Determining an Effective Buffer Against Reinvasion of Restored Sand Dunes.

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Abstract: A major challenge of ecological restoration is to produce communities that are resistant from further invasion. After the removal of *Carpobrotus edulis*, an invasive succulent, in coastal dune habitats, secondary invaders can take advantage of the opened areas, spread rapidly, and impede restoration. This project studies the effectiveness of native annual grasses in preventing invasive grasses from invading at sites of recent *C. edulis* removal. In two sites at Fort Funston, CA, where *C. edulis* had recently been removed, $5m^2$ plots were raked and seeded with high or low densities of native grasses or left unseeded. Plots were left to grow through the rainy season and invasive grasses were collected from each plot. Samples were counted and their dry weight was measured. Preliminary results suggest invasive grass density and biomass/$area^2$ are not related to native seeding density. Preliminary observations implicate sand movement as the determining factor in overall plant growth. Seeding native grasses does not appear to be an effective method of controlling secondary invasive grasses in coastal dune habitats.

Introduction

Carpobrotus edulis, or iceplant, was historically introduced to Fort Funston by the military to stabilize slopes but quickly invaded the area. It was recently turned over to the National Park Service, which has been taking steps to remove the plant over several years. Iceplant is a very visible and often-studied invasive species because of its extreme threat to rare and fragile dune habitats (D'Antonio and Mahall, 1991, D'Antonio, 1993). As an invasive species, it decreases species diversity by outcompeting native plants and preventing sand movement. This hinders the natural processes of disturbance and change in the dune environment, which native plants depend on. This threat to native habitat has mostly been controlled by manually pulling out the plant all along the California coast (Pickart and Sawyer, 1998).

Only during the last couple years have restoration managers discovered new problems after the ice plant's removal. The iceplant leaves behind a layer of debris of dead and decaying organic matter that has accumulated underneath the plant. This has generally been left behind, or at most raked, after *C. edulis* was removed (2001, pers. comm.). Within the debris are dormant seeds of invasive grasses that have accumulated over the years, carried there by wind and other modes of dispersal from invaded areas. These seeds sprout the rainy season after the iceplant has been removed, benefiting from the nutrients that have accumulated there. This secondary invasion of grasses becomes another threat to newly restored areas. The grasses take the opportunity to establish in the cleared areas. While seeds of native grasses are also present, the invasive grasses take advantage of the unnaturally high nutrients from the debris found under iceplant, while in contrast native grasses perform better under normal nutrient levels for dune environments (2001 pers. comm.). Other plants such as bush lupine alter nutrient levels like iceplant (Maron and Connors, 1996, Maron and Jeffries, 1999).

There has been very little research on this secondary invasion, not only because it has been just recently noticed (2001 pers. comm.), but also because it is much less obvious than a dense mat of iceplant. Research is necessary because of a lack of knowledge of a potentially important aspect of sand dune ecosystem recovery from iceplant removal. These secondary invasive grasses are often a threat to rare and endangered species such as *Amsinckia grandiflora* (large-flowered fiddleneck), a rare native annual forb, through competitive exclusion (Carlsen, *e. al.* 2000). It is important for management to consider the effects of secondary invaders to protect and manage native grasses and make it a part of the overall restoration program. Restoration projects must be prepared to combat this consequence of the removal of iceplant (Hobbs and Huenneke, 1992, Hobbes and Humphries, 1995).

Control through the use of native vegetation can be efficient. As native plants grow, they are naturally increasing biomass and groundcover while competing with non-native plants for the same resources (Whitson and Koch, 1998, Carlsen, *et al.* 2000). In one case, areas in a native perennial grassland invaded by exotic annual grasses have been restored with varying densities of the native perennial bunchgrass *Poa secunda*. This study found that restored native perennial grasslands at intermediate densities have a high habitat value for the potential establishment of the forb mentioned earlier, *A. grandiflora* (Carlsen, *et al.* 2000).

There has been little research on the effects of the debris from iceplant. Several studies looked at the change in availability of nutrients in the litter of introduced species and the availability of nutrients left from under other plants. This includes studies on one native dune plant, bush lupine, *Lupinus arboreus*, and how it affects nutrient availability after its death (Maron and Connors, 1996, Maron and Jefferies 1999, Evans, *et al.* 2001).

There has also been research on using native species to compete with or act as a buffer against invasive grasses (Robinson, *et al.* 1995, Biedenbender and Roundy, 1996, Brown and Rice, 2000, Freckleton, *et al.* 2000, Dukes, 2001) and iceplant itself (D'Antonio, 1993). Of the five perennial grasses consisting of Bozoisky Russian wildrye and four wheatgrasses (Critana thickspike, Sodar streambank, Luna pubescent, and Hycrest crested), used in a study against the invasive downy brome, *Bromus tectorum*, the species Sodar streambank, Luna pubescent and Hycrest crested were effective in reducing the re-establishment of downy brome (Whitson and Koch, 1998). Biedenbender and Boundy (1996) seeded seven native grasses into the invasive *Eragrostis lehmanniana* stands and found native grass establishment was initially successful for treatments when sowing was followed by normal summer precipitation. Dukes (2001) found that in grassland communities, high functional diversity reduced the success of invasive *Centaurea solstitialis L*. by reducing resource availability. The growth of species-poor communities was more strongly suppressed. My study will apply the use of native grasses to the removal of nutrient-altering plants as competition for invasive grasses.

The purpose of this research is to see if native grasses can be used effectively to buffer against invasive grasses. If so, I wish to determine what density of native annual plants is best to compete with non-native grasses after the removal of iceplant. While high diversity and relatively high density plant communities are usually less susceptible to invasion, in some situations, this is not the case (Hobbs and Huenneke, 1992, Dukes, 2001).

Methods

The location of this study is at Fort Funston, Golden Gate National Recreation Area, CA (37° 43'N, 122° 30'W). This area of shifting sand dunes is on top of a receding sandstone cliff facing the Pacific Ocean to the west. It is bordered on the south by a golf course and the east by a freeway. The park gradually slopes down into Ocean Beach to the north.

My study was conducted at two sites. Site one is just within the most recent year-round closure area in the northern part of Fort Funston ('Project Area' in Figure 1). A closure area is one fenced off from public use, in this case for plant restoration. This site in a closure area is bordered on the west by hilly dunes where iceplant is still present, the south by a grove of cypress, the north by a drainage into the sea and the east by a footpath. It is officially closed to the public but still has occasional foot traffic. Most of this area has been cleared of iceplant within the last year and some native shrubs that were not removed were still present. Site two is at the southern edge of Fort Funston next to a fence that separates it from an adjoining golf course (To the south of Figure 2). It is on an approximately 20° incline sloping away from the fence. The area has been entirely cleared of iceplant but there has been some regrowth from leftover iceplant fragments. The area just east of it has been revegetated with native plants. This area is not closed and receives light pedestrian and dog traffic.

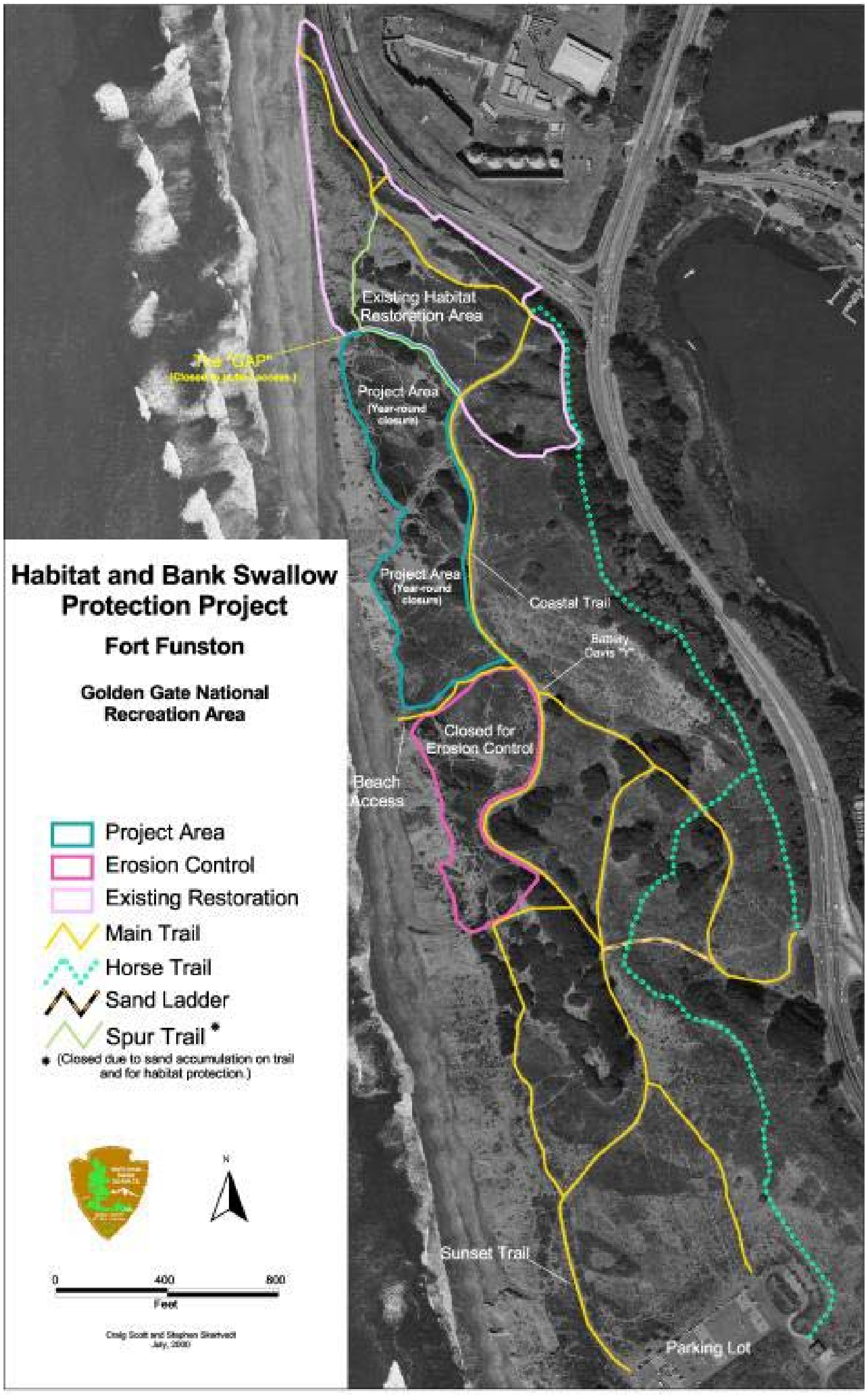

Figure 1. Site 1 is in the southern part of 'Project Area' and site 2 is far to the south of this map on the south side of Fort Funston.

The predominant invasive species present after the removal of iceplant are the annual grasses *Bromus diandrus* and *Vulpia sp*. To compete with these grasses, I planted the native plants

Spineflower (*Chorizanthe cuspidata*), rattlesnake weed (*Daucus pusillus*), and sandmat (*Cardionema ramosissimum*), three annuals native to the area, using seeds collected on site in September 2001.

To determine the number of seeds sown, I had to determine the number of seeds per gram and the viability of the seeds. One difficulty with working with these native species is the lack of data on seed mass and germination rates. The seeds of all three species, *C. cuspidata*, *D. pusillus*, and *C. ramosissimum*, were small and difficult to count due to small size and thorny husks so that it was difficult to obtain an accurate estimate of how many seeds were in each gram. Because of these complications I would have preferred a standard count using a consistent procedure for these seeds. I conducted a seed germination study in the greenhouse to estimate the number of viable individuals per gram of seed to see how many seeds per gram will sprout. This would tell me if the densities for field plantings, determined by seed counts, would be appropriate.

To make seed counts, I put the seeds of each species into separate bags in the form they had originally been collected by volunteers and park staff. *C. cuspidata* and *D. pusillus* were still in their husks and *C. ramosissimum* was still on the twigs it was collected with. I took three samples of 1g of *C. cuspidata* and *C. ramosissimum* and three samples of 0.1g of *D. pusillus* (its seeds are smaller than the others so there are many more per gram) and counted the number of seeds in each sample by counting seed husks. For *C. ramosissimum*, the bag was mixed thoroughly and 1g samples of plant matter were removed, including twigs and seeds. Seeds were carefully pulled out and counted.

For greenhouse germination, three ½m^2 potting trays and a mixing tray were disinfected in a light chlorine water solution (about 10mL/5 liters) and placed on a table disinfected by wiping down with the same chlorine solution. Water was mixed with Sunshine mix, a commercial potting soil, in a tray until thoroughly moist. The moist mix was scooped onto the potting trays and using a stick to push extra dirt off the top without pushing down, the surface was evened out. Each tray is divided into 3 even sections.

I mixed each of the samples counted earlier with a handful of Sunshine mix and evenly sprinkled it over a 1/3 section of tray. The surface was pressed down to flatten but not compress it. I sifted a layer of Sunshine mix on top and gently sprayed it with water to avoid exposing seeds until thoroughly damp. I sprinkled another layer of Sunshine mix and spray again. This last step was to make sure that any seeds that were uncovered by the water the first time were covered again.

For field plantings, I divided site 1 into twelve 5m^2 plots and site 2 into four 5m^2 plots with a 1m border between plots as a buffer to account for the movement of the sand. There were 3 treatments: raked control, raked with no natives planted; high density, raked with native seeds planted at 2g/m^2; and low density, raked with seeds planted at 1 g/m^2. There were a total of 4 raked, 6 high density, and 6 low density treatments between the sites. Location of treatments was determined randomly among the available plots. The plots of each site will be unevenly divided due to differences in size 1. Site 1 contains 5 high, 5 low, and 2 raked. Site 2 contains 1 high, 1 low, and 2 raked.

Plots were marked with .75m longg PVC pipe. Each plot was raked just before seeding. *C. cuspidata*, *C. ramosissimum*, and *D. pusillus* seeds were thoroughly mixed together with sand wet from recent rain from the respective sites. The recent rain made it unnecessary to add water. Then I spread at a seed density of 2g/m^2 (830 seeds determined from seed counts) in low-density plots and 4g/m^2 (1660 seeds from seed counts) in high-density plots, with no seeds placed in the buffer zone. The control plots (raked) were not seeded. Raking and seeding took place in mid-December with the exception of two plots in the second site, which were raked in January.

To account for the difference in the two sites, I marked the depth of each PVC pipe marker and measured how much the level of the sand has changed. This will show me if there is a noticeable difference in sand movement among plots.

In March the invasive plants were weeded from a 1m^2 plot in the center of each 5m^2 plot. Species dry mass was measured. I measured the mass of invasive weeds in the center of the experimental plots and compared dry mass. By comparing the mass of invasive plants in the four treatments I can see which treatment is the most effective in suppressing the growth of invasive plants.

The average mass of invasive plants are expected to be the highest in the raked control plots, then be less in low density plots, and even lower in high density plots. The increasing severity of these treatments should cause a greater impact as we move from an control treatment with only raking and added densities of planting. I looked for a difference between the high and low treatments especially and expecting a difference among all four. I will be using a one-way ANOVA between the masses of the three treatments.

Results

Initial seed counts were made per species and germinations per gram were counted in the greenhouse. There were more *C. cuspidata* germinations than seeds counted, indicating there were more than one seed per counted pod. Counted seeds/gram were close to germinations/gram so the initial seed count was used for planting. Initial and germination counts are in table 1.

Common Name	Scientific Name	total mass	seeds / g	g/500 seeds	# germ. planted	#germ-inated	germ. sprouts/g
Spineflower	*C. cuspidata*	171.1	119	4.20	135	**154**	**159**
					94	**165**	
					129	**157**	
Rattlesnake weed	*D. pusillus*	135.0	930	.538	57	19	880
					112	32	
					110	37	
Sandmat	*C. ramosissimum*	459.0	197	2.54	185	62	48
					221	47	
					185	36	
Total	--	765.1	415	1.20			362

Table 1. This chart shows how many seeds were available, the ratio of each type of seed, and how many I should expect to sprout. **Bold** indicates where more seeds germinated than were seeds counted.

There was no sand movement on the south site while sand movement on the north site varied from none to 2-10 centimeters where there is clear dune movement. Seeded native grasses were observed in seeded plots and rarely in unseeded plots. Native plants never took up a significant portion of groundcover.

Table 2 shows the average mass by treatment with standard error bars. An ANOVA on the average dry mass resulted in no significant difference between the three treatments (df = 2.13; F = 1.1; P = .36).

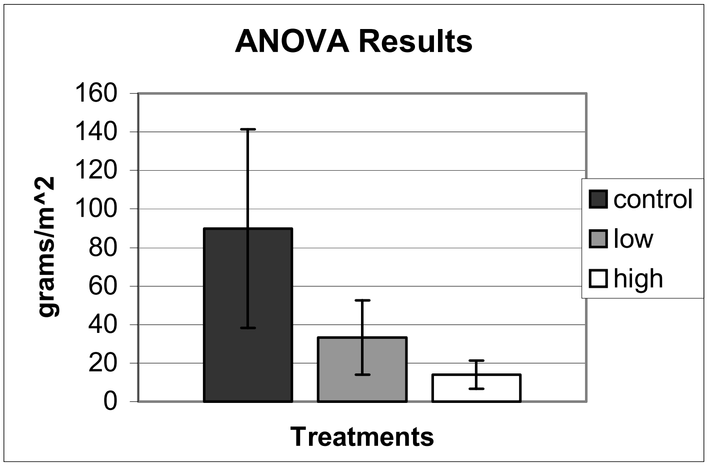

Table 2. The bars indicate the average mass of invasive grass per sample. The error bars indicate standard error.

Seeded samples from south site consisted primarily of *Bromus diandrus* (ripgut brome) and had lower masses than unseeded sites. Seeded sites were also the southernmost and upslope of unseeded sites. North site samples consisted mostly of invasive *Vulpia sp.* and were of less mass near the area of sand movement and higher mass farther away.

To see if there was a significant difference between plots with and without sand movement, I performed a Mann-Whitney *U* test which resulted in a significant difference (P = .0034) between the two types.

Discussion

This study showed no significant difference in seeding native grasses on dry mass of invasive grasses. However, the average dry mass in sites with active sand movement is significantly lower than the dry mass in sites without active sand movement. Seeded plants were observed to germinate in seeded plots but not in effective numbers.

The overwhelming effect of sand movement suggests that seeding is not appropriate at this location because sand can cover a restoration area with no discrimination. Observed low density of seeded grasses suggests that seeding is not an effective method in competing with invasive species because they are not able to out compete the invasive grasses.

One of the most significant weaknesses of this study is there was no adjustment for differences between the two sites. North and south sites were different in slope, aspect, size, sand movement, exposure to wind, adjoining areas and accessibility to visitors/dogs. These and other variations make it difficult to compare sites. While sand movement appears to be the most significant factor in plant growth, other factors, which were not accounted for, may have significant influences.

At the south site, seeded plots had seeded native grasses present and had fewer invasive grasses than unseeded plots in areas where there was no sand movement. By choosing the plot per treatment randomly, the seeded plots were upslope of the unseeded plots and this may have affected the results at this site. While each plot was raked, the site had more debris than the north site and more of it was left behind after raking. Debris was also thicker on the down slope plots.

At the north site, seeded native grasses were also present on all seeded sites while rarely found on unseeded plots. Active sand movement affected part of the site. The density of invasive species and total ground cover increased with distance from sand movement from nearly bare to densely covered in grass. This extreme gradient suggests that the physical process of sand movement determines plant growth and that seeding native grasses is not effective in areas affected. Removal of iceplant, which stabilizes the soil, will increase sand movement to areas that will be restored.

The seeds available limit the species used. All seeds used come from the site itself. Seeds cannot be supplemented from other areas so there is less chance of artificial mixing of genetic information between populations. These were plants that were similar to each other and had an abundant store of seeds. Also, due to time and space restrictions, I would not have been able to adequately study many more species.

The process of seeding also illustrated how inefficient this method is. The area is normally windy because it is on the coastline. Seeds were being blown away as I was seeding. While most fell on the appropriate plots, many were blown away as they were being sown or soon after. For this reason and other forms of disturbance, the density of seeds sown was not high enough to have the desired effect. Seeding higher densities would not be very efficient when considering the time it takes to collect seeds and how little area can be adequately covered. Even then, sand movement can cover the plants or move the seeds.

Seeding native grasses was not an effective means of controlling invasive grasses at Fort Funston both because of the amount of seed needed and forms of natural disturbance. Other methods of suppression should be tested, such as smothering with mats and manual pulling.

Seeded native grasses did grow in plots that were seeded so it can be beneficial to seed after other forms of grass suppression and as other natives are being planted.

To avoid burial of restoration areas, I would advise selective removal of iceplant so that some is left behind to stabilize the soil and monimize sand movement into the area. Once the area has been restored, the remaining iceplant can be removed and that area can be restored in turn.

Seeding native grasses was not found to be an effective buffer against invasive grasses in dune habitat. Although seeding was not appropriate for this situation, native grasses can be used to increase species diversity in restoration projects.

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