Name: ______________________________

Biology Article Assignment #4 - Methods for Restoring Coastal Sage Scrub (5 pts)

Answer the following questions after reading the article: Techniques to Restore Coastal Sage Scrub at a Reclaimed Quarry in Central California by Busnardo et al. 2017

1. What is the difference between active and passive restoration? What are some methods used in active restoration? ____

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2. Why are coastal sage scrub communities some of the most challenging habitats to restore? ________

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____

3. Using the data presented in Table 1, summarize the differences in the organic material, nitrogen (NO_3), potassium (K), and magnesium (Mg) between the soil in the reference area and the soil in the cut and fill restoration areas. ____

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4. Use Table 2, determine how many pounds of *Artemisia californica* were hydroseeded on each hectare (ha). You will need to convert kilograms to pounds. ____________________________________

5. What are propagules? Why did the greenhouse staff incorporate native duff from the reference sites into the potting material? ____

____

6. Why didn't planning crews install chicken-wire cages around coyotebrush, orange bush monkeyflower, silver lupine, or black sage? ____

____

7. What method did researchers use to conduct vegetation monitoring? ________________________

____

8. How did the percent cover of container plants and seeded plants change from year 1 to year 4? _______

____

9. What did the researchers determine was the best restoration method when considering the percent cover of woody species and the cost associated with each method? _______________________________

____

10. What is the common name for *Odocoileus hemionus* and how did it effect the percent cover of the container plants? ____

____

RESTORATION PRACTICE

Techniques to Restore Coastal Scrub at a Reclaimed Quarry in Central California

Max J. Busnardo, Charles D. McClain, Kaitlin M. Schott, Matt B. Quinn and Matt J. Pollock

ABSTRACT

Restoring large, drastically disturbed sites requires active techniques to create stable, self-sustaining native plant communities. We examined the effectiveness of topsoil preparation, seeding, and planting techniques for restoring coastal scrub at a 16.1 ha reclaimed quarry with steep, harsh slopes. Grading within the quarry created a benched slope spanning approximately 230 vertical meters, with a gradient of two horizontal:one vertical (2H:1V). This gentler slope was achieved by cutting the upper portion of the slope and using the cut material to fill the lower portion. Soils on cut slopes (approximately 9.0 ha) and fill slopes (approximately 7.1 ha) were prepared differently, resulting in two distinct substrates. Work crews hydroseeded native shrubs throughout the entire graded slope and installed native shrubs from container plants across half the site. Container plants were irrigated and protected from herbivory and weed competition. We conducted quantitative monitoring of woody vegetation cover for five years. We found that coastal scrub percent vegetative cover established from seed was significantly higher than that from container plantings on fill slopes amended with composted organic matter. Moreover, coastal scrub cover established from seed was significantly higher on amended fill slopes compared to cover from seed or container plants on unamended cut slopes. We conclude that coastal scrub restoration efforts on large, drastically disturbed sites should focus funds and resources on soil preparation, seed application, and site-wide invasive plant control, rather than on container plant installation and maintenance.

Keywords: grading, hydroseed, plant cover, revegetation, soil preparation, topsoil

Restoration Recap

- Five years of post-restoration monitoring at a reclaimed quarry have yielded valuable information on how restoration methods (soil preparation and propagule type) affect the trajectory of coastal scrub establishment on drastically disturbed sites.
- Restored coastal scrub cover established from seed was significantly higher than that from container plantings on fill slopes amended with composted organic matter.
- Restored coastal scrub cover established from seed was significantly higher on amended fill slopes compared to coastal scrub cover from seed or container plants on unamended cut slopes.
- Resources earmarked for restoring coastal scrub on large, drastically disturbed sites should be focused on soil preparation, seed application, and site-wide invasive plant control rather than on container plant installation and maintenance.

Mining and quarrying activities severely alter landscape topography, soils, and vegetation. Disturbed sites can be restored, with the level of effort varying based on site conditions, available resources, time constraints, and the effectiveness of chosen methods at a particular site for a particular plant community. Restoring drastically disturbed sites to pre-disturbance conditions is challenging and typically requires soil preparation, revegetation, maintenance, and monitoring (Hillyard and Black 1987, Newton and Claassen 2003, Ott et al. 2011, Evans et al. 2013). This is particularly true on steep sites where soil erosion and slumping events are often too frequent to allow early successional plants to gain a foothold (Badía et al. 2007, Bochet et al. 2009).

Soil preparation can involve grading to create a stable landform and a natural slope profile, reduce sediment loss, and establish soil conditions conducive to supporting

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desired vegetation communities (Schad and Gay 2002, Hancock et al. 2003, Robson et al. 2009, Ngugi et al. 2015). It also can involve adding amendments to facilitate soil aggregation, increase water retention, and increase nutrient uptake to improve plant establishment (Ruthrof 1997, Kramer et al. 1999, Clemente et al. 2004, Claassen and Carey 2007, Benigno et al. 2013). Several studies have investigated the effectiveness of applying and incorporating soil amendments at disturbed sites. Some studies have found that incorporating amendments into the soil profile improved vegetation establishment (Zink and Allen 1998, Kramer et al. 1999, Bresson et al. 2001, Bowen et al. 2002, Benigno et al. 2013), whereas other studies have suggested that incorporating amendments may not be necessary or worthwhile (Curtis and Claassen 2009, Biederman and Whisenant 2011).

Restoration can take a passive approach that relies on natural processes to restore plant communities (Bradshaw 1997, Ursic et al. 1997, Yuan et al. 2006, DeSimone 2011, Prach et al. 2014, Šebelíková et al. 2015) or an active approach to jumpstart succession (Ott et al. 2011, England et al. 2013, Le Stradic et al. 2014, Kimball et al. 2015). Active restoration can include seeding and planting desired species to control soil erosion, restore self-sustaining plant communities, enhance the appearance of the landscape, and provide ecological connectivity with adjacent undisturbed areas. Some studies have suggested that direct seeding is more effective at restoring woody species than planting container stock (Welch 1997, Palmerlee and Young 2010), but others have found that a combination of using container plants and seeding can be effective (Eliason and Allen 1997). After a site has been seeded or planted, it can be maintained and monitored to support and track vegetation establishment, quantify restoration success, and inform adaptive management. Maintenance generally includes irrigation, weed control, foliage protection, and dead plant replacement until the site meets pre-determined performance and success criteria, such as plant survival or percent cover, which indicate a self-sustaining native plant community is on a trajectory toward establishment.

Coastal scrub communities are some of the most challenging habitats to restore because they are arid, fire-adapted, upland communities that comprise relatively slow-growing shrubs (compared to mesic communities) and are susceptible to weed invasion (Westman 1981, Bowler 1990, Allen et al. 2000). Techniques to restore coastal scrub range from passive approaches reliant on natural processes (DeSimone and Zedler 1999) to more active approaches that include techniques described above (Hillyard and Black 1987, Padgett et al. 2000, Cione et al. 2002, DeSimone 2006, DeSimone 2011). This study presents research investigating the effects of an active restoration approach on restoration of coastal scrub at Leona Quarry, a former hard rock quarry in Alameda County, California, U.S. The restoration approach includes extensive soil preparation, hydroseeding, container plant installation, irrigation, site maintenance, and monitoring.

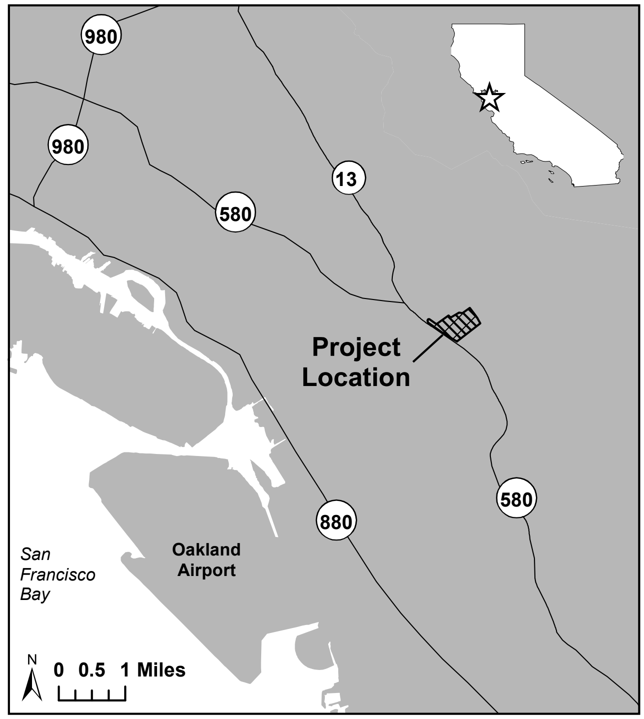

Figure 1. Map of the Leona Quarry vicinity, Alameda County, California, with California inset.

Methods

Study Site

Leona Quarry is located in southeast Oakland, Alameda County, California (Figure 1). Elevations at the site range from 91 m on the southwestern portion of the quarry floor to 325 m along the quarry crest. The area is characterized by a Mediterranean climate with dry, warm summers (long-term average temperature 17.8°C; precipitation 6.8 cm) and mild, damp winters (11.2°C; 37.3 cm), with an average yearly precipitation of 68.7 cm (NOAA 2014). The landscape in the region hosts coastal scrub, northern mixed chaparral, oak (*Quercus* spp.) woodland, and grassland communities (Holland 1986). Leona Quarry operated as a rock quarry from 1904 to the 1990s and produced construction-grade aggregates. Conventional mining practices were employed, which severely altered the topography, soils, and vegetation (Figure 2A).

Restoration Goals

The Leona Quarry restoration area covers 16.1 ha of reconstructed slopes (Figures 2B and 3). The primary goal for this area was to establish moderately dense, self-sustaining, native-dominated coastal scrub. An additional project goal was to restore habitat for *Masticophis lateralis euryxanthus* (Alameda whipsnake), a federally listed threatened species

Figure 2. Photographs of Leona Quarry before restoration in 2001 (A), immediately after restoration in 2006 (B), and six years after restoration in 2012 (C).

associated with coastal scrub and chaparral. We targeted a self-perpetuating plant-soil system that would not require anthropogenic inputs such as fertilizer, water, replantings, or intensive weed control beyond a three-year plant establishment period. Site construction was completed in November 2006. We maintained and monitored the site from 2007 to 2011.

Soil Investigation

We selected a coastal scrub reference area, located next to the Leona Quarry restoration area, as a model for restoration planning. The reference area supported the target native coastal scrub plant community and had the same dominant parent materials (rhyolite/tuff) as did the restoration area. We compared the soil horticultural properties and plant community composition between the reference area, restoration area, and topsoil salvage areas, to inform the quarry restoration plan.

The plant community in the reference area was dominated by *Artemisia californica* (coastal sagebrush). We classified the reference area as central coastal scrub, a community that occurs on exposed, south-facing slopes with shallow, rocky soils (Holland 1986). The reference area contained the nearest stand of central coastal scrub to the restoration area and was situated approximately 300 m northwest of the center of the restoration area. We collected composite soil samples from the reference area, the restoration areas, and the topsoil salvage areas. Composite samples were composed of four soil subsamples taken from all horizons found below the litter layer (O horizon) and above bedrock (Table 1).

Quarry Grading

Initially, the quarry slopes had an overall gradient of approximately 1.5 Horizontal: 1 Vertical (1.5H:1V), with numerous actively erosive, unvegetated areas steeper than 1H:1V (Figure 2A). Heavy equipment operators reconstructed the slopes to create a benched slope spanning approximately 230 vertical meters, with a gradient of 2H:1V (Figure 2B). This gentler slope was achieved by cutting the upper portion of the slope and using the cut material to fill the lower portion, an intensive earthwork operation that moved approximately 2,140,000 cubic meters (m^3) of material (Figure 3). On the fill slopes, a mixture of tuff and rhyolite subsoil with high rock and gravel content composed the finish-grade soil surface. On the cut slopes, the soil surface consisted of exposed, weathered tuff and rhyolite bedrock. Heavy equipment operators compacted the soils installed on fill slopes to approximately 95%, except in the uppermost 30 cm of material, which was compacted to 90%. “Super benches” (three 9-m-wide, level earthen benches) were added to allow placement of a deep, salvaged, topsoil layer (up to 1.3 m deep) (Figure 3). Narrower benches (3 m wide) also were constructed at

Table 1. Leona Quarry (Alameda County, California) laboratory analysis results for selected soil factors: percent organic matter (OM), texture (G = gravelly, S = sandy, C = clay, L = loam), and parts per million (ppm) of various nutrients.

Sample ID	% OM	Texture (USDA)	pH	NO_3 ppm	PO_4 ppm	K ppm	Ca ppm	Mg ppm
Reference Area	4.3	GL	5.9	7	2	250	1,860	372
Cut and Fill Restoration Areas								
Area 1	0.6	GL	6.9	5	7	70	1,620	856
Area 2	0.6	GSL	7.3	4	1	120	1,430	896
Area 3	0.1	GCL	5.3	6	6	90	190	828
Salvaged Topsoil Areas								
Topsoil 1	0.5	GSCL	6.8	4	9	60	2,140	2,050
Topsoil 2	0.6	GSCL	6.7	4	9	70	2,440	3,220
Topsoil 3	0.5	GSL	6.7	4	4	90	3,290	2,300

intervals on the slope to support maintenance roads and drainage features.

Topsoil Salvage and Amendment

Prior to mass grading, heavy equipment operators salvaged topsoil from the upper zone of the soil profile in portions of the quarry with chemical and physical soil properties supportive of plant growth. We prescribed amendments that were mixed with the salvaged topsoil to adjust particular properties (i.e., percent organic matter, pH, calcium:magnesium ratio, potassium concentration) to better mimic those found in the reference area (Table 1). Heavy equipment operators amended the topsoil using green waste compost (2 m^3/10 m^3 soil), soil sulfur (3.6 kg/10 m^3 soil), potassium sulfate (0-0-50 [3.6 kg/10 m^3 soil]), and agricultural gypsum (13.0 kg/10 m^3 soil).

Soil Preparation and Topsoil Distribution

Following grading, heavy equipment operators track-walked the entire cut slope to create on-contour microtopography, intended to facilitate vegetation establishment by increasing water retention and infiltration; slowing surface runoff; and capturing litter, soil, and seeds (Bainbridge 2000). Crews mechanically augered approximately 2,700 large planting holes (45 cm wide, 90 cm deep) throughout the cut slope in an attempt to increase rooting depth and soil water infiltration. Before plant installation, the bottom 60 cm of each hole was backfilled with the weathered bedrock tailings generated by excavating the holes, and the top 30 cm was backfilled with salvaged, amended topsoil. Crews also installed plants on the fill slopes; however, fill-slope planting holes were relatively small, hand-dug holes (20 cm wide and 40 cm deep).

The surface soils throughout the fill slopes were mechanically amended. Crews pre-mixed compost (314 m^3/ha), potassium sulfate (329 kg/ha), and gypsum (1,953 kg/ha) and mechanically incorporated (ripped) it into the upper 7.5 cm of the soil profile by backdragging the teeth of a track-loader bucket across the fill slopes. Equipment operators then track-walked the fill slopes to lightly recompact the surface soils, reducing erosion potential and creating on-contour microtopography.

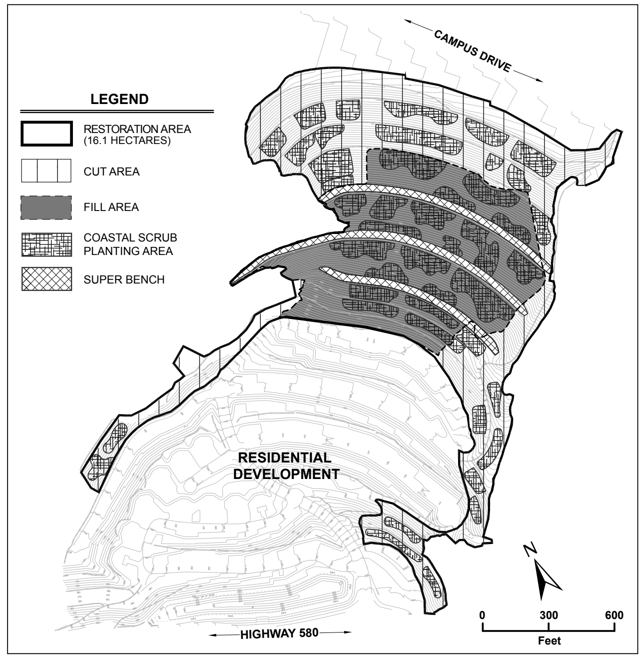

Figure 3. Map of the Leona Quarry restoration area indicating fill area and coastal scrub planting areas.

Hydroseed Application

Work crews completed hydroseeding across the restoration area before container plant installation. The hydroseed application consisted of a native seed mix (66.1 kg/ha

Table 2. Species, growth form, minimum germination rate, and seeding rate (kg/ha) of the native plants hydroseeded at Leona Quarry. Installation was completed in fall 2005. Nomenclature follows the Integrated Taxonomic Information System.

Growth Form	Species	Minimum Germination (%)	Seeding Rate (kg/ha)
Shrub	*Acmispon glaberus*	60	3.3
	Artemisia californica	50	0.6
	Eriogonum fasciculatum	10	1.1
	Eriophyllum confertiflorum	60	0.2
	Salvia mellifera	50	2.2
Forb	*Acmispon americanus*	60	2.2
	Eschscholzia californica	70	2.2
	Lupinus succulentus	85	6.7
Grass	*Bromus carinatus*	80	17.9
	Elymus glaucus	80	13.5
	Elymus trachycaulus	80	6.7
	Nassella pulchra	70	2.8
	Vulpia microstachys	80	6.7
		Total	66.1

Table 3. Quantities of native shrubs installed from containers at Leona Quarry. Initial installation was completed August 2006, and replanting occurred in three subsequent springs (2007–2009). Nomenclature follows the Integrated Taxonomic Information System.

Species	Number Initially Installed
Adenostoma fasciculatum	520
Artemisia californica	1,448
Baccharis pilularis	1,471
Diplacus aurantiacus	280
Eriogonum fasciculatum	166
Lupinus albifrons	444
Rhamnus californica	668
Salvia mellifera	331

[Table 2]), wood fiber (896 kg/ha), Biosol® (6N-1P-3K organic fertilizer, Rocky Mountain Bio Products, Denver, CO; 896 kg/ha), potassium sulfate (196 kg/ha), agricultural gypsum (1,681 kg/ha), and nonasphaltic tackifier (135 kg/ha). After hydroseeding, crews installed biodegradable, 100% coconut-fiber erosion control netting on all 2H:1V slopes.

Container Plant Installation

In summer 2006, work crews installed container-grown native shrubs in localized planting areas on approximately 50% of the site (Figure 3 and Table 3). Plants were grown from propagules collected from the reference sites and other sites within 5 miles of the quarry. We specified the use of deepot (6.4-cm × 25-cm) containers to facilitate healthy root development. Greenhouse staff incorporated native duff from the reference sites into potting material prior to planting to inoculate the soil with site-specific mycorrhizae. Crews installed shrubs throughout the coastal scrub planting areas on 3.0-m centers in planting holes 30 cm deep (Figure 3). Crews constructed irrigation basins (60-cm to 90-cm diameter with a 10-cm high, 10-cm wide earthen berm) at each planting location.

Judging from reference area observations, we expected substantial *Odocoileus hemionus* (mule deer) browse. Therefore, crews installed cylindrical chicken-wire cages around all planted shrubs except on the following species resistant to deer browse: *Baccharis pilularis* (coyotebrush), *Diplacus aurantiacus* (orange bush monkeyflower), *Lupinus albifrons* (silver lupine), and *Salvia mellifera* (black sage). Cages measured 121 cm in diameter by 152 cm tall and were supported by two 2-m-long rebar posts.

Site Maintenance

Workers maintained the planted shrubs for three years following installation (the "plant establishment period"). Crews maintained the irrigation basins and a 7.5-cm-thick layer of wood-chip mulch for all planted shrubs during this period for weed control. They installed a temporary drip-irrigation system to water the planted shrubs between April and October. The quantity and frequency of irrigation was greatest in the first growing season (2007) and was reduced to an as-needed basis in subsequent years. Crews replaced all dead container plants annually from 2007 to 2009 and hand pulled all herbaceous plants from the irrigation basins. Weeds, particularly *Genista monspessulana* (French broom), with potential to outcompete target native woody plants were controlled manually in 2007–2011. Foliage protection cages also were regularly maintained.

Vegetation Monitoring

We measured percent cover of woody vegetation annually from 2007 to 2011, using the line-intercept method (Bonham 1989). Before beginning monitoring, we sited twenty-six 30.5-m-long transects by selecting starting locations of transects and compass bearings from random number charts. During monitoring surveys, we recorded the horizontal length of interception by each woody plant that intercepted any transect, documenting the species and propagule type (container planting or seed). We were able to distinguish container plants from seeded plants because container plants were maintained in irrigation basins that were kept free of other plants throughout the 5-year data collection period.

Data Analysis

We used the "stats" package in the statistical program R (v. 3.0.2, R Foundation, Vienna, Austria) to perform non-parametric Kruskal-Wallis Rank Sum Tests (K-W test), in which substrate (cut or fill) and propagule type (container or seed) were combined into a single treatment variable with four distinct groups. Where K-W tests indicated significant differences ($\alpha = 0.05$) in the percentage of native woody cover between treatments for a given monitoring year, pairwise Wilcoxon Rank Sum Tests were used to identify those specific pairwise differences. Bonferroni corrections were applied to all pairwise tests. Our use of non-parametric methods is intended to provide conservative and robust results, which can be used to inform future restoration efforts.

Results

In Year 1 (2007), percent cover of container plantings on both (unamended) cut and (amended) fill substrates was significantly greater than seeded percent cover on cut substrate (K-W test; $\chi^2 = 22.5$, df = 3, $p < 0.0001$) and slightly greater than seeded percent cover on fill substrate (Figure 4). However, in Year 2 (2008), there was no significant difference between any of the treatment groups (K-W test; $\chi^2 = 2.82$, df = 3, $p = 0.421$). In Year 3, percent cover of seeded plants on fill substrate was significantly greater than percent cover of container plants on fill substrate (K-W test; $\chi^2 = 11.2$, df = 3, $p = 0.011$). In Year 4 (2010), percent

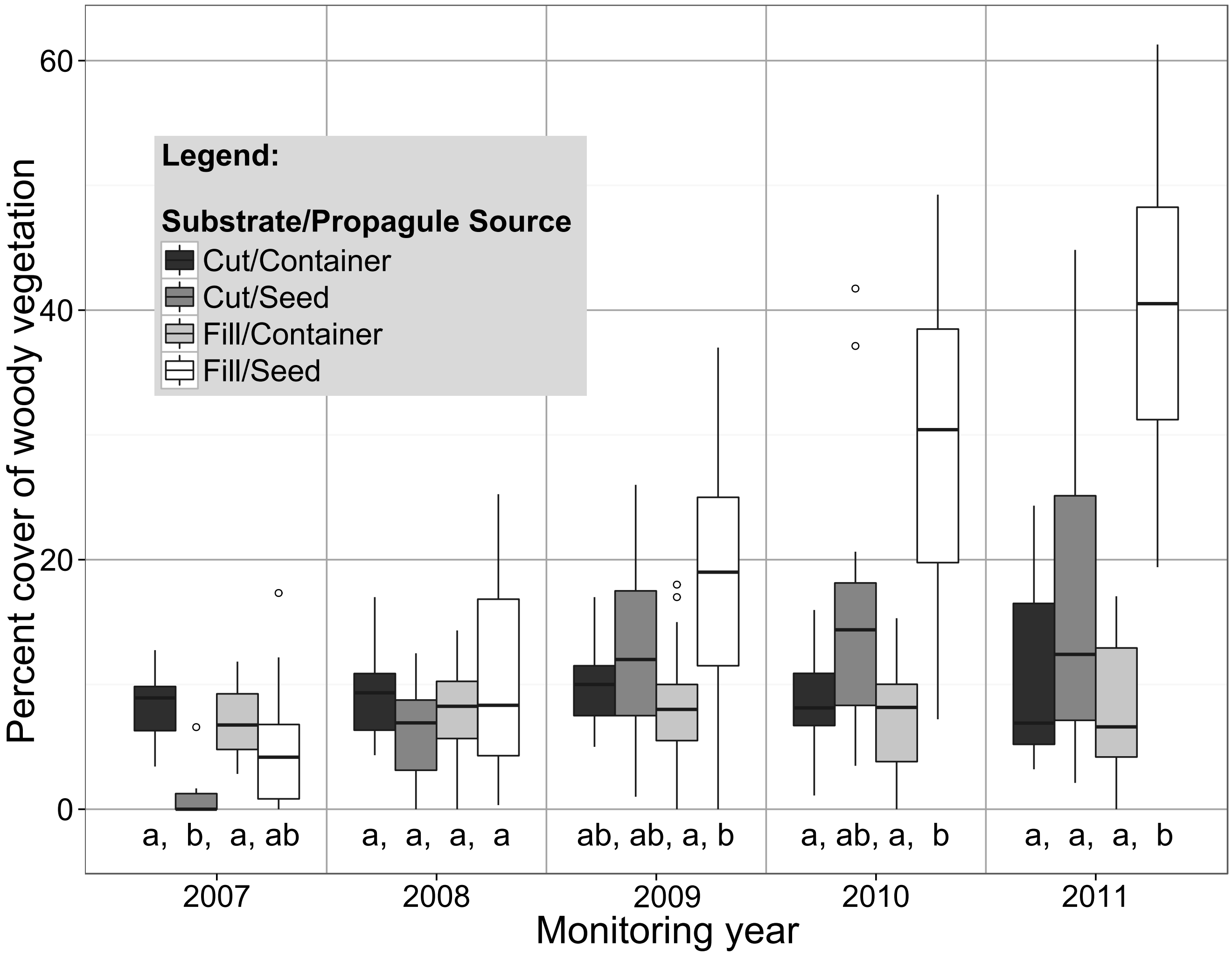

Figure 4. Boxplots comparing percent cover of woody vegetation by treatment type (combinations of substrate [cut or fill] and propagule type [container or seed]) from 2007 to 2011. Boxplot hinges, whiskers, and outliers displayed as specified by Tukey (McGill et al. 1978). Lower case letters denote results of pairwise comparison tests for each year; treatments with different letters were significantly different (α = 0.05).

cover of seeded plants on fill substrate was significantly greater than percent cover of container plantings on either substrate (K-W test; $\chi^2 = 25.5$, df = 3, $p < 0.0001$). Seeded percent cover on fill substrate continued to increase in Year 5 and was significantly greater than percent cover of any other treatment (K-W test; $\chi^2 = 29.2$, df = 3, $p < 0.0001$).

Discussion

Five years of quantitative post-restoration monitoring at Leona Quarry have provided valuable information on how restoration methods (propagule type and soil preparation) affect the trajectory of drastically disturbed sites supporting coastal scrub vegetation. We found that native coastal scrub vegetation established more effectively from hydroseeded and naturally dispersed seed than from container plants that were installed, irrigated, and protected from herbivory at greater cost. We attribute this outcome to the greater density of recruited seedlings relative to container plantings, combined with preferential browse on container plants.

Plant propagule source affected percent cover of native woody plants. Although percent cover of plants established from seed increased significantly from 2007 to 2011, we did not observe the same trend for container plants. Though the survival rate for container plants was high, there was no significant expansion in percent cover of container plantings during the five years following planting, with container plants still representing approximately 8% cover in 2011. In Year 1 (2007), container plants represented greater percent cover of native woody species than plants from seed, but the opposite was true by Year 5 (2011). The greater percent cover from container plantings in Year 1 (a year with average rainfall) reflects their pre-existing above and below-grade biomass, compared to seed, at installation. The site received average rainfall in Years 2 and 3 (2008 and 2009) and above-average rainfall in Year 4 (2010) and seeded percent cover increased on both substrates while percent cover from container plantings remained relatively constant. Rainfall was below average in Year 5 (2011), and the percent cover of container plantings on either substrate and seeded percent cover on cut substrate remained relatively constant.

Several noncompeting hypotheses likely explain why container plant-derived woody cover increased only marginally relative to woody cover derived from seed in the five years following installation. First, shrub seedlings recruited from seed at much greater densities than planted shrubs because seed application and germination rates were high. Next, container plants exhibited intense *O. hemionus* and damage during the plant establishment period, but browse was relatively inconsequential for seeded plants. *Odocoileus hemionus* browse on container plants outside foliage protection cages limited lateral canopy expansion of container plants beyond the cages. Also, maintenance activities around container plants and the relatively low planting density may have prevented establishment of dense vegetation thickets that can protect plants from deer browse. In contrast, seeded plants were able to establish densely throughout the restoration area, and seed input continued as individuals matured and produced seed.

Substrate preparation also affected the percent cover of native woody plants. Heavy equipment operators ripped fill slope soils and amended them with compost (but did not do so for cut slope soils); the resulting improved root penetration and capacity for water infiltration/storage likely explains why native woody plants better covered fill slopes, compared to cut slopes, five years after installation. Several studies have demonstrated that water infiltration and retention is improved by incorporating compost into drastically disturbed subsoils (Bresson et al. 2001, Curtis and Claassen 2009, Benigno et al. 2013). Moreover, fill material originated from higher in the soil profile and likely contained more fines (generated in the extraction, transport, and placement processes) than did the cut substrate. Plants established from seed dominated the cover in 2011, suggesting that it is important to improve soil conditions across an entire site rather than in planting basins only.

We conclude that restoration practitioners planning coastal scrub restoration on large, drastically disturbed sites should consider focusing funds and resources on soil preparation, seed application, and site-wide invasive plant control. Container-grown plants could be used strategically to increase plant community diversity by introducing species that do not readily establish from seed.

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