Conservation of the Remnant Coastal Prairie at UC Berkeley's Richmond Field Station

Alan Cai & Patrick Donnelly-Shores,
and the other students of ESPM 187 in Spring 2012, including:

Dylan Baker, Nathan Bickart, Mauricio Castillo, Kate Clyatt, Lawrence Fernandez, Yvette Gault, Tenaya Jackman, Emma Kohlsmith, Alaska Lather, Carrie Miller, Jessica Reimche, Parsa Saffarina, Jennifer Urban, and Stephanie Wright

Hillary Sardiñas, GSI
Dr. Katharine Suding, Professor

Restoration Management Report
Richmond Field Station
University of California Berkeley

FINAL REPORT
October 25, 2012

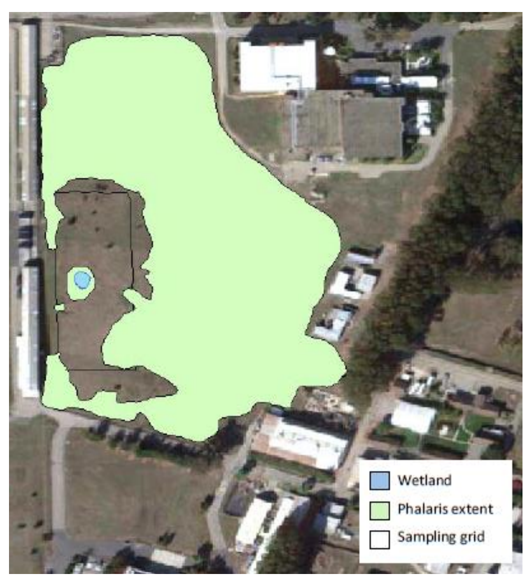
Conservation of the remnant coastal prairie at UC Berkeley's Richmond Field Station

EXECUTIVE SUMMARY

Richmond Field Station (RFS), an academic teaching and research off-site facility, is located 6 miles northwest of the UC Berkeley Central Campus on the San Francisco Bay. The site contains one of the largest remaining areas of native coastal grasslands that were once prevalent throughout the Bay Area. Multiple reports have established the conservation significance of the coastal prairie. In 1999, it was identified as an area of Unique Restoration Opportunities in the Baylands Ecosystem Habitat Goals Report completed through the Wetlands Ecosystems Goals Project.

This report focuses on an array of biotic and abiotic factors which may possibly determine the ability of the exotic grass *Phalaris aquatica* (Harding grass) to invade and persist at the RFS coastal prairie. We demonstrate the need for action with regards to the Harding grass invasion, and detail recommendations of areas of critical knowledge gaps that deserve further study. Specifically, we found the following:

- Over the last decade, the exotic *Phalaris aquatica* (Harding grass) has taken over large portions of the coastal prairie, with only small remnants of native habitat remaining. The largest such native remnant is the southwest portion of the Big Meadow (see map below).
- As expected, the abundance of native *Danthonia californica* (California oatgrass), one of the keystone species of California coastal prairie, was negatively correlated with the abundance of the exotic *Phalaris aquatica* (Harding grass).
- A survey of native plant species in the native core remnant (Figure E2.1) showed certain species (of note is *Stipa pulchra*) had lower abundance in 2012 compared to 2006, while other species (notably *Eryngium armatum*) had increased abundance.
- Several additional invasive species, particularly *Dispacus fillonum* (teasel) and *Helminthotheca echioides* (Bristly oxtongue) were abundant.
- Soil nitrogen availability, small mammal activity, and arthropod abundance were not correlated with *Phalaris* abundance, but can provide baseline data for future studies.



Extent of *Phalaris* and location of study plot in the Big Meadow.

These results inform our six major recommendations for management of the site:

1) ***Control of Harding grass*** should begin immediately, in an iterative, adaptive fashion. Through replicated large-scale experimental plots, the best technique for removing Harding grass should be determined and carried out over the entire coastal prairie.
2) The ***current mowing plan***, while a start in the right direction, may slow the invasion but is not sufficient for the conservation of the incredible native diversity at this site.
3) In conjunction with the focus on Harding grass, the ***re-establishment of native plant species***, particularly *Danthonia*, needs to be prioritized or there will be a high probability that another exotic will replace Harding grass.
4) More data should be collected to better ***characterize the current condition*** of the plant, animal and insect communities at RFS, as a baseline to determine the effects of restoration and management. In particular, 2012 was a very dry year, and changes in abundances need to be assessed over a wider range of rainfall conditions.
5) ***Continued monitoring*** is essential to our understanding of how these actions will change the coastal prairie ecosystem over time.
6) It is critical to ***involve the community***, both that of the University of California, Berkeley and residents of the Richmond Annex near RFS, to ensure ongoing support for restoration actions. An internship program or volunteer program (similar to the Strawberry Creek Restoration program on the main UCB campus) could provide the labor and continuity needed to ensure sustained stewardship of this valuable resource.

In addition, the resources at RFS provide countless opportunities for education and experimentation for UC Berkeley students. This report, which was the culmination of a semester-long Restoration Ecology course in the department of Environmental Science, Policy and Management, offered students the opportunity to engage in on-the-ground science that was greatly appreciated by class members. This unification of educational opportunity with preservation of a unique ecological and cultural resource is rare and ought to be highly valued by UC Berkeley.

Table of Contents

1. INTRODUCTION 2
1.1 Project goals 2
1.2 Intended Audience 3
1.3 Planning Framework 3
2. LITERATURE REVIEW AND RATIONALE 3
2.1 Introduction 3
2.2 Coastal Prairies in California 3
2.3 The Coastal Prairie at Richmond Field Station 5
2.4 Patterns of Exotic Perennial Invasion 7
2.5 No Easy Answers: Management Techniques for Coastal Prairie Restorations 8
3. RFS RESOURCE ASSESSMENT 10
3.1 Objective 10
3.2 Methods 10
3.3 Results 14
3.4 Discussion 18
4. RESTORATION RECOMMENDATIONS 18
4.1 Restoration objectives 19
4.2 Restoration actions 19
4.3 Measurable targets 21
4.4 Critical areas of concern and uncertainty 21
4.5 Next steps/final recommendations 22
APPENDIX A: DATASETS COLLECTED 27

FIGURES

3.1 Location of the Big Meadow plant study site 10
3.2 Location of study sites for other focal resources 13
3.3 Abundance of *Danthonia* and *Phalaris* at the Big Meadow study site 14
3.4 Relationship between *Danthonia* and *Phalaris* abundance 15
3.5 Average abundance of native species by class in 2006 and 2012 15
3.6 Distribution of rare native and invasive species by abundance class 16
3.7 Tests for relationships between *Phalaris* cover and several focal resources 17

1. INTRODUCTION

Richmond Field Station (RFS), an academic teaching and research off-site facility, is located 6 miles northwest of the UC Berkeley Central Campus on the San Francisco Bay. The site contains one of the largest remaining areas of native coastal grasslands that were once prevalent throughout the Bay Area. Multiple reports have established the conservation significance of the coastal prairie (Amme 2005; URS Corp 2007). In 1999, it was identified as an area of Unique Restoration Opportunities in the Baylands Ecosystem Habitat Goals Report completed through the Wetlands Ecosystems Goals Project (Monroe et al. 1999).

The report is organized in four sections. Section one describes the overall restoration objectives, the intended audience and planning framework. Section two reviews the background knowledge related to one of these goals. Section three consists of an analysis of the current status of a focal resource. In section four, we present a conceptual restoration design and a monitoring and adaptive management program for restoring the focal resource in question.

1.1 Project goals

The purpose of this report is to develop a restoration plan for RFS coastal prairie the context of seven over-arching goals. Goals relate to the associated ecosystem, organisms, invasive species, species interaction networks, uncertainties, education and outreach, and administration (Table 1.1). This report focuses on an array of biotic and abiotic factors which may possibly determine the ability of the exotic grass *Phalaris aquatica* (Harding grass) to invade and persist at the RFS coastal prairie. We will demonstrate the need for action with regards to the Harding grass invasion, and flag recommendations for further study.

Table 1.1. Restoration goals at the RFS coastal plain prairie.

Category	Goals
1 Ecosystem	Conserve and Restore the coastal terrace prairie and grassland complex, and its links to tidal marsh and slough complexes, featuring them as outstanding representative examples of Bay area upland ecosystems.
2 Native species	Conserve and enhance populations of regionally rare, declining, or unique native species inhabiting RFS coastal prairie.
3 Invasive species	Eliminate, control significant threats to the site from introductions of non-native invasive plants and animals.
4 Species networks	Maintain the vital links among interacting species populations and food web complexity that characterizes a diverse and well-functioning system.
5 Uncertainties	Address uncertainties in site management and restoration by implementing these processes in an adaptive management context.
6 Education and Outreach	Promote and provide opportunities for education, research, and outreach on the site that enhances understanding and appreciation of the site, its management, and its regional significance.
7 Administration	Establish and maintain sustainable levels of personnel and financial support to implement restoration, maintenance, and monitoring plans.

1.2 Intended Audience

This project is intended to benefit the University of California Berkeley, and in particular to help guide efforts currently led by the EH&S department in managing the coastal prairie. We hope that the restoration plan will allow prioritize the funding and programs necessary to take positive, restorative actions to conserve the prairie. In addition, this project is also applicable to the larger restoration community in the Bay area. For instance, it can be considered a case study on controlling invasive perennial grasses in a highly diverse but fragmented prairie remnant that can provide insight for other similar projects in the region.

1.3 Planning Framework

There has been a long history of appreciation and concern about the coastal prairie at RFS (Amme 2005). From general restoration goals (Table 1.1), this report develops specific project objectives, possible actions, and measurable targets for restoration and maintenance of this valuable natural resource. The planning framework is explicitly designed to link the restoration goals to site-specific objectives, measurable targets, and specific on-the-ground actions. The over-arching framework informs each plan section (literature review, assessment). The resulting objectives, measurable targets, and restoration actions are reflective of this framework (section 4).

2. LITERATURE REVIEW AND RATIONALE

2.1 Introduction

California's coastal prairies are amongst its most rare and vulnerable ecosystems. Having been largely extirpated due to development and agriculture, only a few small remnants remain. One of the most intact of these remnants is at the UC Berkeley Richmond Field Station (RFS), where a *Danthonia-Nassella* dominated community exists on fourteen acres of open grassland. However in recent years, Harding grass (*Phalaris aquatica*), an exotic perennial, has been rapidly increasing in population on the site, displacing native perennials.

This section examines the historical context and current state of coastal prairies in California. Given its rich history of research, there are a number of reports available which also allow an assessment of the specific community at the RFS. We survey relevant literature on patterns of perennial exotic invasion, then use the relevant literature as a guide to explore potential restoration techniques. This section builds the background rationale concerning the necessity to create a comprehensive restoration strategy to enhance native perennial grass cover at the RFS, as the community is under threat of becoming dominated by invasive grasses.

2.2 Coastal Prairies in California

Prior to the introduction of cattle in 1769, California was a landscape dominated by perennial grasslands (Bartolome 1981). Along the coast from Santa Barbara to Humboldt County, inland in the great Salinas, San Joaquin, and Sacramento valleys and up into the foothills of the Sierra, California's grasslands stretched through the wide variety of microclimates and abiotic conditions that the area encompasses.

The composition of these grasslands was thought to primarily differ along a moisture-defined gradient from the more mesic grasslands near the coast to the more arid grasslands in the Central Valley (Stromberg 2001). Botanists have separated these two types of grasslands by terming the mesic grasslands "coastal prairie" and the more arid grasslands "valley grassland," though the two share characteristic botanical traits such as dominance by perennial bunch grasses, and characteristic species such as *Nassella pulchra*[1] (Ford and Hayes 2007).

Coastal prairies generally occur in areas with annual rainfall between 35 and 60 inches per year, and exist largely within the coastal fog belt, where there are lower rates of evapotranspiration than in more inland valley grasslands (Amme 2005). A number of different researchers have done botanical inventories; Ford and Hayes (2007) have synthesized these studies and put forth three roughly defined major vegetation types on the coastal prairie: an oatgrass (*Danthonia*) community, a California annual grassland community, and a moist native perennial grassland community.

Coastal prairie was originally characterized as a "fescue-oatgrass (*Festuca-Danthonia*)" community, with associated plants such as coastal hair-grass (*Deschampsia* spp.), sedges, and purple needle-grass (*Nassella* spp.) (Küchler 1964). This variety of plant assemblages is what makes the ecosystem so unique: it contains elements from both northern Palouse prairie from the Pacific Northwest (such as blue fescue, *Festuca idahoensis)*, and southern grasslands (such as tarweeds like *Hemizonia conjesta,* common in more arid Central Valley grasslands) (Ford & Hayes 2007).

The composition of the coastal prairie, and all California grasslands, began to change with the introduction of grazing and alien grasses, and with the cessation of a natural fire disturbance regime (Angelo 2005). These changes escalated rapidly in scale and severity when rampant overgrazing began in the mid-19th century, with the arrival of white settlers from the East (Bartolome 1981). However, coastal prairies have proven more resilient than other grassland types, being characterized as generally "less invaded," perhaps due to higher water availability, shorter dry seasons ameliorated by the effects of coastal fog, and lower historic levels of grazing (Thomsen et al. 2006).

While perhaps less invaded, these coastal prairie perennial grasslands have gradually given way to exotics across much of their extent. Today, there are no grasslands left in California that are purely native, and almost no locations even contain a majority of native cover (Bartolome 1981). In fact, Ford and Hayes (2007) report that few areas remain of coastal prairie remain with greater than 15% cover of native perennial grasses.

Because of the unique assemblage of their plant communities, California coastal prairies have been recognized as biodiversity hotspots (Stromberg et al. 2001). Additionally, they frequently

[1] *Stipa* and *Nassella* have been basionyms for many years. For instance when Bartolome wrote his 1981 article on the grass, purple needle-grass was *Stipa pulchra*; when Amme wrote his 2003 article on the grass, it was *Nassella pulchra.* While the currently accepted name according to the Jepson Herbarium is *Stipa pulchra,* it has been referred to in field studies recently as *Nassella pulchra,* so it will be referred to as such here for cultural purposes.

contain a high number of state or federally designated "rare" species (Amme 1993). While it is still an open question as to the overall contribution of rare species to ecosystem function, increased biodiversity enhances the potential for the utilization of a wider array of ecosystem traits and concomitant use of resources, which may be a factor in coastal prairie's comparatively greater resilience to invasion (Stromberg et. al 2001).

Due to the high biodiversity and relatively lower level of invasion present in coastal prairies, they have been identified as having high conservation value and potential for restoration (Angelo 2005). Given that most formerly native perennial valley grasslands have completely given way to exotic annual grasslands, coastal prairies are the best remnants of the once vast native California grasslands.

2.3 The Coastal Prairie at Richmond Field Station

The coastal prairie extends along the California coast from the Oregon border to as far south as San Simeon or even Santa Barbara, occurring primarily in flat, clay-type soils (Ford and Hayes 2007). Along much of that coastline, the coastal terraces are a small strip of land between the Coast Range and the Pacific Ocean. As a result, the largest patches of coastal prairie were historically located in the Bay Area, where there are large tracts of flat coastal land in Marin County and surrounding the San Francisco Bay (Amme 2005).

The Coastal Prairie at the University of California Berkeley's Richmond Field Station is the last example of relatively undisturbed coastal prairie in the Bay Area.

Among the chief threats to the continued health and abundance of coastal prairie ecosystems is development pressure (Ford and Hayes 2007). Indeed, most of the lowland areas of the Bay Area have already been developed and urbanized. In combination with cultivation and overgrazing pressures in coastal prairies to the south and in western Marin County, this plant community has been almost completely eliminated, with only a few remnant stands remaining (Amme 2005).

One remnant stand is located at the University of California, Berkeley's (UCB) Richmond Field Station (RFS). It is perhaps the only and last example of a relatively undisturbed coastal prairie in the San Francisco Bay Area (Amme 2005). Though once slated to become a housing development, the area was purchased by the University in the 1950s to develop a research facility (URS Corp 2007). Through this chance occurrence, the 14-acre site remains mostly intact and somewhat undeveloped: the last bastion of this now-rare ecosystem (Amme 2005). However, the RFS is currently being considered for development as part of an extension of the Lawrence Berkeley National Laboratory. It is unclear what role the remnant coastal prairie might play in such a development.

The botanical community at the site is varied. In its native state it was dominated by *Danthonia*, with relatively large populations of *Nassella,* sedges (*Carex* spp.), rushes (*Juncus* spp.), forbs such as buttercups (*Ranunculus* spp.) and suncups (*Camissonia* ssp.), and two wildrye-grass (*Elymus* spp.) (Amme, 1993). There is a core of relatively undisturbed coastal prairie in the western portion of the area known as "The Big Meadow" which not only contains *Danthonia, Nassella,* but also hosts fifteen other species listed as "sensitive" (URS Corp. 2007). Of particular note is the presence of slender wheatgrass (*Elymus trachycaulus*), rarely seen in lowland coastal prairies, which displays a unique growth pattern at RFS (Amme 2003).

Outside of this core, however, exists a disturbed exotic grassland, composed of numerous annual invasives such as annual ryegrass, bristly oxtongue, filaree, teasel, and perhaps most importantly, the perennial invasive Harding grass (Amme 2005).

Other organisms that contribute to the RFS coastal prairie's immense biodiversity include a variety of arthropods. Rare insects can utilize specialized microclimates in areas which are species poor (Mortimer *et al.* 1998). They also provide critical functions to rare populations, such as pollination or seed dispersal. However, it is also possible that exotic species invasion is facilitated by exotic insects leading to positive feedback mechanisms (Goulson 2003).Insect species are often subject to fragmentation and isolation more readily than other, more mobile, plants and animals (Kremen *et al.* 1993).

Mammals inhabiting the RFS coastal prairie, specifically the California vole (*Microtus californicus*) and the pocket gopher (*Thomomys bottae*), can directly impact plant species richness and composition. Because they are fossorial species, they uproot plant matter, mix up seed banks and create small-scale disturbances within a system. The disturbed soils they burrow in are vulnerable to exotic species establishment. The diet of small mammals depends on seasonality and rainfall. During a dry season with low plant productivity, small mammals will forage and store seeds. Through the consumption of the seeds the small mammals become direct dispersal agents and can compose the future plant communities through their tracts and runways. This could be extremely important for plant species that either lack other dispersal agents or dispersal-enhancing traits, as these mammals could be their only means of dispersal (Zedler and Black 1992).

Invasive plants in general, and Harding grass in particular, have been spreading rapidly within the site. Ford and Pitelka (1984) reported that exotic annuals were far less dominant than the perennial natives, comprising only 22% of peak standing crop; moreover, they made no mention of the perennial Harding grass. A decade later, Amme (1993) documented Harding grass in small areas within the disturbed exotic grassland, but found limited incidence within the more intact coastal prairie communities.

However, by 2005 invasive plant species had come to dominate large portions of the meadow. Amme (2005) details the invasive teasel "blowing holes into" the coastal prairie community, and Harding grass as "making significant inroads." Indeed, the 2007 Watershed Project report recorded Harding grass cover over 40% of the grassland.[2]

---

[2] There is a distinct irony in the presence of Harding grass taking over native grasslands at the UCB RFS, because the plant was first introduced in 1912 by a UCB professor, Dr. P.B. Kennedy, as he was searching for alternative forage species to "improve" the rangelands of California for livestock production (Barry et al., 1996).

Given the widespread loss of coastal prairie habitat over the past hundred years, and the relatively intact nature of the Big Meadow's core, RFS should be recognized as possessing a unique natural feature. RFS's coastal prairie is, in the words of David Amme (1993), "scientifically and ecologically invaluable, and virtually impossible to recreate." The fact that it is rapidly being invaded by Harding grass should only give credence to the idea that the conservation and restoration of this unique site must be a priority.

2.4 Patterns of Exotic Perennial Invasion

The pattern of invasion displayed at the RFS coastal prairie is of particular note because it differs from the typical pattern characteristic of California grasslands, which historically have converted from native perennial grasslands to exotic annual grasslands (Corbin and D'Antonio 2004). Rather, at RFS we can see that an exotic perennial, Harding grass, is slowly taking over the terrain formerly dominated by native perennials.

This observation is somewhat paradoxical. It has been posited that communities containing native species with functionally similar traits to invasive species will be most resilient to invasion by those species, a hypothesis which stemmed from basic community ecology theory (Funk et al. 2008). Harding grass, being perennial and forming bunches in its mature state, contains similar traits and occupies the same ecological niche as native perennial bunchgrasses (Corbin et al. 2005). One would therefore expect the native community to be resistant to invasion by Harding grass. However, Corbin and D'Antonio (2010) found that this is not the case: rather than utilizing unique traits or niches, non-native perennial grasses such as Harding grass simply outcompete native perennials such as *Nassella*, causing a reduction in growth amount and percent cover.

In a previous study, Corbin and D'Antonio (2004) found that when variables such as disturbance regime (e.g. grazing or fire) remain constant, native perennial grasslands tend to resist invasion from exotic annual grasses. They posit that exotic annual- and native perennial- dominated grasslands are alternative vegetative states, both with the potential to persist in coastal prairie habitat. An alternative state is one which is resilient to change and has come to a functional equilibrium (Suding et al. 2004). Conversely, if disturbance regimes are significantly modified, exotic annuals are encouraged, however, if these disturbance regimes are not modified, exotic perennials tend to outcompete native perennials. Such complex mechanisms present a challenge for creation of flexible management strategies that can address both components of this native-invasive relationship.

The effect of climate change on invasion dynamics is interesting to consider. Altered precipitation regimes are amongst the predicted effects of global climate change in California, specifically, a delayed wet season until late winter or early spring (National Assessment Synthesis Team 2000). Changing rainfall patterns can significantly affect the success of perennial exotic invasions (Suttle and Thompson 2007). Native grasslands have high resistance to invasion when precipitation follows California's historical rainfall pattern of dry summers. On the other hand, invasions proceed quite rapidly with increased amounts of springtime rain

(Thomsen et al. 2006), indicating high potential for shifts toward higher invasive dominance in California grasslands.

Such predictions provide a potential explanation for the rapid invasion of Harding grass at the RFS site: a cursory look at precipitation data in the East Bay suggests that the past three years (2010 - 2012) have both had unusually wet late springs, preceded by drier winters (NOAA 2012). Regardless of whether this is related to any global climate change, it could be a contributing factor to the Harding grass's rapid movement into the coastal prairie. This is an important consideration in any restoration plan, as uncertainty about future climactic conditions necessitates setting restoration goals which are adaptable to potential or likely change (Hobbs 2007).

A final factor to consider is changes in soil nitrogen availability at the RFS site. Humans have doubled reactive nitrogen in terrestrial ecosystems worldwide over the last century, and this increase is generally greatest in urbanized areas due to local effects of smog and atmospheric deposition. Increased nitrogen availability can change the competitive balance between species, and has been widely shown to reduce diversity. It can also affect the essential assemblages of bacteria and plant-mycorrhizal mutualisms (Watershed Project 2007). Disruption of the soil by animals or by human management exposes the newly bare soil to colonization from seed rain of exotic species such as Harding grass. Exotic species generally produce more seeds and disperse them more rapidly, and these seeds also benefit from the added nutrients from the decomposition of the uprooted plants (Morghan and Seastedt 1999).

The resource-limitation hypothesis posits that native species better tolerate nutrient-poor soils, whereas exotic grasses may grow best in more fertile soils and better respond to resource enrichment, using this advantage to outcompete natives (Morghan and Seastedt 1999, Török et al. 2000, Corbin and D'Antonio 2004, Thomsen et al. 2006, Corbin and D'Antonio 2011). It appears that exotic annual grasses can take up nitrogen more quickly than most perennial grasses (Corbin and D'Anotonio 2011), but that there is less of a nutrient story in the comparison on native and exotic perennial grasses. For instance, Corbin and D'Antonio (2011) found that while annual exotics may be more dependent on nitrogen supply than perennials, there soil nitrogen dynamics did not differ between exotic perennials, such as Harding grass, and native perennials (Corbin and D'Anotonio 2011). Only when native perennials were compared with exotic annuals are there significant differences in nitrogen use (Corbin and D'Anotonio 2011). This may be because of the rapid growth and dieback of annuals generates faster nitrogen cycling rates.

2.5 No Easy Answers: Management Techniques for Coastal Prairie Restorations

Many experiments that have been conducted to assess effective techniques to restore native perennials to coastal prairies; these provide valuable lessons to guide decision-making at RFS.

Hayes and Holl (2003, 2011) conducted tested the effects of manipulated disturbance regimes on coastal prairie ecosystems. They looked at grazing regimes on existing prairie plots, and conducted a controlled experiment implemented clipping practices, intended to simulate grazing, and associated disturbances such as litter removal and soil disturbance. Additionally, they seeded *Danthonia* and *Nassella* seeds on some of their plots. Their results are somewhat paradoxical. They found that while *Danthonia* responded positively to grazing, *Nassella* showed no response. Seeding didn't work for either species. In addition, they found that clipping or grazing encouraged the growth of exotic forbs, which tend to be shorter-statured and better adapted to grazing. They recommend numerous disturbance regimes, not just grazing, administered at a landscape-level in order to mimic the conditions which initially had favored native perennial grasses.

While seeding has often been shown to not be very successful in re-establishing native perennial communities, transplanting tussocks or plugs has much higher likelihood of success (Suttle and Thompson 2007). Weeding, or "neighbor removal" as it is called in one study, has been shown to greatly enhance the viability of native propagules by eliminating direct competition (Angelo 2005; Buisson et al. 2006). Because they found that exotic perennials tend to outcompete natives, Corbin and D'Antonio (2010) suggest that hand-pulling or targeted herbicide application perhaps the only effective measure against them in coastal prairies. In addition, removal of topsoil (which contain the exotic seedbank) was positively associated with transplant survival and increased *Danthonia* biomass after seedling establishment (Buisson et al. 2006). These labor-intensive and highly intrusive techniques are likely only appropriate in significantly degraded prairies, where the topsoil has a depleted native seedbank and other techniques are unlikely to work.

There are a number of gaps in the literature that limit our inherent understanding of the processes taking place on the ground at RFS. It is unclear which methods of Harding grass management are the most effective. Additionally, *Danthonia,* which co-exists with Harding grass, may not respond to management strategies similarly to the more-studied native perennial grass species. For instance, much of the research cited above focuses on the interactions of *Nassella* with exotics, while there is a paucity of research on the response of *Danthonia* to exotics. Finally, there is little known about the effects on other species and species diversity; for example, how native forbs might interact with *Danthonia* and Harding grass.

3. RFS RESOURCE ASSESSMENT

3.1 Objective

Our aim was to characterize the overall plant, mammal and insect communities and soil characteristics of the coastal prairie at the Richmond Field Station. We assessed the distribution of some species of rare native and invasive species, and determined the relationships between the biotic and abiotic factors described above and the presence and success of the invasive Harding grass (*Phalaris aquatica*).

3.2 Methods

3.2.1 Plant Survey. For the portion of our study focused on plant communities, we began by identifying the highest priority area for monitoring, as our time was limited. Since we were broadly interested in the relationship between invasive and native plant species, we chose the area that had the highest concentration of natives (e.g. the highest relative cover of *Danthonia*), with invasive plant species occurring on the margins (Figure 3.1). This area was chosen in contrast to the large portions of the east and north sides of the meadow that are primarily, or in some places exclusively, covered by invasive Harding grass.

Figure 3.1. Location of the Big Meadow plant study site. Depicted is the Big Meadow at RFS, with the areas shaded in white representing those areas heavily or completely invaded by Harding grass. The plant study site (the large rectangle outlines in black to the southwest) was chosen in the area of the coastal prairie that is most intact, and least invaded by Harding grass, to better characterize the native plant community.

We chose a 50m east-west by 150m north-south study area within the Big Meadow. It bordered the Airplane Building, with its origin near the southwest corner of the site along the road. This was identified as high priority because previous surveys indicated a high level of native cover in this area, and that Harding Grass was only beginning to invade the margins of this area. We laid out a grid of 10m x 10m squares to form this strip, 5 plots on the east-west axis and 15 plots on the north-south axis. We put in numbered flags in the lower-left (southwest) corner of each quadrat, denoting its x and y axis number; x being first and starting at 1, y being second and starting at 1. The southwest corner plot (1,1) was located 34 meters north of the dirt road, and 14 meters east of the airplane building.

The sampling design was comparable to the design set up by the Watershed project in 2006 to survey important native species at the prairie. There were two important differences in our design: 1) our grid (5x15 plots) was a subset of the larger grid set up by the Watershed Project; and 2) while the Watershed only surveyed native species of conservation concern, we also included exotic species of concern and abundant native species (e.g., *Danthonia*). We followed the previous protocols from the Watershed Project, counting all stems of each target species, expect for the two most abundant species at the prairie, *Phalaris* and *Danthonia*, where we estimated percent cover.

We attempted to measure our target species during peak blooming period, after a substantial portion of the year's rain had fallen. We selected our target species based on a variety of factors, including importance to coastal prairie plant community, perceived threat of invasion, and visibility and ease of identification. A list of the plants surveyed can be found in Table 3.1. Our surveys occurred between April 10 and 20, 2012.

Table 3.1: Focal Plant Species Surveyed at RFS, April 2012

Scientific Name	Common name	Life Stage
Danthonia californica	California oatgrass	Vegetative
*Phalaris aquatica**	Harding grass	Vegetative
Eryngium armatum	Coyote Thistle	Vegetative[a]
Rannunculus californicus	Buttercup	Flowering
Sisyrinchum bellum	Blue-eyed Grass	Early Flowering[b]
Aster chilensis	California Aster	Vegetative
Camissonia ovata	Suncups	Late Flowering[c]
Nasella Pulchra	Purple Needlegrass	Flowering
*Dipsacus fillonum**	Teasel	Vegetative[a]
*Helminthotheca echioides**	Bristly oxtongue	Vegetative[a]
*Sonchus asper**	Prickly lettuce	Vegetative

**invasive plant*
[a]Vegetative: no flowers present but this season's growth visible
[b]Early Flowering: unopened flowering buds still present
[c]Late Flowering: terminating flowers present

Since the two dominant species on the prairie are *Phalaris aquatica* and *Danthonia californica,* we utilized percent cover rather than individual counts as a measurement technique for these two species. We estimated percent cover using an optical estimation measure, utilizing a 1m x 1m quadrat frame to assist in estimation. Caution was exercised to not measure past year's litter of Harding Grass or *Danthonia*. We used a more fine-grained measurement when Harding grass distribution was low, estimating the percent cover of one plant and counting individuals- this allowed to us capture some of the plots that were just beginning to be invaded.

We hypothesized that an increase in percent cover of Harding grass was associated with a decrease in percent cover of *Danthonia*. Specifically, we were interested in determining whether there were any detectable adverse effects of an apparent Harding grass encroachment from the East. We regressed percent cover of invasive Harding grass (independent variable) and the percent cover of native *Danthonia* (dependent variable) test to determine the relationship between the two species.

We determined species abundance for the rest of the plants by counting individuals. For bunching species (*Eryngium armatum*, *Rannunculus californicus, Nasella pulchra, and Sisyrinchium bellum*), we determined individual plant by following the visual clue of leaves or flowers down to a common originating base. In colonially spreading species (*Aster chilensis*), where vegetative reproduction makes genetic individuals cryptic, we counted individual stems as constituting an individual plant. For all other species (*Camissonia ovata, Dipsacus fillonum, Helminthotheca echioides,* and *Sonchus asper*) individuals were counted as individual rosettes. For particularly abundant species in a given plot, as encountered with *Eryngium armatum* and *Aster chilenses*, abundance estimates were made after passing a threshold of 150 plants. Counts were then grouped into abundance classes to facilitate comparisons with the 2006 dataset (Table 3.2).

To test the change in abundance over time, we compared our species data with the data available from the 2006 botanical survey with an unpaired t-test assuming equal variance. In order to make our data comparable, we consolidated our abundance classes to overlap with the abundance classes used by the Watershed Project (Table 3.2).

Table 3.2: Stem counts were grouped into abundance classes after protocols developed by the Watershed Project (2007).

Abundance Class (adjusted class)	Abundance (#/100m^2)
0	*0*
1	*1*
2	*2-5*
3	*6-10*
4	*11-25*
5	*26-50*
6	*51-100*
7	*>100*

3.2.2. Soil and Arthropod Sampling. For the soil and arthropod investigations, samples were obtained from a shared set of data collection sites (Figure 3.2a). These sites were determined based off of a map from a 2007 report showing the extent of Harding grass invasion at that point in time (Farrell et al. 2007). We identified three classifications of Harding grass invasion: (1) invaded in 2007 and invaded currently (long-term invaded), (2) not invaded in 2007 and not invaded currently (long-term not invaded), and (3) not invaded in 2007 and invaded currently (recently invaded). To avoid confounding effects of soil and landscape heterogeneity, we sought samples from each of these three categories that were located near each other. This meant we specifically chose our blocks to be located along the boundaries between circa-2007 invaded and not-invaded areas.

To obtain arthropod samples, we placed a pit-fall trap at one corner of each plot. The pitfall traps were made out of plastic 16-oz cups and filled with soapy water to the first inch and a half of depth. Two flags were placed on either side with a Styrofoam-plate cover. We collected samples one week after and arthropods were sorted into functional groups.

To obtain soil samples, we established a one meter by one meter quadrant at each of the 24 sample sites and placed flags in the soil at each of the corners. We labeled one of the flags with the block number, Harding grass invasion classification, and inundation state (flooded or not flooded). We also recorded the percent cover of Harding grass for each site, based on a visual inspection. The height and density of the Harding grass was not taken into account in this process. A total of 8 blocks, or 24 sample sites, were established. We obtained 2 soil cores, each 15 cm deep, from different, randomly selected locations within the 1m x 1m plots. These samples were taken for processing to determine soil moisture, inorganic nitrate, and inorganic ammonium content following standardized protocols (Robertson et al 2009) in the Suding lab.

a)

b)

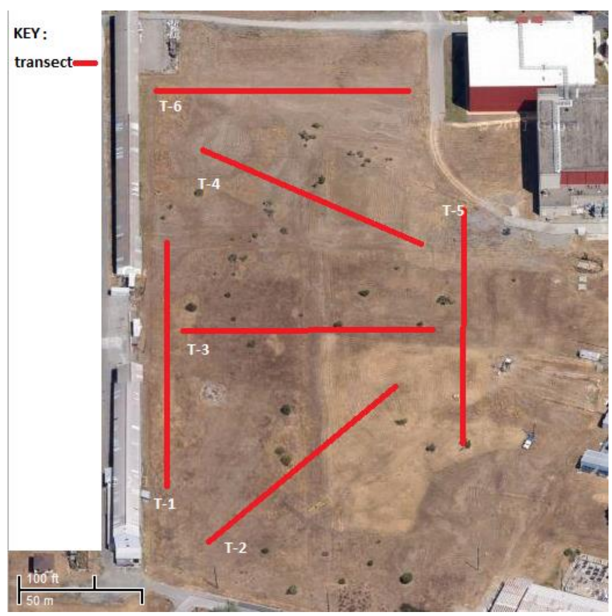


Figure 3.2. Location of study sites for other focal resources. (a) Placement of 8 sample sites used for tests of relationships between Harding grass cover and soil nitrogen, soil moisture, and arthropod abundance. Each sample site included 3 one-square meter plots: a plot for a Harding grass invasion, one for non-Harding grass invasion, and one of a previously invaded (2006) plot, all located within a 30m radius of each other. Orange-shaded areas represent areas with Harding grass cover as of 2007. (b) Placement of 6 transects at the Richmond Field Station coastal prairie for mammal studies.

3.2.3 Small mammal sampling. Observations of mammal abundance were conducted along six 100 meter transects across the coastal prairie (Figure 3.2b). We walked along each transect noting evidence of small mammal presence, specifically the number of vole and gopher burrows. In addition, on each transect we sampled three 1m^2 plots, one at the area with the highest density of gopher burrows, one at the area with the highest density of vole burrows, and one control plot where no small mammal presence was observed. Within each plot we estimated the percent cover of exotic and native plant species.

3.3 Results

3.3.1 Plant survey. Harding grass was most abundant in the southeast corner of the study plot, where it peaked at 60% cover in 2012 (Figure 3.4). Other areas of high abundance were located near the ephemeral pools and along the center of the west side of the study plot (Figure 3.4). These areas also had the lowest abundance of *Danthonia* (indicated by the darker areas of Figure 3.4). Conversely, the most abundant areas of *Danthonia* were in the southwest and south-central regions of the study plot, where it peaked at 90% cover, and in the northeast corner, where it peaks at 70% cover, have very little Harding grass cover. There was a negative relationship between Harding grass and *Danthonia cover* ($r^2 = 0.15$, $p < 0.001$; Figure 3.3).

S

Air plane building

N

	1	2	3	4	5
1	60	90	50	85	35
2	50	80	85	55	2
3	35	75	75	35	15
4	50	75	70	70	10
5	30	70	60	25	0
6	35	55	70	30	0
7	20	10	55	40	25
8	50	2	25	45	40
9	25	5	15	25	0
10	40	20	30	15	10
11	15	35	30	20	25
12	12	50	55	60	30
13	15	55	65	55	50
14	65	50	60	70	65
15	55	45	50	60	70

Danthonia california

	1	2	3	4	5
1	7	2	5	1	15
2	5	0	0	20	15
3	2	0	0	35	60
4	0	0	0	15	60
5	0	0	5	15	15
6	10	3	0	0	0
7	7	45	15	1	0
8	7	5	3	1	0
9	10	25	0	1	0
10	1	0	0	0	0
11	0	0	0	3	0
12	4	0	0	0	0
13	15	1	0	0	0
14	4	5	0	0	0
15	5	0	0	0	0

Phalaris aquatica

Train tracks

W E

Figure 3.3. Percent of *Danthonia* and *Phalaris* at the Big Meadow study site. Brighter colors correspond to a higher percent cover. While peaks in *Danthonia* exist along the southern and northern portions of the site, peaks in Harding grass can be seen in the southeast corner of the site, and along the western side near ephemeral pools. Note that this sampling area contained the lowest cover on *Phalaris* within the prairie complex; in areas outside of the grid plots *Phalaris* averaged 70-80% cover.

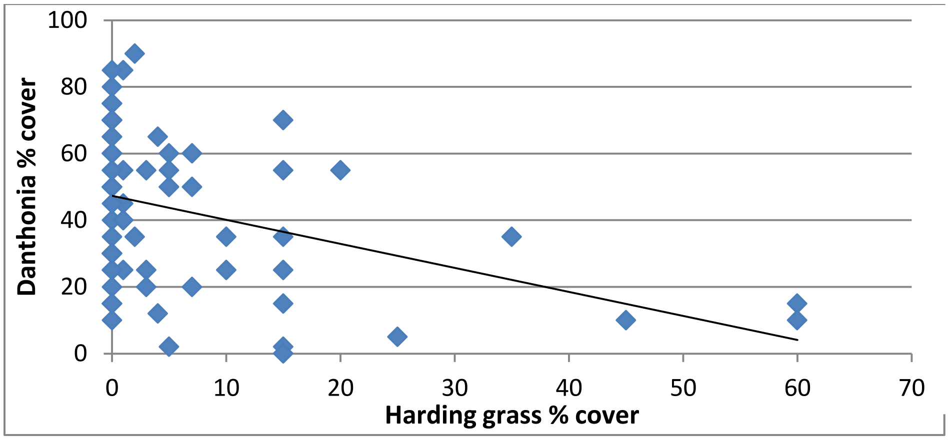


Figure 3.4. High percent cover of Harding grass (*Phalaris)* was negatively associated with *Danthonia* percent cover (r^2 = .1475, p <.001; the two plots where both species were absent were not included).

We did not detect any overall trends in direction of shifts in abundance between 2006 and 2012 for the native species. Instead, some native species increased in abundance while others decreased (Figure 3.5, 3.6). *For instance, N. pulchra* and *T. ovata* decreased in abundance significantly between 2006 and 2012 (*Nasella*: t = 4.55, df = 137, p < 0.001′; *T. ovate*: t = 3.67, df = 15, p < 0.001). While *S. bellum* (t=-4.36, df=211, P<1.03×10^{-5}); *E. armatum* (t=-2.87, df=27, P< 8.73×10^{-2}); and R. californicus (t=-6.84, df=91, P<8.75×10^{-10}) had greater abundance in the 2012 survey. *A. chilensis* did not significantly change in abundance. It is important to note that the Watershed Project, who conducted the surveys in 2006, did not measure the abundances of *Danthonia* or *Phalaris*, so we cannot make comparisons for these species. In addition, 2012 was extremely dry; changes based on these two time points may not indicate temporal trends.

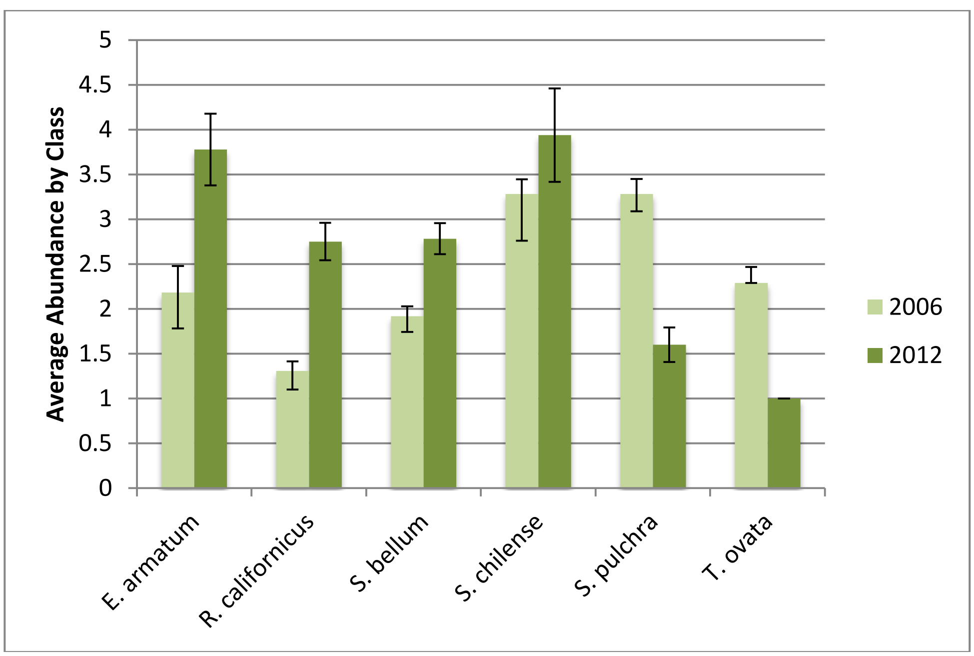


Figure 3.5 Average abundance class of native species by class in 2006 and 2012. We found significant increases for *E. armatum, R. californicus, S. bellum*, but significant decreases for *S. pulchra (Nassella)* and *T. ovata.* There was no significant change in *A. chilensis abundance.* See Table 3.2 for the stem count range for each abundance class.

Airplane building
S ↑ … ↓ N

	1	2	3	4	5
1	1	0	0	2	3
2	3	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	2
5	4	2	4	5	4
6	2	1	0	3	4
7	0	0	0	0	3
8	4	0	0	0	0
9	4	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	1	0	0	0	0
13	2	0	0	0	3
14	3	2	0	0	0
15	0	5	6	5	0

Nasella pulchra

	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	1
4	0	0	0	0	0
5	0	2	0	0	0
6	0	0	0	0	0
7	0	0	0	0	4
8	0	0	2	0	5
9	0	0	2	5	5
10	0	5	6	4	6
11	0	6	6	5	5
12	0	4	4	5	5
13	0	5	5	5	6
14	0	5	6	2	5
15	0	0	0	0	0

Rannunculus californica

	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	1
4	0	0	0	0	0
5	0	1	0	0	0
6	0	0	0	0	0
7	0	0	0	0	2
8	0	0	1	0	3
9	0	0	1	3	3
10	0	3	5	2	4
11	0	4	4	3	3
12	0	2	2	3	3
13	0	3	3	3	5
14	0	3	3	1	3
15	0	0	0	0	0

Camissonia ovata

	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	2	0	0	0
8	0	7	5	6	0
9	0	6	7	5	0
10	0	6	7	0	0
11	0	0	3	0	0
12	0	0	0	5	0
13	0	6	5	6	0
14	0	4	7	5	5
15	0	0	0	0	0

Eryingium armatum

	1	2	3	4	5
1	5	5	3	4	6
2	7	4	0	4	5
3	5	5	3	2	5
4	6	3	3	4	4
5	6	3	3	5	4
6	7	3	4	4	5
7	6	2	0	4	6
8	2	5	4	3	0
9	0	3	5	6	5
10	6	4	5	6	5
11	3	5	6	5	4
12	3	7	7	6	5
13	5	5	6	4	4
14	3	6	5	5	4
15	5	5	5	5	2

Sisyrinchium bellum

	1	2	3	4	5
1	0	6	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	3	0	0
5	0	0	0	0	6
6	0	0	0	7	5
7	0	0	0	7	7
8	7	6	0	0	7
9	0	5	0	0	0
10	0	2	0	0	1
11	5	0	0	0	0
12	0	0	7	0	0
13	0	0	1	0	0
14	0	0	0	0	0
15	0	0	0	0	0

Aster chilensis

	1	2	3	4	5
1	3	0	0	0	6
2	1	0	5	4	3
3	2	0	2	0	1
4	5	0	0	0	0
5	2	0	1	1	4
6	4	0	0	4	0
7	5	1	3	3	3
8	5	0	2	6	2
9	0	3	6	6	4
10	6	6	4	0	4
11	7	7	6	4	3
12	7	7	6	6	4
13	6	6	7	7	4
14	6	5	6	5	5
15		5	2	0	1

Dipsacus fullonum

	1	2	3	4	5
1	4	6	6	4	3
2	6	6	1	0	2
3	6	5	5	3	4
4	5	4	5	5	4
5	5	5	6	4	0
6	5	5	3	1	0
7	3	3	3	2	4
8	4	2	4	3	2
9	3	3	4	4	2
10	2	3	3	4	3
11	4	2	2	3	2
12	5	2	1	2	4
13	5	4	2	0	3
14	5	4	4	4	4
15	6	6	4	4	6

Helminthotheca echioides

	1	2	3	4	5
1	1	0	0	0	0
2	1	0	0	0	1
3	0	2	0	0	0
4	0	0	0	0	0
5	4	0	0	0	0
6	3	1	0	0	0
7	2	2	0	1	0
8	2	2	0	0	0
9	1	1	2	0	0
10	0	0	0	0	0
11	1	0	0	0	0
12	0	1	0	0	0
13	2	0	0	0	0
14	0	0	0	0	0
15	0	1	0	2	0

Sonchus asper

E ← Train tracks → W

Figure 3.6 Distribution of rare native and invasive plants, displayed by abundance classes (for a description of abundance classes, see Table 3.2). Native plants have green shading indicating abundance, invasive plants have red shading.

While the 2006 survey focused on only native species, we also surveyed some exotic species that are currently less abundant but could pose threats to the prairie: *Dipsacus fullonum*, *Helminthotheca echioides*, and *Sonchus asper*. *Dipsacus* and *Helminthotheca*, in particular, were relatively widespread and, in some places, very abundant in the 2012 survey (Figure 3.6).

3.3.2. Soil, Arthropods, Mammals. Our assessment of soil characteristics, arthropod abundance, and small mammal activity indicated little effects of Harding grass on these other components of the prairie ecosystem. Cover of invasive Harding grass was not significantly related to soil moisture or soil inorganic nitrogen content (Figure 3.5a, b). In addition, there was no difference in the percent cover of invasive plant species along transects with high levels of small mammal activity (Figure 3.5c). Finally, there was no significant difference in arthropod abundance between plots invaded with Harding Grass and not invaded with Harding grass (Figure 3.5d).

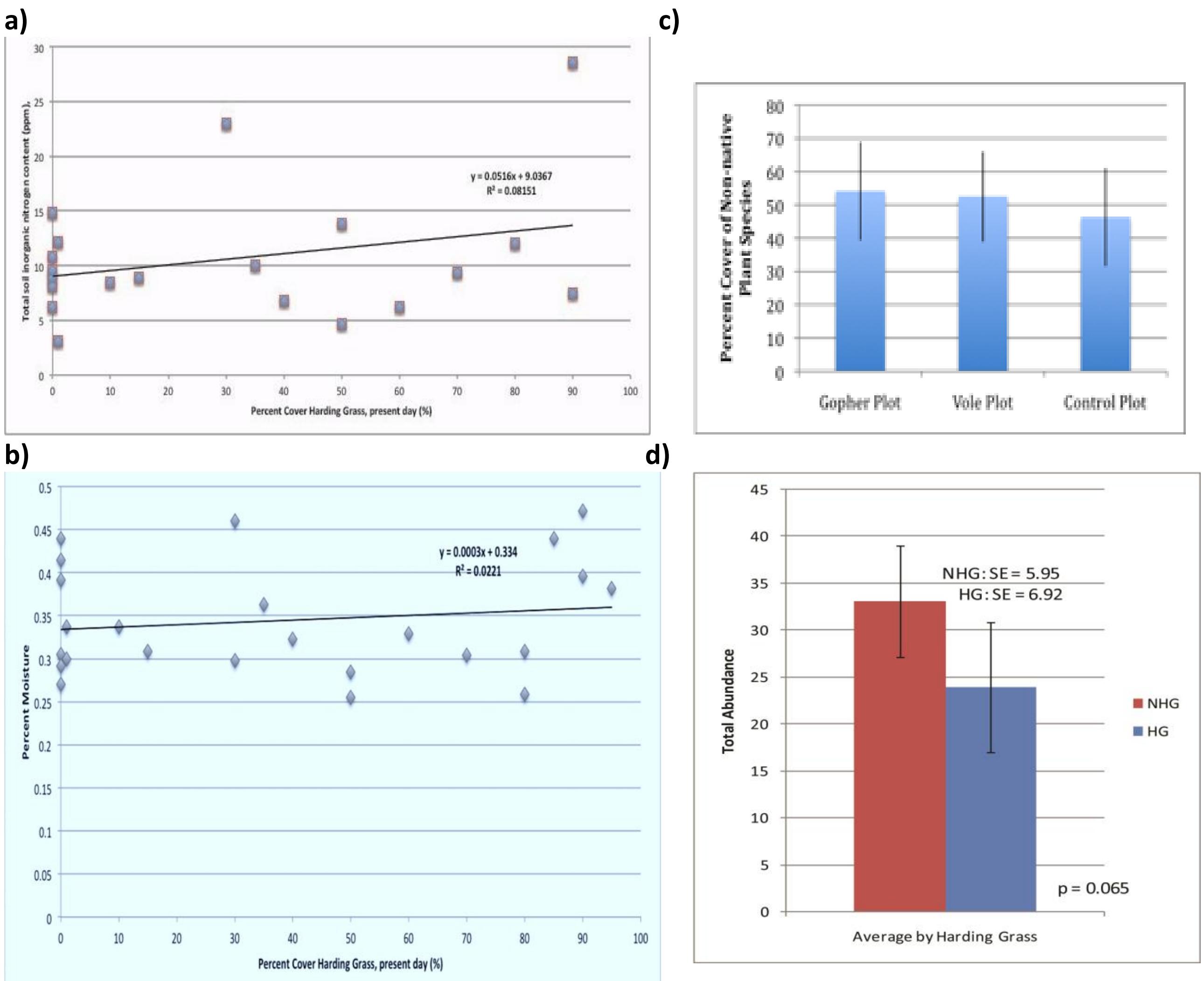


Figure 3.7: We found little evidence that Harding grass was associated with differences in a) soil inorganic nitrogen, b) soil moisture, c) small mammal activity, or d) total arthropod abundance.

3.4 Discussion

We found a negative correlation between Harding grass cover and *Danthonia* cover, indicating that greater Harding grass cover was associated with lower *Danthonia cover*. It is important to consider these results in the larger context of the Big Meadow. In the area immediately surrounding our study site, Harding grass cover is quite high, and along the eastern and northern periphery of the meadow, it is likely near 100% (Figure 3.4). In our study site, Harding grass appears to have highest abundance along the edges, and is increasing quite rapidly into the central prairie areas. Given the relationship determined here, there is a reasonable likelihood that further expansion of Harding grass from its current areas of high abundance would result in a decrease in the abundance of *Danthonia* in that area. Without fairly rapid management action, our data indicate that Harding grass will continue to invade into the most unique and specious remnants of the Big Meadow.

We were not able directly compare the spatial distribution of the 2006 data with our data, as we were unsure of their grid locations. We speculated that the dry year and late rains of 2012 would mean less abundant rare species. Had that been the case, we projected an overall decrease in rare species abundance. That some species increased significantly while others decreased significantly indicates that precipitation is not be the single driving factor in species abundance. Specifically, we noticed that low growing *T. ovata* was often found beneath thick layers of built up thatch that could be limiting access to light and pollinators, such limited access could be one of the reasons causing the decline in abundance between the two surveys. The absence of *Nasella* in the middle of the grid might have been due to hydrological factors, as the presence of seasonal pools might favor wetland adapted species. *Nasella* was also more abundant in areas surrounding old growth *Baccharis pilularis*, potentially due to shade or protection from mowing. In the 2006 botanical survey, *S. anjugoides* was recorded much further southeast (See WP 2009, p 200) than the patch we surveyed (Figure 3.2C) and we detected no connecting population in the plots between 2006's observations and 2012's.

Harding grass presence was not related to arthropod abundance, soils characteristics, or mammal activity. This leads us to conclude that these three factors do may not predict or be affected by the level of Harding grass invasion at the RFS prairie; however, we note that this is just one sample in one year. Because these components are vital to a fully-functioning ecosystem, we recommend that their status continue to be monitored.

4. RESTORATION RECOMMENDATIONS

The conceptual restoration recommendation section builds from an adaptive management planning framework, the literature review (section two) and the site analysis (section three). It includes restoration objectives, restoration and management strategies, and measurable targets for further monitoring. We end by acknowledging some areas of concern and uncertainty, and giving some final remarks and recommendations.

4.1 Restoration objectives

Restoration objections are specific objectives that relate to the focal resources and its related goal (Table 1.1). Measureable targets (see Table 4.3) are set with these objectives in mind.

Table 4.1 Summary of broad restoration program objectives, as assessed based on the literature review and data collection in this report

Restoration Objective	Related Goal (#)
1. Protect and expand native rare grassland species	1,2,3
2. Reduce cover of non-native and invasive species	3
3. Resist reinvasion by best practices in the core native remnant	2,3,4,5
4. Increase community involvement and interest in the RFS prairie.	6
5. Institute robust, accountable monitoring system for recording the geographic location of all treatments applied to the field, experimental sites, and the subsequent results and analysis.	5,7

4.2 Restoration actions

Restoration and monitoring actions are set up in an adaptive management framework where restoration actions work to meet specific measurable targets (or performance measures), and monitoring actions are set up to evaluate whether the measurable targets are met. The results of monitoring and subsequent analysis provide a basis for managers to make decisions to change management actions.

Table 4.2 Summary of coastal prairie restoration actions for the focal resource. Actions are broken down into phases (I, year 1; II, years 2-5; and III, year 10) to reflect the process of restoration work recommended for the site. Uncertainties are current unknowns that require monitoring and adaptive management to ensure that these actions meet the proposed objectives.

Action	**Phase (I, II, III)**	**Uncertainties**	**Related Performance Measure**
1. Remove all Harding grass, beginning with areas in close proximity to *Danthonia* core	Phase I	Control method needs further experimental assessment: manual pulling, herbicide, mowing, combinations of several control types at different times in the year.	2,3
2. Propagate and transplant *Danthonia* plugs or tussocks, explore seeding some of the rare native species	Phase I	Follow-up measures such as watering, herbivory protection need to be addressed; labor-intensive, may want to begin with small plots	1,4
3. Spot-weeding following initial removal, increase scope to other invasives (e.g., teasel).	Phase II	Could be costly or labor-intensive; weeding may be necessary for many years until seedbank is exhausted	2,3
4. Complete biotic and abiotic assessment	Phase III	Over seasonal and annual timescales, re-assess the botanical and animal communities as well as analyze soil, nutrient, and other abiotic characteristics at RFS to determine success of project or to suggest revisions to management plan.	1,2

4.3 Measurable targets

Performance measures (Table 4.3) describe the restoration targets this project aims to achieve. New information from baseline studies and literature reviews may update these performance measures. Monitoring is critical to measure whether the specific restoration targets/ performance measures are met.

Table 4.3 Measurable targets for assessing achievement of restoration objectives (Table 4.1).

Performance Indicator	Related Objectives	Key Resource Monitoring	Metric	Target (phase)
1. Expansion of *Danthonia* population, other native species	1	*Danthonia* population , other native species	% cover over entire meadow	Maintain or improve baseline value over time (III>II>I)
2. Reduction of Harding grass population	1	Harding grass population	% cover	Maintain or decrease baseline value over time (I>II>III)
3. Harding grass removal technique assessment	2	Harding grass population in test plots	Difference in % cover	Identify one technique that has highest long-term success rate (II, III)
4. *Danthonia* outplanting assessment	3	*Danthonia* population in test plots	Difference in % cover	Determine if propagation was successful in increasing total cover
5. Formalized community involvement	4	Volunteer or Internship Program	# of Participants/ Hours	Implement volunteer program or internship program for sustained stewardship of land (I, II, III)

4.4 Critical areas of concern and uncertainty

As outlined in the literature review, exotic perennial grasses present a significant threat to native perennial grassland communities. Harding grass has the potential to exclude *Danthonia* as the dominant plant in the RFS coastal prairie, forever changing what is an extremely valuable and rare ecosystem. A series of reports at RFS over the past 30 years reveal that the extent of the Harding grass invasion has increased dramatically since the first surveys in the 1980s (could site them all again for posterity). Our initial assessment indicates that extent of Harding grass has continued to increase just in the past several years, although continued monitoring of the extent of the population is advisable. While there have been tremendous personal efforts by individuals to address this invasion, they have garnered little University support. ***Thus, we are at a critical juncture in the fate of the RFS coastal prairie ecosystem. Continuing management as it exists now could spell disaster for the native Danthonia coastal prairie community.***

Further study is needed to determine the best course of action. A more comprehensive assessment of the extent of the Harding grass invasion needs to be made, in order to determine areas of highest priority for management. Similarly, an exhaustive assessment of the current population of *Danthonia* needs to occur, in order to determine the most at-risk areas. A more fine-grained assessment of the plant community should also be made, to better understand the relationship between elements thereof. For instance, it was noted observationally that there are more forbs on the north side of the study site than the south side; this is also the area of least Harding grass invasion. Might the two be related? This is an area for further study.

A crucial limitation of our study is the narrow, one-off nature of the experiments we conducted. They do not account for seasonal or inter-annual fluctuations in rain and temperature, population cycles of plants and animals, and potentially other factors as well. A majority of our resource appraisal consisted of observational studies, which can only be used to establish correlation but not causation. Experimental manipulation building on findings in this report (for instance, actively removing Harding grass in controlled plots and monitoring for regrowth) would provide stronger conclusions.

The literature is conflicted as to the best management techniques for Harding grass, and the exact current status of management of the coastal prairie at RFS is unknown. Where mowing is currently taking place, and at what intervals, are key questions that need to be answered before a comprehensive restoration plan can be put into place. The role of mowing or other managed disturbance regimes should be studied to determine both efficacy at reducing Harding grass, and other ecosystem effects, both positive and negative.

4.5 Next steps/final recommendations

California coastal prairies are a rare and unique ecosystem, whose conservation value and restoration potential is high due to the relatively intact nature of the remnant patches. The Richmond Field Station houses perhaps the largest and best example of a coastal prairie in the San Francisco Bay Area. This prairie has been under increasing pressure from invasive Harding grass, amongst others, and its restoration should be made a highest priority. Without a management intervention, invasive plants threaten the very existence of one of the last remaining examples of this native California ecosystem.

We suggest the following priorities for management of the costal prairie at RFS:

- Control of Harding grass should begin immediately, in an iterative, adaptive fashion; through study plots or other experimental designs, the best technique for removing Harding grass should be determined and carried out over the entire coastal prairie.

- *Danthonia* tussocks should be transplanted in areas where Harding grass was removed, with the recognizing that there could be unanticipated consequences of wholesale removal of the invasive grass, such as invasion by another equally pernicious exotic.

- More data should be collected to better characterize the current condition of the plant community at RFS. This data will form a baseline from which to determine the effects of restoration and management.

- Continued monitoring is essential to our understanding of how these actions will change the coastal prairie ecosystem over time. Without monitoring, it is not possible to know whether restoration actions have achieved their objectives over either the short- and long term.

- It is critical to involve the community, both that of the University of California, Berkeley and residents of the Richmond Annex near RFS, to ensure ongoing support for restoration actions. An internship program or volunteer program (similar to the extant Strawberry Creek Restoration program on the main UCB campus) could provide the labor and continuity needed to ensure sustained stewardship of this valuable resource.

- In addition, the resources at RFS provide countless opportunities for education and experimentation for UC Berkeley students. This report, which was the culmination of a semester-long Restoration Ecology course in the department of Environmental Science, Policy and Management, offered students the opportunity to engage science in a hand-on way that was greatly appreciated by class members. This unification of educational opportunity with preservation of a unique ecological and cultural resource is rare and ought to be highly valued by the UC system.

4.6 Acknowledgements. We thank the College of Natural Resources and the staff at the Richmond Field Station for facilitating our use of the facility, and Karl Hans (UCB), William Lidicker (UCB), Liana Nichols (UCB), Loralee Larios (UCB), Jessie Olson (UCB), Sybil Diver (UCB), Scott Stephens (UCB), Doug Johnson (California Invasive Plant council), Phil Stevens (Urban Creek Council), Stu Weiss (Creekside Center for Earth Observation) and Phil Williams (UCB and PWA) for sharing their expertise.

LITERATURE CITED

Amme, D. 1993. Richmond Research Center Master Plan, Environmental Impact Report: Existing Conditions of Grassland Resources.

Amme, D. 2005. UC Richmond Field Station's Remnant Coastal Terrace Grassland. *Grasslands*, *15*(2): 3-5.

Angelo, C. 2005. Restoration of Danthonia californica, Elymus glaucus, and Nassella pulchra at Elkhorn Slough National Estuarine Research Reserve. *Elkhorn Slough Technical Report Series 2005*(1). Retrieved from http://elkhornslough.org/research/PDF/angelo2005.pdf on March 23, 2012

Barry, S., Larson, S., & George, M. 1996. California Native Grasslands: A Historical Perspective. *Grasslands*, *63*: 7-11.

Bartolome, J. W. 1981. *Nassella pulchra,* a survivor from the pristine prairie. *Fremontia*, *9*(1): 3-6.

Buisson, E., Holl, K. D., Anderson, S., Corcket, E., Hayes, G. F., Torre, F., Peteers, A., & Dutoit, T. 2006. Effect of Seed Source, Topsoil Removal , and Plant Neighbor Removal on Restoring California Coastal Prairies. *Restoration Ecology*, *14*(4): 569-577.

Corbin, J. D., & D'Antonio, C. M. 2004. Competition between native perennial and exotic annual grasses: Implications for a historical invasion. *Ecology*, *85*(5): 1273-1283.

Corbin, J. D., & D'Antonio, C. M. 2010. Not novel, just better: competition between native and non-native plants in California grasslands that share species traits. *Plant Ecology*, *209*(1): 71-81.

Corbin, J. D., Thomsen, M. A., Dawson, T. E., & D'Antonio, C. M. 2005. International Association for Ecology Composition Summer water use by California coastal prairie grasses: fog, drought, and community composition. *Oecologia*, *145*: 511-521.

Corbin, J. D., and C. M. D'Antonio. 2011. Abundance and productivity mediate invader effects on nitrogen dynamics in a California grassland. Ecosphere 2:1-19.

Ford, L. D., & Hayes, G. F. 2007. Northern Coastal Scrub and Coastal Prairie. In M. Barbour, T. Keeler-Wolf, & A. Shoenherr (Eds.), *Terrestrial Vegetation of California* (3rd ed., pp. 180-207). Berkeley: University of California Press.

Ford, R. G., & Pitelka, F. A. 1984. Resource Limitation in Populations of the California Vole. *Ecology*, *65*(1): 122-136.

Funk, J. L., Cleland, E. E., Suding, K. N., & Zavaleta, E. S. 2008. Restoration through reassembly: plant traits and invasion resistance. *Trends in Ecology & Evolution*, *23*(12): 695-703.

Goulson, D. 2003. Effects of introduced bees on native ecosystems. Annual Review of Ecology Evolution and Sytematics. 34:1-26.

Hayes, G. F., & Holl, K. D. 2003. Cattle Grazing Impacts on Annual Forbs and Vegetation Composition of Mesic Grasslands in California. *Conservation Biology*, *17*(6): 1694-1702.

Hayes, G. F., & Holl, K. D. 2011. Manipulating disturbance regimes and seeding to restore mesic Mediterranean grasslands. *Applied Vegetation Science*, *14*(3): 304-315.

Hobbs, R. J. 2007. Setting Effective and Realistic Restoration Goals : Key Directions for Research. *Restoration Ecology*, *15*(2), 354-357.

Kremen, C., RK Colwell, TI Erwin, DD Murphy, RF Noss, MA Sanjayan. 1993. Terrestrial Arthropod Assemblages: Their Use in Conservation Planning. Conservation Biology. 7,4:796-808.

Küchler, A. W. 1964. Potential Natural Vegetation of the Conterminous United States. Retrieved from http://www.ngdc.noaa.gov/ecosys/cdroms/ged_iib/datasets/b13/reprints/ek1.htm

Monroe, M., O. PR, C. JN, G. RM, H. J, and W. C. 1999. Baylands Ecosystem Habitat Goals. Goals Project. A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project.

Morghan, K. J. R., and T. R. Seastedt. 1999. Effects of Soil Nitrogen Reduction on Nonnative Plants in Restored Grasslands. Restoration Ecology 7:51-55.

Mortimer, Simon R, John A. Hollier, Valerie K. Brown. 1998. Interactions between Plant and Insect Diversity in the Restoration of Lowland Calcareous Grasslands in Southern Britain. Applied Vegetation Science. 1,1:101-114.

National Assessment Synthesis Team. 2000. *Climate Change Impacts on the United States: the Potential Consequences of Climate Variability and Change.* Washington, DC: US Global Change Research Program. Retrieved from http://www.globalchange.gov/what-we-do/assessment on March 23, 2012

National Atmospheric and Oceanic Administration. 2012. Hydrology: Precipitation data. Retrieved from http://www.cnrfc.noaa.gov/rainfall_data.php on March 23, 2012

Stromberg, M. R., Kephart, P., & Yadon, V. 2001. Composition, Invasibility, and Diversity in Coastal California Grasslands. *Madroño*, *48*(4): 236-252.

Suding, Katharine N, Gross, K. L., & Houseman, G. R. 2004. Alternative states and positive feedbacks in restoration ecology. *Trends in ecology & evolution*, *19*(1): 46-53.

Suttle, K Blake, & Thomsen, M. A. 2007. Climate change and grassland restoration in California: Lessons from six years of rainfall manipulation in a North Coast grassland. *Madroño*, *54*(3): 225-233.

The Watershed Project. 2007. University of California, Berkeley Richmond Field Station Remediation and Restoration Project Habitat Restoration Progress Report 2003 – 2007.

Thomsen, M. A., D'Antonio, C. M., Suttle, K. B., & Sousa, W. P. 2006. Ecological resistance, seed density and their interactions determine patterns of invasion in a California coastal grassland. *Ecology Letters*, *9*(2): 160-170.

Thomsen, M. A., J. D. Corbin, and C. M. D'Antonio. 2006. The effect of soil nitrogen on competition between native and exotic perennial grasses from northern coastal California. Plant Ecology 186:23-35.

Török, K., T. Szili-Kovács, M. Halassy, T. Tóth, Z. Hayek, M. W. Paschke, and L. J. Wardell. 2000. Immobilization of soil nitrogen as a possible method for the restoration of sandy grassland. Applied Vegetation Science 3:7-14.

University of California Jepson Herbarium. 2011. *Nassella pulchra (Hitchc.) Bankworth*. Jepson Interchange for California Floristics. Retrieved from http://ucjeps.berkeley.edu/cgi-bin/get_cpn.pl?34420 on March 23, 2012

URS Corp. 2007. Richmond Field Station Botanical Survey Report.

Zedler, P. H., and C. Black. 1992. Seed Dispersal by a Generalized Herbivore Rabbits as Dispersal Vectors in a Semiarid California Vernal Pool Landscape. American Midland Naturalist. 128.1:1-10.

APPENDIX A: DATASETS COLLECTED

Plant Data:
All data was collected April 11 and 18, 2012. Refer to section 3.2 of this report for methodology.

Harding Grass, Percent cover, by grid number

	x-axis				
y-axis	1	2	3	4	5
1	7	2	5	1	15
2	5	0	0	20	15
3	2	0	0	35	60
4	0	0	0	15	60
5	0	0	5	15	15
6	10	3	0	0	0
7	7	45	15	1	0
8	7	5	3	1	0
9	10	25	0	1	0
10	1	0	0	0	0
11	0	0	0	3	0
12	4	0	0	0	0
13	15	1	0	0	0
14	4	5	0	0	0
15	5	0	0	0	0

Danthonia, percent cover, by grid number

	x-axis				
y-axis	1	2	3	4	5
1	60	90	50	85	35
2	50	80	85	55	2
3	35	75	75	35	15
4	50	75	70	70	10
5	30	70	60	25	0
6	35	55	70	30	0
7	20	10	55	40	25
8	50	2	25	45	40
9	25	5	15	25	0
10	40	20	30	15	10
11	15	35	30	20	25
12	12	50	55	60	30
13	15	55	65	55	50
14	65	50	60	70	65
15	55	45	50	60	70

Nasella pulchra, abundance, by grid number

	x-axis				
y-axis	1	2	3	4	5
1	1	0	0	3	10
2	9	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	2
5	15	2	12	41	19
6	3	1	0	10	17
7	0	0	0	0	10
8	11	0	0	0	0
9	18	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	1	0	0	0	0
13	2	0	0	0	7
14	6	2	0	0	0
15	0	40	81	12	0

Rannunculus californica, abundance, by grid number

	x-axis				
y-axis	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	1
4	0	0	0	0	0
5	0	3	0	0	0
6	0	0	0	0	0
7	0	0	0	0	11
8	0	0	2	0	35
9	0	0	5	29	37
10	0	38	94	15	59
11	0	72	73	39	29
12	0	17	15	48	43
13	0	47	28	32	84
14	0	27	50	3	35
15	0	0	0	0	0

Taraxia ovata, abundance, by grid number

	x-axis				
y-axis	1	2	3	4	5
1	0	0	0	0	0
2	0	0	1	0	1
3	0	0	0	1	3
4	0	0	1	0	0
5	0	0	0	4	1
6	0	0	1	2	0
7	0	8	1	1	0
8	9	0	0	0	1
9	3	0	0	0	2
10	0	0	0	0	0
11	0	0	0	2	2
12	0	2	0	0	1
13	0	0	0	0	0
14	0	3	0	0	1
15	0	0	0	3	2

Eryingium armatum, abundance, by grid number

	x-axis				
y-axis	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	4	0	0	0
8	0	300	41	72	0
9	0	86	180	46	0
10	0	90	328	0	0
11	0	0	7	0	0
12	0	0	0	29	0
13	0	85	47	67	0
14	0	18	242	36	25
15	0	0	0	0	0

Sisyrinchium bellum, abundance, by grid number

	x-axis				
y-axis	1	2	3	4	5
1	48	25	10	24	86

2	134	20	0	19	29
3	31	30	8	5	29
4	85	7	6	17	20
5	68	7	10	25	22
6	109	8	16	21	26
7	52	4	0	22	90
8	3	42	11	8	0
9	0	10	33	60	43
10	74	11	37	78	39
11	8	47	97	35	14
12	7	107	101	88	27
13	30	48	56	24	21
14	7	99	43	39	15
15	33	40	26	47	2

Aster chilense, abundance, by grid number

	x-axis				
y-axis	1	2	3	4	5
1	0	81	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	6	0	0
5	0	0	0	0	63
6	0	0	0	1400	29
7	0	0	0	1000	1000
8	141	93	0	0	950
9	0	32	0	0	0
10	0	3	0	0	1
11	38	0	0	0	0
12	0	0	127	0	0
13	0	0	1	0	0
14	0	0	0	0	0
15	0	0	0	0	0

Dipsacus fillonum, abundance class, by grid number

	x-axis				
y-axis	1	2	3	4	5
1	3	0	0	0	6
2	1	0	5	4	3
3	2	0	2	0	1
4	5	0	0	0	0

5	2	0	1	1	4
6	4	0	0	4	0
7	5	1	3	3	3
8	5	0	2	6	2
9	0	3	6	6	4
10	6	6	4	0	4
11	7	7	6	4	3
12	7	7	6	6	4
13	6	6	7	7	4
14	6	5	6	5	5
15		5	2	0	1

Helminthotheca echioides, abundance class, by grid number

	x-axis				
y-axis	1	2	3	4	5
1	4	6	6	4	3
2	6	6	1	0	2
3	6	5	5	3	4
4	5	4	5	5	4
5	5	5	6	4	0
6	5	5	3	1	0
7	3	3	3	2	4
8	4	2	4	3	2
9	3	3	4	4	2
10	2	3	3	4	3
11	4	2	2	3	2
12	5	2	1	2	4
13	5	4	2	0	3
14	5	4	4	4	4
15	6	6	4	4	6

Sonchus asper, abundance class, by grid number

	x-axis				
y-axis	1	2	3	4	5
1	1	0	0	0	0
2	1	0	0	0	1
3	0	2	0	0	0
4	0	0	0	0	0
5	4	0	0	0	0
6	3	1	0	0	0
7	2	2	0	1	0

8	2	2	0	0	0
9	1	1	2	0	0
10	0	0	0	0	0
11	1	0	0	0	0
12	0	1	0	0	0
13	2	0	0	0	0
14	0	0	0	0	0
15	0	1	0	2	0

Arthropod Data:

Dataset - sampling of arthropods by species group. Two or three pitfall traps were placed at each current Harding grass invasion plots and no invasion plots were used for statistical analysis. All past Harding grass sites were also sites of current Harding grass invasion. At site B, we substituted the past Harding grass plot data for the current Harding grass plot data. See soil focal group dataset for Harding grass % cover data.

Harding grass (Current - 1, None - 0, Past - 2)	Site	Plot	Spide r	Sow bug	Beetl e	Was p	Ant	Leaf Hoppe r	Earwi g	Grass hoppe r	bee	miliped e	larv a	Total Abundanc e
1	A	1	6	15	2	0	0	2	0	0	0	0	0	25
0	A	2	3	23	0	0	1	0	0	0	0	0	0	27
2	B	3	11	15	0	0	0	0	1	0	0	0	0	27
0	B	4	25	9	1	0	0	0	4	0	0	0	0	39
2	C	5	4	16	0	0	0	0	0	0	0	0	0	20
0	C	6	6	27	0	0	2	0	0	0	0	0	1	36
1	C	7	10	7	1	1	0	0	1	0	0	0	0	20
1	D	8	3	9	1	0	0	0	0	0	0	0	0	13
0	D	9	10	5	0	0	0	0	0	0	0	0	0	15
0	E	10	30	9	0	0	0	0	0	0	0	0	0	39
1	E	11	15	26	0	0	0	0	0	0	0	0	0	41
0	F	12	31	3	1	0	0	0	0	0	0	0	0	35
1	F	13	4	5	0	0	0	0	0	0	3	0	0	12
1	G	14	15	6	0	0	0	0	0	0	0	0	0	21
2	G	15	15	24	0	0	2	0	0	0	0	0	0	41
0	G	16	12	11	0	0	0	0	0	0	1	10	0	34
2	H	17	3	26	2	0	1	0	0	0	0	0	0	32
0	H	18	18	20	1	0	0	0	0	1	0	0	0	40
1	H	19	8	22	0	0	0	1	0	0	1	1	0	33

Mammals data:

Table 1 was collected on multiple dates, March 21st, 2012, April 4th, 2012, April 11th, 2012, and April 18th, 2012. The table represents the number of vole and gopher burrows along each of the six transects.

Table 2 was collected on multiple dates, March 21st, 2012, and April 4th, 2012. The table shows the percent of non-native plant vegetation that was present in each of the plots. We collected data from eighteen plots total. Each of the six transects had three separate plots, one with vole burrows, one with gopher burrows, and one with no small mammal signs that we designated as our control plot.

Table 3 was collected on multiple dates, March 21st, 2012, and April 4th, 2012. The table shows the percent of native plant vegetation that was present in each of our plots. We collected data from eighteen plots total. Each of the six transects had three separate plots, one with vole burrows, one with gopher burrows, and one with no small mammal signs that we designated as our control plot.

Table 1. Number of vole and gopher burrows along each of the six transects.

Transect Number	Number of Vole Burrows	Number of Gopher Burrows
1	2	18
2	6	1
3	13	6
4	1	9
5	2	12
6	2	8

Table 2. Percent of non-native plant vegetation that was present in each of the plots

Transect #	% Non-native plant cover- Gopher Plot	% Non-native plant cover-Vole Plot	% Non-native plant cover- Control Plot
1	85	75	90
2	65	70	3
3	65	0	20
4	90	90	20
5	20	30	75
6	0	50	70
Average % plant cover for all transects	54.16666667	52.5	46.33333333

Table 3. Percent of native plant vegetation that was present in each of our plots

Transect	% Native plant cover-Gopher Plot	% Native plant cover-Vole Plot	% Native plant cover-Control Plot
1	0	0	0
2	0	0	97
3	25	20	25
4	5	0	70
5	50	60	25
6	100	0	0
Average % plant cover for all transects	30	13.33	36.17

Soil Data. Abbreviations: PHG (long-term HG invasion), HG (recently invaded by HG), NHG (no harding grass), f (flooded), D (drained)

Block Number-Sample identity	**% Cover Harding Grass**	**Inundation Status**	Moisture content (weight of water moisture in sample / weight of dry soil)		Nitrogen content in ppm (NH4 and NH3 * 50 / dry weight of soil in grams)
1-PHG	90	F	**0.39**		**7.49**
2-PHG	80	D	**0.25**		**12.01**
3-PHG	30	D	**0.45**		**22.94**
4-PHG	10	F	**0.33**		**8.43**
5-PHG	30	F	**0.29**		**2.8**
6-PHG	85	F	**0.439**		**6.063**
7-PHG	95	D	**0.381**		**9.498**
8-PHG	80	D	**0.30**		**6.65**
1-HG	15	D	**0.308**		**8.91**
2-HG	35	F	**0.36**		**9.9**
3-HG	50	D	**0.284**		**4.6**
4-HG	50	D	**0.254**		**13.79**
5-HG	40	D	**0.323**		**6.777**
6-HG	60	D	**0.329**		**6.22**
7-HG	90	D	**0.471**		**28.521**
8-HG	70	D	**0.303**		**9.34**
1-NHG	0	D	**0.270**		**8.10**
2-NHG	0	D	**0.30**		**6.274**
3-NHG	0	D	**0.39**		**8.85**
4-NHG	1	D	**0.299**		**3.14**
5-NHG	0	D	**0.41**		**14.87**
6-NHG	1	D	**0.33**		**12.09**
7-NHG	0	D	**0.439**		**10.79**
8-NHG	0	D	**0.291**		**9.62**