Effect of Seedballs in Native Plant Restoration at Muir Woods National Monument

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Abstract In this experiment the effectiveness of seedballs are studied as a direct seeding technique in native plant restoration at Muir Woods National Monument. Seedballs are broadcasted onto the restoration area where nonnative vegetations are dominant. I examined the germination success and the survivorship of seedball seedlings in grasses and forbs. However, unexpectedly rapid growth of nonnative grasses along with slow growth of seedball seedlings made the study design infeasible. Also, small and uneven sample sizes of seedball data were insufficient. The total number of plants in seedballs between March and April were not significantly different, yet comparisons with some standard measure or other restoration techniques are needed. Grasses, though fewer numbers of seeds were used, were more abundant both in March and in April than forbs.

Introduction

When human activities push the balance of natural systems far from their equilibrium, the self-healing ability of nature may be disrupted (Rolston 1994, Whisenant 1999) and the healing processes require deliberate repair, restoration (Jordan1994, Rolston 1994). Some environmental philosophers argue that restoration is impossible and that we should focus more on preserving what already exists (Elliot 1982, Katz 1992). Others emphasize that while complete restoration is impossible, conservation is on the same line (Rolston 1994, Jordan 1994). Although a restored ecosystem may not be a perfect replica, a goal of ecological restoration should remain to reestablish coevolutionary species in a self-sustaining homeostatic system (Westman 1991) of both structural and functional integrity (Cairns 1991). Ecological restoration should, with minimal intervention, encourage the self-healing process that leads to a properly functioning ecosystem (Turner 1985, Jordan 1994, Whisenant 1999). According to Jordan (1994) restoration practice is "to provide a healthy relationship between nature and culture." Although there are some cases in which reversions of lands used by humans have been successful without any restoration efforts (Wells et al 1976, Marrs and Gough 1990), the likelihood of natural recolonization by many native plant species usually shows decline (Lowday 1984, Miller, this report), and actually shifting community structure away from original ecosystem condition (Jackson 1985).

In recent years researchers have gained greater understandings in environmental problems and restoration practices, yet many restoration methods remain relatively costly and labor intensive (Whisenant 1999, Miller, this report), and in restoration settings budgets are usually limited. The disadvantage of transplanting seedlings is the high cost to grow relatively few plants (Whisenant 1999). Of the restoration techniques available, direct seeding is usually the most cost effective (St. John 1998.). While transplanting is more effective than direct seeding for some perennials and trees in harsh environments that have high probability of failing in direct seeding (Harmer and Kerr 1995), direct seeding is the most common technique for establishing grasses and herbaceous plants (Whisenant 1999).

Fukuoka (1973) first suggested the use of seedballs, a mixture of a variety of seeds, soil, water and clay, as a method of direct seeding in farming practice. Seeds and plants left untouched in natural conditions grow more vigorously than plants that are taken care of by human hands in a long run and maintain a healthy ecosystem (Fukuoka 1973, Bones 1990, elect. comm., Jordan 1994). Seedball restoration reduces the amount of workload to the minimum while maintaining the quality of work (Fukuoka 1973).

Ingredients used in seedballs are seeds, soil, clay and water, and each of these plays a significant role (Fukuoka 1973, Bones 1990, elect. comm.). Seedballs contain a fundamental unit of medium to grow plants, but can also be sufficient in many situations. Symbiotic mycorrhizal fungi, many of which are host-specific, can be found in local soil of seedballs and enhance the performance of plants (St. John 1998). Mycorrhizae aids absorption of water and nutrients in plants and prevents diseases and uptake of excessive amount of salt and toxic metals (Alexander 1977, Brandy 1999). Therefore, it is beneficial to include local soil in seedballs because in degraded environments the absence of host plants leads to a decline in the population of the fungi (Perry et al., 1989). One study shows that seed reserves have declined by predation of granivores, such as rodents and ants by 30-80% in some ecosystems (Archer and Pyke 1991), therefore, protection of seeds is important in direct seeding. Clay content of seedballs reduces loss of water by increased water potential (Brandy 1999) and helps to prevent foraging of insects and birds on the seeds (Fukuoka 1973, Bones 1990, elect. comm.).

The most distinguishing aspect in seedball restoration from other types of restoration methods is the unpredictability of outcomes (Fukuoka 1973). Mixing all seeds and broadcasting seedballs support the idea that natural processes are more productive than what human knowledge can deliver (Fukuoka 1973). Mixing seeds and throwing seedballs randomize the seeding process and allow the occurrence of unpredictable locations that plants germinate and establish (Fukuoka 1973).

After sufficient rain is received at the site, seedballs start to melt and form small clay covered patches (Fukuoka 1973). These patches create disturbance that decreases vegetation cover and increases availability of resources, such as nutrients and access to beneficial organisms (Parker and Reichard 1998). Growing space and sunlight from decreased vegetation and the availability of resources encourage growth of the seedlings (Parker and Reichard 1998). Water, sunlight and resource encased in seedballs creates a favorable condition for seedlings to grow.

If established native species add sufficient quantity of seeds to the seed bank, those plants in seedballs may also have greater success rate of germination and establishment relative to other species in seedballs because of the maintained population of mycorrhizal fungi.

In this study I will 1) examine the germination success and survivorship of the native species in the seedballs in different exposure to the sunlight (exposed, partially exposed or not exposed) and 2) compare the germination results of seedballs with mature native grasses and forbs that can contribute to the native seed bank.

In the first part of the experiment, I expect establishment of native plants to be greater in areas with seedballs than in areas without. Also, I expect to find seedballs placed in protection from direct sunlight to have greater germination success than those not in covered areas. In the second part, I expect the greater number of already established native plants to also have greater germination success in seedballs.

Methods

Study Site The experiment was conducted in Muir Woods National Monument, which is located in Mill valley, California, approximately 10 miles north of San Francisco. The experimental site is comprised of grassland that is disturbed coast live oak woodland. The site is an open, south-facing hillside of 85-120% slope. An area uphill from the site has been used as a weather station platform for over 25 years. Non-native forbs and grasses are dominant at the site and vicinity, particularly, *Cytisus monspessulanus*, commonly known as French broom, *Cirsium sp.*, thistle, and *Rubus discolor*, Himalayan blackberry. There are also signs of past restoration efforts at the site with the lower density of *C. Monspessulanus* than the surrounding areas.

Experimental Design The site is 45m x 30m in dimension. The site was divided into four 22.5m x 15m plots, 2 experimental and 2 control plots and named A, B, C and D respectively (Fig.1). This experiment was conducted between November 2001 and April 2002.

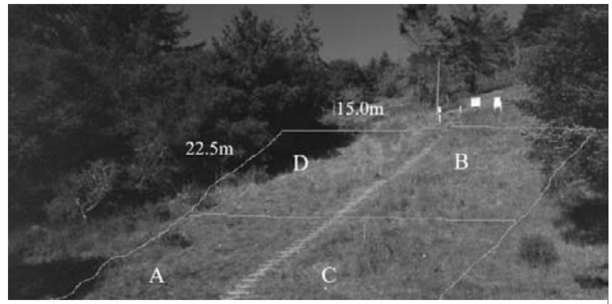


Fig 1. Experimental design of restoration site. The site, 45m x 30m in dimension, was divided into four 22.5m x 15m plots, 2 experimental and 2 control plots and named A, B, C and D respectively

Preparation of Seedballs The ingredients are prepared in the following proportions: 1 part of dry seed mix, 3 parts of dry native soil, 5 parts of dry red clay and 1-2 parts of water. Locally collected soil, used to replicate the natural environment, is dried and sifted to remove large pieces destroying uniformity. Large pieces of soil and rocks occupy considerable volume in seedballs, thus making one less dense with seeds than others. Dry red clay powder, purchased from Clay People Co. in Richmond, Calif., was also sifted. Seeds are collected locally to preserve the genetic variation between the restoration area and areas outside the park. Some seeds are more difficult to collect in a large amount than others, thus available seeds for each species vary significantly (Van Noord 2002, pers. comm.). The weight of seeds used, year of harvest, the total number of seeds per gram and the number of seeds in seedballs are listed for each species on table 1. The seed were collected between 1997 and 2001. Seeds from some species may have reduced viability due to their ages since harvest.

Once the materials needed were prepared, I mixed together 1 part of dry seed mix and 3 parts of dry, sifted soil to ensure thorough contacting of the soil on the seeds. This will maximize likelihood of mycorrhizal fungi finding their host plant species. Then, I added 5 parts of sifted red clay. When seeds, soil and clay are mixed thoroughly, I added water a little at a time until the mixture reached uniform thickness to be rolled into 1/2-inch balls in my hands. If the mixture becomes too soggy, I added extra clay to reach the desired thickness. Clay has greater capability of absorbing water of than other materials (Brady 1998), therefore it can minimize the amount of the extra material added. I pinched off small bits of the mixture and rolled in my hands until they became solid and cohesive enough that they would not fall apart when dried. The seedballs are then placed in dry, plastic containers large enough to keep individual seedballs from contact. In this research many school children and adult volunteers are involved in making seedballs and the size of seedballs vary from 1/4-inch to 1-inch diameter, which may have added inconsistency to the experiment. The prepared seedballs are dried for a week or longer until they are completely dry on the outside. The number of seedballs scattered are approx. 480.

Scattering Seedballs The equal numbers of dried seedballs, 240 each, were scattered randomly onto two experimental plots, plot A and B, on November 16, in the beginning of rain season. 15 seedballs in each site were randomly marked with flags. Intended use of these marked seedballs was initially to see how well the plants from seedballs grow and what stage they are at. However, the experimental methods turned out to be unpractical because unexpectedly rapid growth of nonnative annual grasses growing over other native seedlings, thus the marked seedballs are employed in data collection methods.

Germination Success and Survivorship in Seedballs I collected seedball data twice on March 13-15 for the first set of data collection and on April 20 2002 for the second with approximately one-month interval to see survivorship of seedball plants. Seedball data contain the following variables: the number of grasses and forbs respectively and the sum of both, diameter of melted seedballs, degree of exposure to the sun (fully exposed, partially exposed or covered) and dryness of seedballs (dry or moist). These data are then converted to the average number of seedlings in each plant type (grasses, forbs) per seedball for both March and April. Degree of exposure to the sun is measured by how well seedballs are covered. If seedballs receive almost no direct sunlight (thick layer of litter, tall vegetation, tree shade, etc), it is categorized as covered. Any seedballs with nothing directly above and no shading from vegetations except annual grasses are categorized in fully exposed (abbr. Full exp) and everything else is partially exposed (part exp).

At the beginning of first data collection I bordered melted seedballs by thin steel wires and secured in place. This will eliminate the possibility of counting seedlings that grow near the enclosure borders and that are not previously counted. All seedlings coming inside the enclosure are assumed to be native plants growing from seedballs unless seedlings are identified as non-native and pulled out. This is because it is extremely difficult to distinguish native seedlings from non-native at juvenile stage even to experienced eyes. However, when I collected data again in April, some nonnative grasses and forbs grew large enough to be distinguished from natives. Seedlings counted were initially categorized into different types of grasses and forbs. However, distinctive characteristics among grasses and among forbs are still unclear, I broadened the categories to grasses and forbs to avoid mistakenly identifying plant species.

The Influence of Established Plants on Seed Bank Germination success in seedballs was compared with already established plants or colonies of plants whose species are added to seedballs. I chose colonies for perennial grasses that tend to colonize and individual plants for everything else. 4 native species, *Achillea millefolium* (yarrow), *Chiorogalum pomeridianum* (soap plant), *Eriophyllum staechadifolium* (lizard tail) and *Scrophularia californica* (bee plant) were used for comparison. To count the number of plants and colonies I set 1m X 1m quadrat around each flagged seedballs, placing the quadrat in the way that seedballs come right in the center (marking midpoints, 50cm from each end, on each bar of quadrat) of the quadrat. I counted the number of native plants in each quadrat.

Statistical Analysis Because of the small and uneven sample sizes, I first tested for assumptions for statistical testing. For germination success of seedballs in different exposure type Kruskal-Wallis test was used if the assumptions were met. The germination success was tested for grasses, forbs and total (grass + forb).

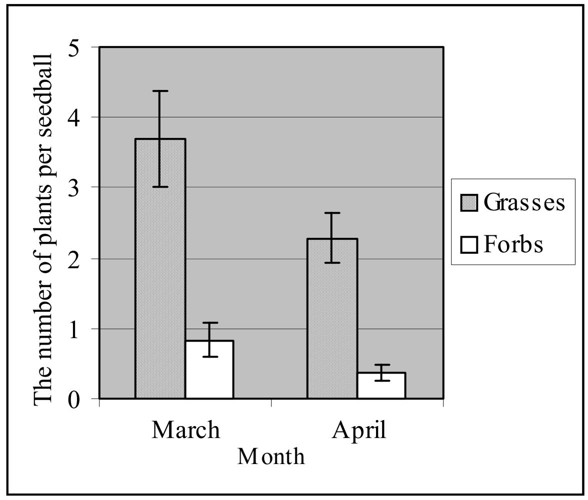
The populations of grasses and forbs are compared using Wilcoxon paired-sample test both in March and April.

To test the survivorship of seedball seedlings between March and April, Wilcoxon paired-sample test was performed on grasses, forbs and total.

Results

The original data collection method using transect to find the density of newly emerging plants in both experimental and control plots became unpractical because extremely high density of nonnative annual grasses completely filling the area and overgrowing native seedlings. Moreover, distinguishing young native grasses from nonnative grasses and accurately identifying them were unreasonable tasks. Therefore, I could not compare the densities of native plants germinating in control and experimental plots. Furthermore, the data collected from seedlings emerging from seedballs were only identified to the broad categories of grasses and forbs, therefore it was inadequate to make comparison between the established plants and the seedlings from seedballs.

Even though Seedball A3 had the greatest number of plants emerging, it was excluded from all statistical analysis because it had distinctive microenvironment that differed drastically from all other seedballs examined. All seedballs except A3 were found in relatively low grass and perennial areas. However, A3 was found in blackberry, coyote brush thicket.



Germination Success in Seedballs The result showed no significant difference in grasses (p=0.96), forbs (p=0.36) and total (p=0.91). Sample sizes are 5 seedballs (n=5) for fully exposed to sun, 20 for partially exposed and 5 for covered.

	Grasses	Forbs
March	3.69	0.83
April	2.28	0.38

Table 1. The average number of grasses is significantly greater than that of forbs both in March (p=0.0003) and in April (p=0.0001). The unit is in the number of plants / seedball, (n=29).

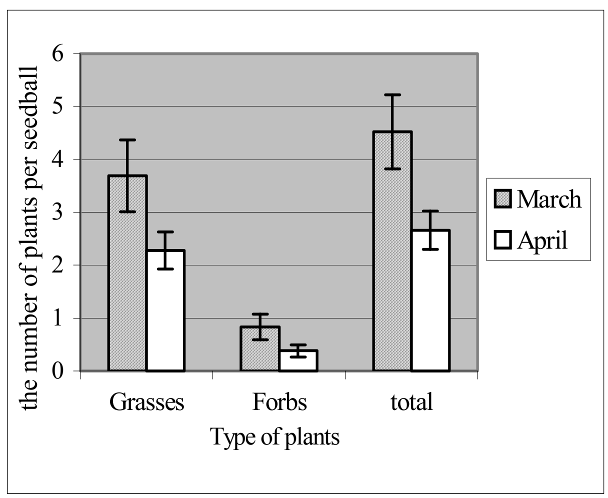


Figure 3. Seedling survival had no significant differences in grasses (p=0.24), forbs (p=0.33) and total (p=0.10) between March and April.

The average density (the number of plants per seedball) of grasses was significantly greater than that of forbs both in March (p=0.0003) and in April (0.0001) (Table 1) (Fig. 2).

Survivorship of Seedlings in Seedballs Seedling survival had no significant differences in grasses (p=0.24), forbs (p=0.33) and total (p=0.10) between March and April (Table 1) (Fig 3).

Discussion

In this experiment, the early start of nonnative annual grasses may have obstructed and made the original data collection methods infeasible. Also, seedlings emerging from seedballs had few distinctive characteristics to be distinguished accurately from one another. These unexpected obstacles may be overcome by the longer-term monitoring because larger plants are more distinct in their physiological characteristics. The earlier seed dispersing and yellowing may, in fact, make data collection feasible later in the season.

Apparently, the time period is too short to test the survivorship of seedlings accurately. In order to find out about survivorship of seedball germinants more accurately, follow-up monitoring is necessary. Even if germination success of seedball plants cannot be studied, survivorship of plants from seedballs can be used to show how successful seedball restoration is. It is possible that seedball may not enhance germination, but survivorship by maintaining small areas of growing space. In restoration settings it is much more important to have small numbers of plants germinating and reaching maturity than to have large numbers of plants germinating but all dying off before reaching maturity. In some circumstances self-recovery process of nature is hindered by a lack of seeds, seed predation and a harsh microenvironment that kills developing seedlings (Whisenant 1999). Primary aim of restoration should remain bringing back the self-healing ability of nature (Turner 1985, Jordan 1994) and one aspect of the self-healing process is for native plants to be able to regenerate their populations over time (Whisenant 1999). Thus, high survivorship to reach maturity and consequently dispersing seeds for next generation are great assets on the plants that can be restored from direct seeding (Whisenant 1999).

Grasses had the higher germination rate and also maintained the relative density higher than forbs. This indicates that grasses are more suited to seedball restoration than forbs at these stages.

However, the category is still too broad to conclude that more grasses should be used in seedballs rather than forbs because the majority of counts in forbs seemed to come from one type of plant. Follow-up monitoring at later stages is essential to determine which particular plants are responsible for the discrepancy between grasses and forbs.

The rough estimates of both grass and forb seeds were compared with seedball data. The number of seeds added to seedballs were approximately 42000 and 58000 respectively (Table 2). The estimate seed counts of forbs is thought to be higher than 58000 because the data for many forb species are not obtained. This suggests that the greater amount of forb seeds in seedballs is not necessarily associated with higher success of forb germination. However, as mentioned above, it is necessary to identify individual species as well as to continue follow-up monitoring.

The results of seedling survivorship of grasses and forbs show that there were no differences between March and April. If seedballs do extremely well on creating safe site that is a microsite protected from weathering and desiccation is more suitable for germination and establishment of seeds (Harper et al., 1965), it makes sense that populations of both grasses and forbs in April are not significantly less than in March. Seedling establishment can be increased by increasing the number of seeds in safe site rather than the total number of available seeds (Harper et al., 1965). This implies that if seedballs create safe site, consequently increasing survival rate of seedlings. However, a closer examination is needed to identify the survival rate of different species because some species may have higher survivorship than others. It is possible that lower survival rate than an average of one species might have been compensated by the higher survival rate of another species. In any case, seedling survival also needs comparison to be made with direct seeding or other restoration techniques to find out the effectiveness of seedballs.

One seedball labeled A3, excluded as an outlier, was found in notably different microenvironment that remained moist for all time of my observation period. A tall coyote brush was completely shading the seedball and the surrounding area. This seedball was excluded as an outlier because exceptionally high number of emerging seedlings and the high moisture level did not fit into the general site description of dry grassland. When compared to the average, the seedball contained approximately 30-50 times greater number of forbs (25 in March and 20 in April) and 2-3 times greater number of grasses (10 in March and 9 in April). However, the high moisture level may be explained by the existence of large redwood forest close by and the location of study site in transition zone from moist to dry. To detect the occurrence of this type of microenvironment at the site greater sample size is needed.

If A3 is genuine rather than an outlier, the high germination rate suggests that the microsite that retains moisture enhances the germination in seedballs even in dry oak woodland-chaparral environment. The microsite of this seedball fits into the characteristics of safe site. (Harper et al. 1976, Whisenant 1999).

Accuracy of seedball data can also be improved by making the sampling area large enough to contain all the falling seeds from seedballs. Sampling individual seedballs tend to miss the seeds that are washed off of seedballs. If one type of seeds is more prone to seed fall from seedballs, those species are more likely to be counted as low success species even though they may have high establishment rate in surrounding areas. In this experiment, *H. lanatum* was not found directly on seedballs, however seedlings of *H. lanatum* as well as its seeds were found in the surrounding areas without presence of parent plants.

A few assumptions that I have made for the data collection may be fallacious. Since local soil was used for preparing the seedballs, it is possible that the soil contained nonnative seeds and some of those germinated from seedballs rather than penetrating through or nonnative seeds falling on seedballs. Thus, it is also important to know if nonnative species can be found from the seedballs in a controlled environment.

Practicing seedball restoration probably necessitates slight modification because restoration sites typically contain a large number of invasive non-native species. In order to reduce further germination and colonization of invasive plants, controlled grazing and prescribed burning may be used (Collins 1987). Many native grasses and forbs in coastal live oak woodland and coastal scrub environments are adapted to fire (Botkin and Keller 2000). Also, some native grasses in California were benefited by grazing more than no grazing (Hatch et al. 1999). Any disturbance, whether caused by artificial or natural source, that removes existing cover of vegetation tends to increase germination success and establishment of grasses (Bullock et al., 1995).

The use of seedballs is not yet widely known as a restoration technique, but it has potential for low cost, low maintenance, large-scale operation and more research is needed to find out how effective seedballs are.

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SCIENTIFIC NAME	SEED (grams)	YEAR HARVESTED	# SEED /GRAMS	TOTAL SEED COUNT	
Achillea millefolium	3.7	1999	750	2775	
Anaphalis margaritacea	1.9	2001	16540	31426	*
Aquilegia formosa	0.2	1999	N/A	N/A	
Bromus carinatus sp. Carinatus	3.1	1999	165	512	
Bromus carinatus sp. Carinatus	28.6	2001	165	4719	
Bromus carinatus sp. Carinatus	30.0	2000	165	4950	
Chiorogalum pomeridianum	0.9	2001	132	119	*
Danthonia californica	4.5	2000	250	1126	*
Daucus pusillus	0.5	1997	812	406	*
Dudleya farinosa	0.8	1999	3300	2640	*
Elymus californicus	0.3	1998	90	27	
Elymus californicus	20.4	1999	90	1836	
Elymus glaucus ssp. Virescens	2.2	2001	349	768	
Elymus sp.	15.0	1999	90	1350	
Elymus sp.	6.3	1998	302	1902	
Eriophyllum staechadifolium	2	1999	709	1418	*
Festuca rubra	7	1998	1094	7658	*
Festuca rubra	0.7	1999	1094	766	*
Festuca rubra	4.9	1999	1094	5361	*
Festuca rubra	9.9	2001	1094	10831	*
Fragaria californica	0.3	2001	N/A	N/A	
Heracleum lanatum	N/A	N/A	N/A	N/A	
Lomatium dasycarpum	1	2001	171	171	*LOCA(**)
Lupinus nanus	1.2	2001	241	289	*LUBI(**)
Polystichum dudleyi	0.2	1999	N/A	N/A	
Ranunculus californicus	0.8	2001	610	488	*
Sanicula crassicaulis	1	1999	490	490	*SAAR(**)
Satureja douglasii	0.1	2001	N/A	N/A	
Satureja douglasii	0.3	2001	N/A	N/A	
Scrophularia californica	2.4	1999	1230	2952	
Scrophularia californica	11.3	1999	1230	13898	

Sisyrinchium bellum	0.8	2001	448	358	*
Sisyrinchium bellum	0.1	2001	448	45	*
Stachys ajugoides var. ajugoides	0.4	2001	736	294	*
Triteleia laxa	0.1	2001	N/A	N/A	
Wyethia angustifolia	2.9	2001	N/A	N/A	
Total	162.9				

Table 2. Native species used in seedballs are listed with the scientific name of plants, species code (first two letters of genus and species combined), seed weight, year harvested, and the number of seeds per gram and the total number of seeds is then

*For these species the total number of seeds per gram is provided by Fort Funston nursery, GGNRA.

**Seeds per gram is weight from the same genus, but different species for these species