282.

DOI: <https://doi.org/10.31979/etd.md2x-n4zn>
https://scholarworks.sjsu.edu/etd_theses/2282

This Thesis is brought to you for free and open access by the Master's Theses and Graduate Research at SJSU ScholarWorks. It has been accepted for inclusion in Master's Theses by an authorized administrator of SJSU ScholarWorks. For more information, please contact scholarworks@sjsu.edu.

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

**ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600**

UMI[®]

**RESTORATION OF NATIVE GRASSLANDS
AFTER ROOTING BY FERAL PIGS (*SUS SCROFA*)**

A Thesis

Presented to

The Faculty of the Department of Biological Sciences

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Debie Ann Kinsey

May 2002

UMI Number: 1408799

UMI[®]

UMI Microform 1408799

Copyright 2002 by ProQuest Information and Learning Company.

**All rights reserved. This microform edition is protected against
unauthorized copying under Title 17, United States Code.**

**ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346**

© 2002

Debie Ann Kinsey

ALL RIGHTS RESERVED

APPROVED FOR THE DEPARTMENT OF BIOLOGICAL SCIENCES

Dr. Chris Brinegar

Dr. Rod Myatt

Dr. Sulekha Anand

APPROVED FOR THE UNIVERSITY

ABSTRACT

RESTORATION OF NATIVE GRASSLANDS AFTER ROOTING BY FERAL PIGS (*SUS SCROFA*)

by Debie A. Kinsey

This pilot study explores the restoration of native grasslands in the Long Ridge area of the Midpeninsula Regional Open Space District (MROSD) by reseeding with native grasses after rooting disturbance by feral pigs (*Sus scrofa*). The purpose of reseeding was to inhibit invasions of rooted areas by non-native thistle species while also incorporating a sterile native hybrid, *Elymus X Triticum*, into the reseeding mixture to aid in outcompeting the thistle species. The rooted areas in the study were not threatened by invasion from thistle species after the first growing season. The data suggest a trend for the abundance of two invasive species (*L. multiflorum* and *B. diandrus*) to decrease by reseeding with or without the inclusion of the native hybrid in the reseeding mixture. The mean percent of bare ground cover was less in reseeded plots. It is imperative to continue the research and data collection over consecutive growing seasons to determine long-term effectiveness of reseeding.

ACKNOWLEDGMENTS

I would like to thank Dr. Brinegar, my major advisor and head of my committee, for his support and encouragement during the thesis process and during my entire graduate schooling. I would also like to thank the following people for their help with the field data collection during hot summer afternoons: Matt Nichols, my sister Dee Kinsey, my brother Deano Kinsey, Lindsay Pecoraro, and Bill Montana.

For their expertise and advise in grassland restoration, I would like to extend my gratitude to Mark Stromberg of Hastings Natural History Reservation (UC Berkeley), Rachel O'Malley (San Jose State University, Department of Environmental Studies), and Stan Hooper and Jodi Isaacs (Midpeninsula Regional Open Space District).

I would also like to thank my committee members, Dr. Rod Myatt and Dr. Sulekha Anand, from the Department of Biological Sciences, for their time and advice, and the Native Plant Society, Santa Clara Chapter, for a graduate research scholarship awarded to me last February.

Ultimately, I would like to thank my friends and family who have supported me throughout my schooling, both financially and emotionally, and my best friend Bill, who has supported me and believed in me unconditionally for so long.

TABLE OF CONTENTS

Table of Contents	vi
List of Tables	vii
List of Figures	viii
Introduction	1
Invasive Plants	1
Feral Pigs	2
Midpeninsula Regional Open Space District	5
Purpose	7
Methods	10
Study Site	10
Site Selection and Description	10
Treatments	13
Data Collection	14
Statistical Analysis	15
Results and Discussion	16
Presence of Thistle	16
Ground Cover Analysis	19
Correlation Analyses	19
Planned Comparisons	21
Grass Species Analysis	23
Summary and Recommendations	27
Works Cited	30

LIST OF TABLES

Table 1.	GPS coordinates of sites analyzed in the study	pg. 12
Table 2.	Raw data of thistle presence in the four areas included in the study	pg. 16
Table 3.	Results from MANOVA	pg. 23

LIST OF FIGURES

Figure 1a.	Large scale topographical map of study site.	pg. 11
Figure 1b.	Topographical map of the Long Ridge area and the study sites (numbered) that were initially included in the study.	pg. 11
Figure 2.	Average percent ground cover for seven dominant categories in three treatments.	pg. 20
Figure 3.	Planned Comparison #2 between Native and Mixed Treatments.	pg. 22

INTRODUCTION

Invasive Plants

Approximately one quarter of California's native plant species is being threatened by competition from invasive non-native plants (Bossard, 2000). In 1996, the National Park Service reported that sixty-one percent of its supervisors considered invasions by non-native plants to be of moderate to major concern within their parks. In fifty-nine percent of the 1,500 preserves owned by The Nature Conservancy, exotic plant species are the highest-ranking management problem (Bossard, 2000). Exotic species play such an important role in land management because of the seriousness of their impacts. Exotic plant species have the ability to change ecosystem functions such as the hydrology of the land, nutrient cycles, and wildfire frequency. They may harbor exotic animal species while excluding native animal and plant species, and also tend to hybridize with native plants. Many exotic plant species have already begun spreading into national parks, wildlands and preserves, therefore reducing the presence of the species these lands were meant to protect (Bossard, 2000).

There is evidence that some plant invasions can be stopped or suppressed even in strongly affected areas through restoration efforts. The main problem is that although the invasive species may no longer be actively introduced into areas, they usually continue to spread and invade other areas. Because of this, no restoration effort is ever finished. Restoration is an on-going process that needs to be continuously evaluated for its effectiveness and, if need be, adjusted.

Feral Pigs

The term invasive exotics is also used when referring to introduced animals, such as the feral pig. The rooting behavior of feral pigs is a primary cause of soil disturbance, which encourages the growth and dominance of invasive non-native species in grassland habitats. Domestic pigs (*Sus scrofa*) were first introduced to North America by the Spaniards upon their arrival in 1769 (Barrett, 1999). In 1925, more pigs were brought from North Carolina of the Eurasian wild boar stock by George Gordon Moore who let these swine loose on his property, the San Francisquito Ranch near Carmel. Twelve years later many more were released in the surrounding area and eventually the domestic pigs and wild boar that had escaped began to interbreed. Today the population in the western states is estimated to be between 70,000 and 80,000. The feral pig is now considered one of the major game animals in California. Next to the white tailed deer it is the most sought after hunting trophy (Synatzske, 1999). The feral pig we see today at the preserve is thought to be a hybrid of the domestic pig and wild boar. Its habitat preferences are varied and highly adaptable. The feral pig has been studied in mountainous regions, semi-arid brush, grasslands, oak woodlands, and even marshes (Synatzske, 1999).

The feral pig is an aggressive, omnivorous feeder, taking advantage of any food source that is readily available. Several studies have demonstrated a variety of food preferences (Wood, 1992; Singer, 1982; Kroll, 1985; Schwartz, 1988) which seem to be consistent across states. In Georgia, Wood determined feral hogs to be the cause when 80% of sea turtle nests were depredated on Ossabow Island (1992). Singer (1982) found

the red-cheeked salamander, a threatened species, to be the food of choice by feral pigs. In 1985, Kroll determined earthworms to be a highly prized food item, indirectly affecting the richness of the soil. In 1988, Schwartz reported a case of hogs stripping bark off trees in search of overwintering insects, not only making the trees vulnerable to pests and disease, but also decreasing the insect population, including pollinating species.

When food sources are not readily available, the pigs must seek out food elsewhere. They begin to root for bulbs, tubers, roots, insects, acorns, and invertebrates. This rooting causes many disturbances which directly and indirectly affect the health of the ecosystem. Whether these effects are harmful or beneficial to the ecosystem remains in dispute.

It is possible that rooting can diminish the natural seed crop of the native species of grasses and forbs in grassland areas, causing the reproductive ability of these species to plummet. This, in turn, may either increase or decrease successional timing of incoming crops and may encourage invasive non-native species to move in. According to Spatz and Mueller-Dossbois (1975), the rooting by feral pigs in Hawaii caused the component of non-native invasive species to dramatically increase over the native component even when a high percentage of natives were previously occupying the rooted area.

Surrounding the issue of the invasive feral pigs is the controversy that perhaps these animals are not as harmful to their environment as was once believed. If their rooting behavior is instead beneficial to the grassland community, either by decreasing competition among grass and forb species or allowing natives to get a head start in

establishing, then time and an extensive amount of money may be wasted on trying to eradicate the pigs instead of merely controlling their populations.

Some studies address the positive impacts the pigs may have on flora and fauna. In 1995, Kotanen determined that disturbance, in this case rooting plays an important role in the succession of an ecosystem dominated by native species of plants. Kotanen discovered that meadows experienced a first-year decline in species richness after rooting followed by an increase in species richness in successive years when compared to control plots, which remained undisturbed. Kotanen also showed that in the disturbed plots native species were more associated with this increase in species richness than alien grass species. This was not the case in the control plots where pigs had been kept out. Kotanen's theory is that, in this particular area of meadows in Northern California, the ecosystem was once exposed to some type of disturbance, either annually or even more frequently, which it may have depended upon or at least had adapted to. These disturbances may have been flooding, fire, or erosion. Today, these types of disturbances are usually avoided. Perhaps the rooting by the feral pigs is simply replacing a disturbance this ecosystem requires to regenerate and maintain its species richness and diversity.

In addition, Kotanen (1995) has stated that rooting may create habitat suitable for noncompetitive native species. These species cannot, under stable conditions, become established. However, with the disturbance in the soil moisture and chemical balance, these natives may be able to germinate and become established in the absence of competition.

It is uncertain if pigs are in fact causing such severe damage to ecosystems. Their rooting behavior scars the landscapes and creates an instinctive urge to be rid of them. However, there are many possibilities that need to be considered and studied before conclusions are drawn. Without statistical data it is difficult to know if the pigs really are damaging our hillsides by encouraging non-native plant invasions or if they are naturally facilitating succession and soil turnover while promoting native species to germinate and grow. There is no conclusive evidence supporting the theory that rooting is allowing more invasive species in and keeping natives out.

Midpeninsula Regional Open Space District

Midpeninsula Regional Open Space District (MROSD) is a publicly owned agency formed by voters in 1972. It was created in an effort to preserve an open space area which would connect the preserves with additional public parklands. In 1976 the boundaries of the preserves were extended to include southern San Mateo County, and northern Santa Cruz County was added to the District in 1992. The land is used to protect a greenbelt that supports wildlife and the native flora of the area, and for public awareness, enjoyment, education, and research. Today, the District is made up of 330 square miles and is home to more than 600,000 residents. It contains 23 preserves open to the public year-round (MROSD, 2000). The competition between invasive and native species creates an obstacle in preserving natural biodiversity and has become a leading management issue among park officials at the District as well (Isaacs, personal communication). Many of the non-native invasive species have caused so much damage

that without interdiction and control by the District, it may become impossible to protect any viable populations of native species, making it more difficult to sustain or protect many of the natural communities that exist in the area (Bossard, 2000).

In 1996, it was deemed necessary to eradicate the feral pigs (*Sus scrofa*) inhabiting the grassland and oak woodland areas in the Long Ridge preserve within MROSD. The feral pigs were destroying the native grasslands by rooting for bulbs, invertebrates, acorns, roots, and debris. This rooting is thought to diminish the seed crop for the consecutive seasons and also make the grasslands vulnerable to invasions by non-native species such as various thistle species and grasses. These non-native species excel in becoming dominant in disturbed areas created by trails, roads, rooting, and erosion.

Unfortunately, the removal of these invasive species (both the feral pigs and the invasive weedy grass species and thistle) is a slow process that is both time-consuming and costly. The District is exploring several methods of control and eradication to eliminate the problems that invasive species present. The trapping program, initiated in 1999, has removed over 70 pigs from Long Ridge, including sows and juveniles, but the rooting continues with an unknown population of pigs moving throughout the preserve. In an effort to slow the spread of invasive plant species through various disturbed areas, the District has begun to reseed root-disturbed areas with a native seed crop gathered at Rana Creek, an area with similar habitats and grassland species in the Carmel Valley. This reseedling is expected to increase the native grass component in the seed bank, which will enable it to outcompete the invasive non-native grass species after such a disturbance. This program has proven somewhat useful. However, with the population of

feral pigs at an all time high and their numbers undetermined, a more aggressive approach to this problem may soon be required.

Purpose

Controlling and eradicating invasive species are the District's priorities. The District has been reseeding rooted areas with a native seed mixture for the past three years. Photopoints have been used to document several areas that are repeatedly rooted and re-seeded to demonstrate regrowth, but actual species measurements have not been taken. Photopoints are pictures that are taken at the same location and same frame during each observation and time interval. The District was taking photopoint data every month for rooted areas throughout the District property to determine regeneration success of rooted areas that had been reseeded. Photopoint data is typically used for studies concerned with plant size and/or height, levels of herbivory, and sometimes flowering effort in the area studied (Elzinga, *et al.*, 1998). Currently the reseeding efforts by the District are viewed as a success based on the photopoint data. However, although vegetative ground cover is present after reseeding, this does not prove that the reseeding was effective. Invasive species may be more abundant after rooting, moving into areas with bare ground before the native grasses can. There have been no controls to determine that reseeding is even necessary in rooted areas. Therefore it remains unclear if this reseeding effort is useful in increasing the amount of ground cover occupied by native species while decreasing the cover occupied by non-natives.

Initially, the main assumption of this study was that a particular weedy species, thistle (and its various forms abundantly present in Long Ridge), moves into rooted areas with ease and takes over. This seemed a fairly safe assumption based upon the growing characteristics of the thistle species, their competitive abilities, resiliency, and the large seed bank produced each season. According to Bossard (2000), a major contributing factor determining which species are likely to invade is whether they invade in similar habitats as well. Thistle has spread in Australia, Spain, and California, and thistle species have demonstrated their ability to invade either human or naturally disturbed areas. It was also thought that species that are self-compatible are likely candidates for invasion. Any individual is likely to become established rapidly when many seeds are released at one time or if they are released repeatedly (Bossard, 2000). The thistle species addressed in the current study, bull thistle (*Cirsium vulgare*), California thistle (*Cirsium arvense*), yellow star thistle (*Centaurea solstitialis*), purple star thistle (*Centaurea calcitrapa*), and Italian thistle (*Caruus pycnocephalus*), meet the majority of these characteristics, with the exception that only one of the four species, *C. pycnocephalus*, is self-compatible. This species is also bisexual and pollinated by many different insects. In fact, *Caruus pycnocephalus* can produce up to 20,000 seeds in one growing season, while large *C. solstitialis* plants can produce up to 75,000 seeds. Still another obstacle to address in the control of these invasive exotics is the ability, among the majority of them, of their seeds to remain dormant in the soil over several growing seasons until conditions become favorable. For example, *C. arvense* seeds may remain dormant for up to twenty-one years (Bossard, 2000).

It is important to note that many of the species referred to as native grasses in this paper are in fact “naturalized” species brought over from Europe that have become an integral part of the landscape at MROSD. The difference between these naturalized species and invasive species is the ability of the latter to outcompete native species instead of sharing resources with them.

This purpose of this study is to determine whether reseeding is effective in outcompeting invasive thistle species and inhibiting invasions by thistle in rooted areas within the Long Ridge Preserve. This is a pilot study with data for one growing season. It will be important to measure percent cover and species presence in consecutive years following the disturbance so it can be determined how effective this treatment may be over the long term. If it is concluded that species composition and cover are not significantly altered after treatment, then perhaps the rooting is more aesthetically damaging to the area than anything else. Alternatively, future studies may indicate that there is an increase in native grasses within treatment areas after rooting and reseeding with a highly competitive mixture of seeds, suggesting that this treatment should be continued. This study may also set the stage for an ongoing monitoring project to explore different methods of restoration and to look at successional patterns in consecutive growing seasons.

METHODS

Study Site

Site Selection and Description

The study was conducted at Long Ridge Open Space Preserve, a 1,946-acre portion of the Midpeninsula Regional Open Space District (Fig. 1). At an elevation of 600 to 1000 ft, the habitats within Long Ridge consist of oak woodland, grassland, wetlands, and orchards, along with mixed evergreen forest consisting of coast live oak (*Quercus agrifolia*), tanoak (*Lithocarpus densiflorus*), and Douglas fir (*Pseudotsuga menziesii*). There are several trails running through the preserve, with one contiguous trail of 13 miles that connects Long Ridge to the Skyline Ridge Preserve (MROSD, 2000).

The target areas for this study were the rooted grassland communities. A total of seven rooted areas were selected based on several attributes: proximity to trails, size of area rooted, and timing and extent of the rooting. All areas were within 100 feet of the main trail and easily accessible. Areas ranged from 20 to 80 square meters and all areas were considered 100% rooted with no live plant material present at the start of the study.

The extent of the rooting in each area was rated by the presence of live patches of grass or forb species that were untouched and intact. If there were any of these patches then the area was not considered 100% rooted and it was therefore not selected as a treatment area.

Figure 1a. Large scale topographical map of study site. Red Flag Marks general location. (Printed from TOPO! © 1996 Wildflower Productions)

37°17'15", 122°11'43"

37°17'15", 122°06'11'

37°14'05", 122°11'43"

37°14'05", 122°06'11'

TN* MN

15 1/2°

A horizontal scale bar with markings at 1, 0, 1, and 2 MILES. The bar is divided into segments by vertical lines. The text "1 0 1 2 MILES" is printed above the bar. Below the bar, there is a line of text that is mostly illegible but appears to read "1:50,000 SCALE".

Printed from TOPO! ©1996 Wildflower Productions (www.topo.com)

Figure 1b. Topographical map of the Long Ridge area and the study sites (numbered) that were initially included in the study.

The amount of time that had passed since rooting occurred was also taken into consideration. Each site was considered recently rooted if there was no new growth within the rooted area since germination usually takes three to four weeks after a disturbance. Reseeding recently disturbed areas would enable the species in the treatment recipes to germinate without being outcompeted by species already in the seed bank and already germinating.

The selected areas were all reseeded with the two treatments (p. 13) and contained unseeded control plots as well. Areas 1 through 4 were treated within six hours of each other in November of 2000. In February of 2001, three additional areas, 5, 6, and 7, were reseeded using the same protocol and also contained controls. However, Areas 6 and 7 were continuously re-rooted and eroded following the seeding. Area 5 was destroyed during sledding season. Therefore areas 5, 6, and 7 were not included in the study. Area 3 lost one plot of each treatment when an all-terrain vehicle was driven through them during pig trapping efforts. However, the remainder of Area 3 was unaffected and therefore was included in the analysis. The GPS coordinates and sizes of the remaining sites used in the statistical analysis are listed in Table 1.

Table 1. GPS coordinates of sites analyzed in the study.

AREA	GPS COORDINATES	Size, m²	# Plots
1	37° 15' 42"; 122° 10' 09"	70 m²	9
2	37° 16' 11"; 122° 09' 15"	40 m²	6
3	37° 15' 39"; 122° 08' 20"	20 m²	6
4	37° 15' 42"; 122° 08' 33"	80 m²	10

According to Sutherland (1996), the appropriate and most often used quadrat size for studying densely growing grassland species ranges from 0.25 to 16 m². The plots in this study were 1x2 m. Each area had a varying number of plots (ranging from 6-10 plots) based on area size. Plots were randomly placed within the rooted areas using a point intercept method. In Area 1 there were three plots of each treatment (native reseeded and mixed reseeded) with three control plots. Areas 2 and 3 contained two plots of each treatment and two control plots. Area 4 contained three Native Treatment plots, four Mixed Treatment plots and two control plots.

Treatments

Two treatments were applied to four different rooted areas in an effort to increase native grass ground cover and ultimately keep thistle species from invading. The Native Treatment consisted of reseeding with a native seed mixture collected at Rana Creek Reserve. The recipe consisted of 40% California Brome (*Bromus carinatus*), 40% Blue Wild Rye (*Elymus glaucus*), 10% California Poppy (*Eschscholzia californica*), and 10% Sky Lupine (*Lupinus nanus*). This recipe is the current mixture being used to reseed at the District.

To increase the competitive ability of the native seed mixture, a sterile hybrid rye-wheat species (*Elymus X Triticum*) was added to the Mixed Treatment. The hybrid species is quick to germinate and grows rapidly. It was expected that this hybrid species would decrease the amount of open soil area, discouraging invasive plants from

germinating while encouraging the natives to thrive. Then, in the next growing season, with no seed production from the hybrid plants, the surviving native seedlings could utilize the space. Therefore, the Mixed Treatment consisted of a 70% native seed mixture and 30% *Elymus X Triticum* sterile hybrid cross obtained from Pacific Coast Seed Co. (Livermore, CA.). The two seed recipes were pre-mixed in the 70:30 ratio before entering the field. The technique for reseeding was the same for both treatments.

Two cups (approximately 500 ml) of the pre-mixed seed recipe were measured out and spread evenly by hand over the plot, then patted down by foot in an effort to prevent seeds from blowing away or being eaten by birds or small rodents. This technique is consistent with current management practices at MROSD (Isaacs, personal communication).

The assignment of treatments to plots was determined before entering the field. After the first plot was chosen randomly, the following plots were placed a minimum of twelve inches away from the initial plot and each other. Treatments were applied in the same order for each area, beginning with the Control, followed by the Native Treatment, and then the Mixed Treatment last.

It should be noted that the use of a seed spreader was attempted but the seeds used were too large to be efficiently spread in this manner.

Data Collection

Data were collected using cover estimation classes according to the Daubenmire system developed in 1959. This is one of the most commonly used systems of estimating

cover, next to the Braun-Blanquet method developed in 1965 (Elzinga *et al.*, 1998). A frame quadrat was laid down six times within each treatment plot to cover the entire quadrat area. Percent cover was visually estimated and assigned to a class (1=0-5%, 2=6-25%, 3=26-50%, 4=51-75%, 5=76-95%, 6=96-100%). Midpoints of these classes were calculated automatically as data was entered into a spreadsheet. The six midpoints for each plot were then averaged to obtain the average percent cover of each category for each plot. The midpoint value was used in the statistical analysis. All plots were sampled by the same person and within two days to avoid inconsistencies.

Statistical Analysis

The seven categories analyzed were bare ground, litter, *Avena fatua*, *Hordeum jubatum*, *Lolium multiflorum*, *Bromus diandrus*, and the hybrid species *Elymus x Triticum*. Pearson's correlation analysis was run to determine if any of the seven categories were correlated.

A multivariate analysis of variance (MANOVA) was run to determine if there was a significant interaction between the dependent variable (mean percent of ground cover) and the independent variable (treatment). The significance level for all statistical tests was set at 0.05. After MANOVA, planned comparisons were run to determine which treatments differed from each other. In the first planned comparison, the control data for ground cover were compared to the treatment data (mixed and native). The second planned comparison was run to test for differences in ground cover between the Native Treatment and the Mixed Treatment.

RESULTS AND DISCUSSION

Presence of Thistle

Ideally, differences in the presence of various thistle species would have been compared between plots. However, contrary to the hypothesis, no treated or control plots demonstrated a strong, measurable invasion by thistle species. Therefore data were instead collected on grass species present in the plots with seven dominant categories selected and analyzed to determine treatment effects on these categories. Presence of thistle species was recorded (Table 2), but no single thistle species demonstrated a strong enough presence to be considered a dominant species in any of these rooted areas after one season of growth.

Table 2. Raw data of thistle presence in the four areas included in the study.

Area	No. thistle plants (cover class)	Treatment Plot where thistle was located
1	2 (0-5% cover) 1 (0-5% cover) 1 (0-5% cover)	Native Recipe Mixed Recipe Control Plot
2	1 (0-5% cover)	Native Recipe
3	None	
4	None	

This absence of thistle was especially surprising in Area 1. Three of the four sides of this area were bordered with hundreds of thistle plants, including bull thistle (*Cirsium vulgare*), yellow star thistle (*Centaurea solstitialis*), and purple star thistle (*Centaurea calcitrapa*). The south perimeter of the rooted area had been invaded by *C. vulgare*, which had recently gone to seed. When this site was visited in August of 2000, three months before treatments were applied, the ground was covered by a blanket of thistle seeds. It was assumed that the thistle species would invade this rooted area rapidly. It is a safe assumption that there were already thistle seeds contained in the seedbank from previous growing seasons, yet no thistles were present in the control plots after treatment and one growing season. The area adjacent to the site, which had been invaded by *C. vulgare*, no longer showed what type, if any, of disturbance encouraged this invasion. Because the thistle seeds can remain dormant for long periods of time, it is important to revisit this site in future years.

The high degree of presence of *C. calcitrapa* surrounding Area 3 that resulted in only minimal cover in an excluded control plot can be explained by the lack of pappus on the seed of the plant. Without the pappus this species does not have a large dispersal area or rate. The sites are in a prime location for species that use wind for seed dispersal. However, *C. calcitrapa* depends on animals and birds to disperse its seeds and therefore may not be as aggressive.

Because of the low number of thistle plants present after treatment, it is unclear whether the hybrid species would have had an effect in suppressing them. This effect and

any advantage to using the hybrid to reseed with may become more obvious in the second or third growing season.

It is clear that in the four areas analyzed, thistle species were not the major threat to native or naturalized plants germinating during this growing season. According to Bossard (2000), competition by reseedling is currently the most effective means of controlling *C. vulgare* and *C. solstitialis*, while rooting was considered an effective method of controlling invasions by *C. calcitrapa*. Perhaps the rooting actually suppressed germination of *C. calcitrapa* in Area 1.

The data show that in Area 1, *C. vulgare* and *C. solstitialis* were only present in mixed and native treatment plots, with the exception of a small presence of *C. calcitrapa* in one control plot. This may be explained by the ecology of the species. Both *C. vulgare* and *C. solstitialis* have been reported to be controlled successfully by competition induced in reseedling efforts (Bossard, 2000). However, both *C. vulgare* and *C. calcitrapa* seeds, once dispersed, will not begin to germinate until the second growing season. It is safe to assume that the mature plants have been dispersing seeds before August of 2000, so a consecutive growing season may result in more germination and growth of thistle species. On the other hand, Bossard's theory that species that have invaded areas in the past are likely candidates to invade similar areas anywhere may be too broad. Although the root-disturbed areas appeared to be likely candidates for invasion, it appears that after one growing season thistle is not yet a major threat of invasion. In fact, in the case of *C. calcitrapa*, perhaps the rooting plays a functional role in suppressing invasion by disturbing the seeds that would have otherwise germinated.

Ground Cover Analysis

Correlation Analyses

The seven dominant categories analyzed included the average percent cover of bare ground, litter, *Lolium multiflorum*, *Avena fatua*, *Hordeum jubatum*, *Bromus diandrus*, and the sterile hybrid *Elymus X Triticum* (Fig. 2).

Among the grass species analyzed, it is interesting to note that *B. diandrus* was showing a slight, though not significant, positive correlation with *H. jubatum* ($r_{(30)}=0.51$, $p>0.05$). This relationship is likely the result of the similar habitat and soil types these species inhabit. *H. jubatum* prefers moist soils, while *B. diandrus* is adaptable to most soil types. It would be useful to pay attention to this correlation in future studies.

Results of the correlation analysis also indicate a statistically significant negative relationship between *B. diandrus* and *L. multiflorum* ($r_{(30)}=0.06$, $p<0.05$). A negative relationship between these two species may indicate a strong competition taking place during the germination period between them.

L. multiflorum was showing a slight negative correlation ($r_{(30)}= -0.41$, $p>0.05$) with bare ground cover. Although not statistically significant, this may demonstrate a trend that the presence of *L. multiflorum* moves into open areas and/or recently disturbed areas rapidly and is able to outcompete other species before they have a chance to germinate.

Figure 2. Average percent ground cover for seven dominant categories in three treatments.

Planned Comparisons

In the first planned comparison comparing the mean percent of ground cover in control plots to native and mixed plots, the p -value was 0.083 (Table 3, planned comparison #1). With no significant change in ground cover between control plots and treated plots, the data determined that the reseeding effort was no more effective at encouraging new growth than simply leaving the site to regenerate under natural conditions.

Although this p -value was not low enough to be considered statistically significant (p -value must be less than 0.05), trends in the data suggest that the amount of bare ground does decrease when reseeded, but one growing season is not sufficient to demonstrate the result strongly enough. There is a possibility that there will be a significant difference in bare ground cover between control plots and the treatment plots in subsequent seasons.

The second planned comparison showed a significant difference in the mean percent of ground cover between plots in the Native Treatments and plots in the Mixed Treatments. However, trends suggest that when the hybrid was used to reseed in Mixed Treatments, the mean percent of bare ground decreased visibly, with a mean bare ground cover of 7.6% in mixed treatment plots (Fig. 3). The control plots showed a much higher mean of bare ground (12.4%). The decrease in the mean percent of bare ground cover in the presence of the hybrid species may demonstrate the advantage of reseeding for aesthetic reasons. Using this alternative quick-growing species may outcompete invasive species slightly better than the standard seed mix used at the District.

Figure 3. Planned Comparison #2 between Native and Mixed Treatments.

Table 3. Results from MANOVA. F statistics were computed from Wilks' Lambda. * Symbol denotes significant effects ($p < 0.05$).

	F	df	P
Overall MANOVA	2.502	14, 44	0.010 *
Control vs. Native + Mixed (Planned Comparison #1)	2.126	7, 22	0.083
Native vs. Mixed (Planned Comparison #2)	3.230	7, 22	0.016 *

Grass species analysis

Avena spp. had a noticeably higher mean cover in plots reseeded with native mixture (5.8%) than in plots reseeded with the hybrid treatment. This may demonstrate that the mixture of seeds used in native treatments is not effective against the competitive ability of *Avena spp.* The hybrid species did have an affect, with *Avena spp.* having a decreased mean ground cover (3.6%) in mixed treatment plots containing the hybrid species. Although *Avena* is not a targeted problem species for the District, it is a naturalized weedy species that invades grassland and oak woodland areas easily and rapidly. If the aesthetics of the grasslands were a priority in restoration, *Avena spp.* would be one of the top priorities for removal. It is one of the tallest grass species, is the first to be seen, and easily shades out other grassland species.

Bromus diandrus had the highest mean ground cover in control plots (7.4%), lower in mixed treatments, (3.0%), and lowest in treatments of native seed mixture (2.3%). In this case the hybrid was probably not useful in suppressing this exotic species, but perhaps the use of other competitive native species in reseeding efforts should be explored. *Bromus diandrus* is a very aggressive and adaptable species. These numbers indicate that its growth or success is hindered by competition with other grass species and in this case, perhaps the native species used have a stronger influence on its decline in cover.

Hordeum jubatum had a higher mean percent ground cover in plots reseed with the mixed treatment containing the hybrid species (Fig. 3). Once again, perhaps the competitive ability of *H. jubatum* is too strong for the hybrid recipe to overcome, or perhaps a different species would be more useful in this type of control plan.

Elymus glaucus, one of the species used from Rana Creek to reseed, did not show up in the treatment plots when data were collected. *Elymus glaucus* was noticed outside the treatment perimeters in Areas 3 and 4 however. Although this species is accustomed to Mediterranean climates, it is most commonly seen in open stands under oaks and some conifers, but rarely in open stands containing no trees for partial shade. No treatment areas were within 10 meters of any oak or conifer stands. According to Crampton (1974), the conditions for *E. glaucus* may not have been suitable to expect a high success rate in germination or survival. The soil ecology, hydrology, humidity, sun exposure, and competition from seeds already in the seed bank could all be limiting factors that determine the success or failure of this species.

Lolium multiflorum was one of the most abundant species measured. The characteristics of this species may explain the absence of other species. *L. multiflorum* (annual or Italian ryegrass) was introduced from Europe and is now considered a naturalized species (Crampton, 1974). Although it is not considered an invasive weedy species of concern, it is a very aggressive and fast-growing species able to move into areas rapidly and outcompete slower growing species. According to Crampton (1974), *L. multiflorum* is commonly used as a space-filler in lawns to provide a temporary lawn in business areas and, most importantly, as forage in rangelands. The use of *L. multiflorum* as forage material may explain its abundance in the seed bank in the grasslands within the open space land as grazing was allowed before MROSD purchased the land.

The other grass species used to reseed in treatment plots, *Bromus carinatus* (California brome) was measured but was not one of the dominant species and was therefore not included in the statistical analysis. It was observed in Area 3 very minimally, with 0-5% cover in one plot. *Bromus carinatus* occupies open stands of pine and oak and is most commonly found in the wooded areas of the foothills and also in mountainous habitats (Crampton, 1974). Open grasslands may not be an optimal or even suitable habitat to expect this species to be successful in, especially considering the germination competition posed by thistle species, *L. multiflorum*, and other aggressive, more adaptable exotics and naturalized species.

The variability among sites was quite high, as seen by the error bars in Figure 2. No two sites included in this study contained soil types, aspects, elevations, soil moisture, or species compositions that were identical. The high variability in the measurements of

ground cover may also be the result of the reduction in sample size when Areas 5, 6, 7, and plots within Area 3 were removed from the study due to unforeseen accidents. These areas represented a reduction in sample size by nine plots in each treatment.

SUMMARY AND RECOMMENDATIONS

The addition of the hybrid species to the mixed seed treatment was intended to fill open soil areas to promote native grasses to move in and germinate before the invasive species could do so. Trends in the data suggest that treatments, with or without the addition of the hybrid species, are somewhat effective in decreasing the amount of bare ground after one growing season. This trend should be explored again after consecutive seasons. It would also be useful to continue this study for additional growing seasons to determine the succession these sites will go through. How these treatment sites react to reseeded efforts over multiple growing seasons will help the District to better understand the germination and growth competition taking place between the species being used to reseed.

The use of photopoint data by the District was not sufficient to determine the success or failure of reseeded efforts. The photopoints taken by the District will, however, be useful in documenting repeat disturbance caused by rooting. In some cases photopoints may be considered useful in detecting weed invasions, but considering the height of the *Avena* spp. observed in the study plots and the effort required to identify the understory weedy grasses through the *Avena* spp. during data collection, it is unlikely that this method is sufficient to meet the goals of the District.

In studies conducted over several growing seasons, trends in the analysis, although not “statistically” significant, need to be recognized and used in determining future actions. The trends observed among the invasive species included in the analysis have strong implications for future management and control.

If future studies of these treatment areas continue, it would be useful for the District to begin measuring forb species present in the rooted areas after reseeding to explore interactions between forbs and grasses during the successional process.

It is clear that it is possible to focus restoration efforts on more than one species or problem at a time. In this study reseeding decreased both the invasive weedy species *B.diandrus* and *L. multiflorum* while also decreasing the amount of bare ground that promotes growth and invasion of these weedy species.

Because this is the first year of a pilot study, the trends seen here will be useful and have strong implications for the restoration of the grasslands in the Long Ridge area. This study clarified that data from a single growing season are not sufficient to determine if reseeding will be effective if only done once. Most likely reseeding will need to be a continuous effort because the existing seedbank contains hundreds of thousands of thistle seeds waiting for the perfect growing conditions before they germinate. The District needs to anticipate these invasions in order to avoid them. Area 1 will be most useful in supplying data that will reveal whether invasions can be suppressed by continuous reseeding because it is surrounded by several different thistle species and hundreds of individuals. Each individual can produce roughly 20,000 seeds. This area is a likely candidate for intense invasion within the next couple of years and will provide the District with valuable information in the following seasons.

It was the goal of this study to explore methods of preventing thistle invasions in root-disturbed areas. Although thistle species were determined not to be the dominant threat in these areas, the reseeding efforts were able to decrease the amount of bare

ground susceptible to invasions by non-native species. The District will now be able to design restoration efforts around the trends observed among various other invasive species in this study. It is hoped that this information will be useful in restoring disturbed, invaded areas in the Long Ridge area while anticipating and avoiding future large-scale invasions.

Works Cited

- Barbour, M., Pavlik, B., Drysdale, F., and Lindstrom, S. 1993. California's Changing Landscape. 245 pp. California Native Plant Society, Sacramento, CA.
- Barrett, Reginald H. 1999. Feral Swine: The California experience.
<http://texnat.tamu.edu/symp/feral/feral-15.htm>. Department of Forestry and Resource Management, University of California, Berkeley, CA, 94720.
- Benyus, J.M. 1989. The Field Guide to Wildlife Habitats of the Western United States. 336 pp. Simon and Schuster, New York.
- Bossard, C., Randall, J.M., and Hoshovsky, M.C. 2000. Invasive Plants of California's Wildlands. 360 pp. University of California Press, Berkeley, CA.
- Crampton, B. 1974. Grasses in California. 178 pp. University of California Press, Berkeley, CA.
- Dytham, Calvin. 1999. Choosing and Using Statistics. 218 pp. Blackwell Science Ltd, Paris.
- Elzinga, C.L., Salzer, D.W., and Willoughby, J.W. 1998. Measuring and Monitoring Plant Populations. 476 pp. The Nature Conservancy. Bureau of Land Management, National Business Center. Denver, CO. BLM Technical Reference 1730-1.
- Everitt, J.H. and Alaniz, M.A. 1980. Fall and winter diets of feral pigs in South Texas. J. Range Management. 33(2):126-128
- Higginbotham, Billy. 1999. Feral Swine: Research needs and summary.
<http://texnat.tamu.edu/symp/feral/feral-25.htm>.
- Isaacs, J. Aug. 2000-Aug. 2001. Personal Communication. Director, Midpeninsula Regional Open Space District. Los Altos, CA.
- Kachigan, S.K. Statistical Analysis. 1986. 589 pp. Radius Press, New York.
- Kotanen, P.M. 1995a. Effects of feral pigs on grasslands. Fremontia 22(2): 14-17
- Kroll, J.C. 1985. Interspecific competition between feral hogs and white-tailed deer in the Post Oak Savannah region of Texas. P.R. report W-109-R-8 Job. No. 44.
- Midpeninsula Regional Open Space District, Pamphlet, 2000.

- Schwartz, D.M. 1988. Hog havoc. *National Wildlife* June/July 1988.
- Singer, F.J., Swank, W.T. and Clebsch, E.E.C., 1982. Some ecosystem responses to European wild boar rooting in a deciduous forest. *Research/Resources Management*. Report No. 54 USDI, NPS, SERO, Atlanta 31 p..
- Singer, F.J., Swank, W.T. and Clebsch, E.E.C., 1984. Effects of wild pig rooting in a deciduous forest. *J. Wildlife Management*. 48(2):464-473
- Spatz, G. and Meeller-Dombois, D., 1975. Succession patterns after pig digging in grassland communities on Mauna Loa, Hawaii. *Phytocoernologia* 3(2/3):346-373.
- Stromberg, Mark. Hastings Natural History Reservation. Univ. California, Berkeley. Personal Communication, July, 2001.
- Sutherland, W.J. 1996. *Ecological Census Techniques*. 336 pp. Cambridge University Press. New York.
- Synatzske, David R. 1999. The ecological impacts of feral swine. <http://texnat.tamu.edu/symp/feral/feral-9.htm>
- TOPO! Software, 1996. Wildflower Productions.
- Welaratna, S. 2000. Report to Fish and Game by MROSD.
- Wood, G.W., Woodward, L.A., Matthews, D.C., and Sweeney, J.R., 1992. Feral hog control. Reprint 1992 proceedings of Annual Conf. Southeast Assoc. Fish and Wildl. Agencies.
- Zar, J. H., 1996. *Biostatistical Analysis*, 3rd edition. Prentice Hall, New Jersey. 718 pp.