Restoration in Type-Converted and Heavily Disturbed Chaparral: Lessons Learned[1]

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Abstract

A wide range of disturbances including recreation, utility corridors, too frequent fire and invasive plants have led to the type conversion of native chaparral habitats to non-native grasslands on the Angeles National Forest. These often compounding disturbances have led to the recent planning, implementation and monitoring of a wide variety of restoration techniques across the forest. Restoration techniques have included imprinting, hydroseeding, container planting and aggressive weed control with a variety of results. Factors influencing these results are adequacy of planning, timelines, weather patterns, hydrology and soil conditions, pre-project invasive plant infestations, availability of materials and personnel, and as always, cost. The highest performing restoration sites appear to be those that either had a low presence of non-natives beforehand or had aggressive weed control in the first two/three years of restoration, combined with the use of enough genetically appropriate, early seral native plants introduced to the site as container plants at the correct time in the early fall and watered consistently.

Keywords: chaparral restoration, Angeles National Forest, topsoil salvage, soil decompaction, invasive plant removal, hydroseeding, container planting

Introduction

The Angeles National Forest (ANF) is home to over roughly 2000 different plant species, spread across roughly 80 vegetation types, with the dominant type being chaparral (Stephenson and Calcarone 1999). In addition to this plant biodiversity, the ANF is crisscrossed by hundreds of miles of pipeline and powerline rights of way (ROW's), utility and recreational roads, and trails. All of this infrastructure, which services Los Angeles and its 10 million residents (U.S. Census Bureau 2014), has contributed to vegetation disturbance in the form of invasive plant proliferation, soil erosion and compaction, vegetation cutting or removal, dust pollution, increased fire intervals and increased cross-country unauthorized vehicle travel. The effects of these disturbances, especially when combined, have led to the vegetative type conversion of native chaparral habitats into stands of non-native annual grasses or forbs.

Prior to 2007 very little historical evidence can be found for chaparral vegetation restoration activities occurring on the ANF to mitigate the impacts of this infrastructure construction and maintenance (J.Nickerman, personal communication, November 6, 2014). However, around 2007 it was recognized that the habitat fragmentation and degradation caused by infrastructure across the ANF needed to be mitigated in the form of onsite vegetation restoration. The first challenge was

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creating a comprehensive restoration plan that would document the strategy for enacting restoration principles on the ground. A template for such a restoration plan has now been developed.

The intent of this paper is to describe the processes of chaparral restoration planning on the ANF by detailing the methods employed and the lessons learned over 100 different sites across the Castaic and San Gabriel Mountain ranges from 2009 to 2014. Approximately 40 of the sites had restoration started in 2009, 10 in 2010, 10 in 2011, 10 in 2012, 25 in 2013 and 5 in 2014. Sites vary in size from 0.06 to 5 acres, cumulatively amounting to approximately 75 acres. Elevations range from 2000 to 7000 feet, with annual precipitation ranging from 10-15 inches in the Castaic range sites and 30-35 inches in the San Gabriel range sites (Stephenson and Calcarone 1999). The sites primarily occur in vegetation dominated by chamise chaparral, semi desert chaparral, California buckwheat (*Eriogonum fasiculatum*) scrub, scrub oak chaparral, mixed chaparral, oak woodland and non-native annual grassland. However, some work was also done in cottonwood/willow riparian woodlands as well. All of the sites were scheduled to be restored due to utility or road construction or maintenance disturbances.

Restoration Methods and Lessons Learned

Restoration sites were evaluated through the use of aerial photographs and multiple field visits. The seed palettes (described in the paper "Guidelines for Choosing a Plant Palette and Collecting Native Plant Materials" of this General Technical Review (GTR)), erosion control best management practices (BMPs), and restoration methods were tailored to the soil conditions, slope, aspect, elevation, hydrology, vegetation and severity of disturbance at each site. The following headings highlight the main components that must be considered when planning for chaparral restoration. Each heading is divided into two sections: the "Methods" portion and the "Lessons Learned" portion. The headings are discussed in the order in which they should be considered for successful restoration planning.

The information provided below is derived from observations over the large variety of restoration sites described above, conversations with restoration practitioners and technical restoration literature. Data are not analyzed statistically because the main goal was to get native plant cover back on the sites, not to conduct rigorous and extensive monitoring. Therefore, the reader should note that the restoration recommendations provided below in the "Lessons Learned" sections are primarily anecdotal in nature. However, starting in 2013, the ANF, in cooperation with partners, has begun to record statistically valid baseline data prior to site disturbances with the goal of monitoring restoration trends (typically 7-10 years).

Topsoil and Vegetation Salvage and Replacement—

Topsoil and vegetation salvage are the first steps in the restoration site preparation process as they must occur before a site is disturbed. They are only needed, however, if the site will be disturbed by activities that remove or alter the soil horizons and existing native vegetation (e.g. grading, compaction). If these disturbances do not occur, this step in the restoration planning process would be skipped.

Methods—

In an effort to preserve seed banks, native mycorrhizae and soil nutrients, the top 5-16 inches of soil were salvaged in areas scheduled for ground disturbing activities. Heavy equipment (bulldozers, excavators, etc.) was used to carefully scrape off the topsoil and move it in a designated area on site. Topsoil salvage on the ANF has included the O, A, and B soil horizons which were salvaged together given since these horizons are typically thin (less than a few inches). Topsoil was salvaged in a dry state in the late summer to early winter when most plants had finished seeding and seeds in the seedbank were dormant. Every effort was made to avoid salvaging soil in the late winter to spring, as salvaging at this time would have the most deleterious impact on the quantity of seeds in the seedbank. At this time of year seeds germinate and topsoil salvage would likely destroy them, in addition to the offspring they would have produced that season, therefore even further depleting the amount of seed in the seedbank. Since the viability of the beneficial seeds, fungi, bacteria, and nutrients in topsoil decreases with time (Steinfeld et al. 2007) topsoil was for the shortest amount of time possible (still ended up being over 12 months in most cases).

Topsoil stockpiles were protected to maximize recoverability and to minimize the effects of wind and water erosion. This was done by placing topsoil piles in wind-rows around the perimeter of the construction area. Piles were less than five feet in height, in an attempt minimize anaerobic conditions in the soil. Piles were cordoned off from construction activities so they were not disturbed by vehicles or equipment. Attempts were also made to remove all nonnative plants from the stockpiles before they produced seeds that could contaminate the soil. In order to minimize erosion jute or coir netting covered the stockpiles, but plastic covering was used since it sterilizes the seeds and microbes in the topsoil (especially problematic in warm months). Wattles or silt fences were also installed around the stockpiles to act as a barrier and prevent erosion.

Vegetation growing in the salvaged topsoil was either incorporated into it (if it was less than 2-3 feet tall and not robustly woody in nature) or salvaged into its own stockpile (if it was over 3 feet tall or woody) by using heavy equipment before the topsoil was piled.

Once construction, slope recontouring and decompaction (both described in section below) were completed, the topsoil was replaced with a bulldozer and excavator working in tandem. Topsoil was re-spread to a uniform depth comparable to soil site conditions in adjacent undisturbed areas. The topsoil surface was left in an uneven/roughened condition and the bulldozer then track-walked over the soil perpendicular to the site contours, but not to the point of creating soil compaction over 85%. Usually two to three passes with the dozer were sufficient. Track-walking created small depressions in the soil which captured water, soil and seed, thus helping to stabilize the site. In addition, the dirt clod size was kept at 2–3 inches to create a roughened surface that maximized soil/seed contact. Topsoil was not spread with a substantial use of water (only a fine misting was used to keep dust to a minimum), especially during the months of April through August. The goal was to minimize compaction while at the same time preventing seed germination during the driest times of year.

After topsoil was replaced, native woody vegetation not incorporated into the topsoil was placed back over the site either as chipped material, slash, or vertical mulching to discourage unauthorized vehicle traffic.

Lessons Learned—
Well in advance of construction activities (preferably at least 6 months) areas suitable for topsoil and vegetation salvage should be delineated. This will allow for adequate equipment mobilization and storage design.

- Top soils in the San Gabriel and Castaic Mountains tend to be very thin (less than 6-12 inches), thus making separation of the O and A horizons from the B horizon infeasible with heavy equipment. However, every site is different and a site-by-site determination should be made as to whether it is necessary and/or possible to separate the horizons, as salvaging results may be enhanced.
- Do not salvage topsoil that has more than 25% non-native plant cover.
- Do not salvage topsoil that contains a highly noxious weed such as perennial pepperweed (*Lepidium latifolium*) or yellow star-thistle (*Centaurea solstitialis*). When topsoil was salvaged and re-spread in areas with greater than 25% non-native cover or that had a highly noxious weed present the soil was recolonized by non-natives, making it harder to restore the native vegetation.
- Carefully consider if the salvage of topsoil is worth causing a larger footprint of disturbance. On the ANF topsoil was stored on site, as storing topsoil offsite and then bringing it back was cost prohibitive. This meant that the disturbed construction area had to be slightly larger to accommodate the topsoil piles.
- Use smaller sizes of dozers (e.g. D5/D4 CAT) and excavators for topsoil and vegetation salvage work. Larger equipment is not suitable for this detail-oriented work.
- Salvaging topsoil on slopes over 30% is difficult because heavy equipment does not perform well on steeper terrain.
- Ensure that topsoil piles are well flagged and signed so that disturbance is avoided.
- Avoid using jute or coir to cover piles if hand weeding is necessary as it is very difficult and time consuming to remove all of the roots and see invasives through the woven covering.
- The best time of year for topsoil replacement is August through November, because the topsoil seedbank receives the maximum amount of rainfall to stimulate germination. However, replacement in December through February has been moderately successful if a substantial rain event (over 1 inch) occurs post-replacement.
- It is very important to ensure track-walking over the site is enough to hold topsoil/subsoil in place, but not so much that the site is compacted. Track-walking must be done perpendicular to the contours, otherwise the depressions from heavy equipment tracks will channel water/soil down slope leading to rilling or even slope failure.
- Do not add fertilizers to the topsoil. Fertilizers have been shown to increase weed abundance (Newton and Claasen 2003, Steinfeld et al. 2007).
- Non-local mycorrhizae were added to approximately 15 of the restoration sites. Based on field observations the added mycorrhizae did not appear to increase or decrease the amount of plant cover. This may be because 1) the added mycorrhizae were not local and so were not effective or 2) the amount or type of mycorrhizae added was not adequate to increase plant productivity or 3) the mycorrhizae was added to the soil incorrectly.

- To maintain the effectiveness of vertical mulching or slash it may need to be reset or even replaced as it can blow down/away or be crushed by motorists. For this reason it is best to combine mulching/slashing with boulders and/or container plants, which are more effective over the long term.
- Vegetation slashing or mulching may hinder weeding (especially if herbicide is not the eradication method) by making weeds hard to reach and easily camouflaged.

Slope Recontouring and Decompaction—

Slope recontouring and then decompaction are the next steps in the restoration site preparation process (after topsoil/vegetation salvage and replacement). Similar to topsoil and vegetation salvage, slope recontouring is only needed on a restoration site if the original landscape contours have been altered and returning the contours would improve erosion control, hydrologic function and/or scenic integrity. Likewise, soil decompaction is only necessary if the soil horizons have been compacted to the point that plant germination and growth would be inhibited (which is typically only caused by the repeated use of heavy equipment on the site). Decompaction is most often needed when restoring roads, trails or other graded areas.

Methods—

Disturbed areas that had the native surface altered were recontoured using a bulldozer and an excavator as the first step in the on-site restoration process. Recontouring was done by referring to pre-disturbance photos or by comparing the disturbed site to the surrounding terrain. Special care was taken to re-incorporate drainage features.

After recontouring was completed, restoration sites were assessed for soil compaction which would likely inhibit vegetation recolonization. About a third of the restoration sites disturbed areas were tested using a static cone penetrometer, or similar instrument, and compared to several undisturbed, adjacent locations. Decompaction was deemed necessary when the disturbed area range showed more compaction than the undisturbed area.

If restoration areas were compacted a bulldozer, excavator or backhoe was used to loosen the soil to mimic undisturbed conditions. The most common decompaction technique utilized was soil ripping with tines (such as those on a bulldozer) or the teeth on an excavator or backhoe. Ripping occurred prior to topsoil placement, with dry soils, to an average perennial plant rooting depth (~2 ft.), along the contour line of the site. In areas where topsoil was not salvaged but instead mixed with subsoils light track-walking (2-3 passes) with the bulldozer was performed perpendicular to the contours of the site directly after ripping. If the site did not experience any topsoil grading, but decompaction would be beneficial, then great care was taken to not mix the topsoil with lower soil horizons. If there was a potential for soil erosion to occur, erosion control measures such as hydromulching, wattles, wood fibers, or jute netting were installed after recontouring, decompaction and/or topsoil placement.

Lessons Learned—

- Ensure that ripping for decompaction is done in line with the contours of the sites slope. If ripping is done perpendicular to the contours it will most likely lead to soil erosion as water is channeled down the rip lines, creating rills.
- Recontouring and decompaction are best done within a few days of seeding (e.g. hydroseed, imprinting, etc.), which carried out between September to

the middle of December (depending on temperature and precipitation conditions of that season). The soils on the ANF restoration sites tended to develop a thin, hard crust within a few days after recontouring/decompaction (especially after even a minimal amount of precipitation). This crust can make it difficult for seeds to embed in the soil and germinate.

- Erosion control measures must be installed before the first precipitation event to prevent soil erosion.
- Great care should be taken when determining which erosion control measures to utilize and the order in which they are applied. For example a site should not be hydromulched or sprayed with a soil tackifier (e.g. guar) for erosion control and then seeded within the first year. This is because the hydromulch will prevent much of the seed from coming in contact with the soil and greatly decrease germination. Another erosion control material such as wood fibers (applied at less than 40% cover) or wattles should be chosen, as they are compatible with seeding. Similarly, wattles should be placed on a site prior to hydroseeding as the hydroseed material is easily disturbed by foot traffic.
- Work with heavy equipment operators on site to ensure details of recontouring, decompaction, topsoil replacement and trackwalking methods are followed. Do not expect that lengthy restoration plans will be read by those on the ground implementing the restoration.

Chaparral Seeding Techniques

Of the three seeding methods described below, broadcast seeding and hydroseeding can be done without much soil preparation (typically hand tools only). Imprint seeding, however, normally does require soil preparation with the use of heavy equipment (although small areas can be imprinted with a hand imprint tool).

Broadcast Seeding—

***Methods*—**To capitalize on higher soil moisture levels, spreading seed by hand was mostly completed between late October and January 1. Before broadcasting, seeds were mixed with a dispersal agent such as rice hulls or bran to achieve consistent coverage. After evenly broadcasting seeds at the specified rate, they were lightly raked into the soil surface to ensure good soil-seed contact. Seed should not be over-raked as the seed should be buried no further than the length of the longest side of the seed.

Lessons Learned:

- Broadcast seeding has been tried on approximately 40 sites within the past five years. On average, the percent germination and resulting canopy cover of native plants on these sites has been very low (less than 5% cover in year one post seeding), making broadcast seeding the least effective seeding technique across the range of restoration sites. Thus, broadcast seeding is not recommended for reestablishing native cover in a short (under ten years) time frame.
- Two hypotheses as to why broadcast seeding has been ineffective on the ANF is 1) because of high rates of predation by namely birds and rodents and 2) wind dispersal. To mitigate these losses, fall broadcast seeding in 2014/2015 will be covered with wood fibers.

- Broadcast seeding may be the only choice in remote or inaccessible areas where hydroseeding or imprinting is not feasible, or in sites that have minimal impacts such as minor vegetation cutting or trampling.
- If broadcast seeding is the only option, the seeding rates should be 50–75% greater than rates for imprinting or hydroseeding to compensate for losses to predation.

Imprinting—
***Methods*—**Imprint seeding was used in disturbance sites over 50 ft^2 and accessible by equipment (bulldozer and roller). To date roughly 20 sites have been imprinted during the months of November to January. Imprinting was conducted using an imprinting roller with V-shaped angles. The diameter of the roller (20 to 24 inches), the angle length (8 inches) and width (8 to 11 inches), the angle type (straight or bowlegged), and imprinting pressure (15 to 30 pounds per square inch) varied slightly according to site conditions. Imprint size, shape, spacing, and pattern were designed to maximize water concentration and infiltration. Imprinting rollers were towed behind a D4 or D5 CAT sized bulldozer. A drop seeder was attached to the top of the imprinting roller so that seeds were released on the ground before the imprinter rolled over them. Wheat bran, or a similar binder, was mixed with the seed to improve the uniformity of application. Imprinting was always performed before container plants were placed on the site.

Lessons Learned:

- Germination rates and subsequent native plant cover varied from 5-15% across the 20 sites in the first year. Imprinting sites always performed better than areas treated with broadcast seeding. Most likely because imprinting created better soil/seed contact and provided many micro-catchment troughs to collect water.
- To prevent soil compaction, bulldozers or other tracked vehicles pulling the imprinter should not be over the weight of a D4 CAT.
- Compacted or hard soils should be loosened by ripping prior to imprinting to ensure that the imprint troughs are deep enough to retain water. The deeper the imprints the better, since imprints can be washed out by several rain events or one large one.
- Take care to not mix too much bran in the seed mix, as this can clog the drop seeder.
- Do not perform imprinting when soils are more than damp. This can cause soil compaction and/or not allow for deep enough imprint troughs as soil sticks to the imprint roller.
- Perform imprinting well before the first fall rains (September-October) to expose seeds to as much precipitation and other dormancy breaking conditions (freeze, thaw, etc.) as possible.

Hydroseeding—
***Methods*—**Approximately 25 of the restoration sites were seeded using a modified two-stage hydroseed application from late October to late January. The modified method allows for better seed-to-soil contact that is required for good seed germination and reduces the number of trips with the hydroseeding truck (Newton and Claasen 2003, Steinfeld et al. 2007). The application procedure was as follows:

First Application:

- Bran mixed with specified seed mix applied by hand using broadcast seeding method.

Second Application:

- 1,500 lbs./acre of long-strand wood fiber applied by hydroseed truck
- 100 lbs./acre Ecology Control "M" or similar environmentally benign binder applied by the hydroseed truck

All hydromulch mixing was performed in a clean tank. The tank was rinsed a minimum of three times, to remove any undesirable seeds, such as ornamental seeds from a previous hydroseeding job. The hydromulcher was equipped with a built-in continuous agitation and recirculation system of sufficient operating capacity to produce homogeneous slurry and a discharge system that applied slurry to the restoration areas at a continuous and uniform rate. Hydromulch was applied in a sweeping motion and in an arched stream until a uniform coat was achieved, taking care not to create areas of heavy hydromulch accumulation (more than ½ inch thick).

Lessons Learned:

- Hydroseeding helps protect seed from being blown away or eaten, and helps trap moisture in the soil that promotes seed germination. The hydromulch also provides some erosion control by dissipating water over a slope. However, on more than several sites heavily applied hydromulch appeared to accelerate erosion where water did not uniformly penetrate the mulch. This caused water to sheet into openings or at the bottom of sites, which then caused rilling and sediment discharge down the slope.
- Compacted or hard/smooth soils should be loosened and roughened using ripping shanks or similar equipment, prior to hydroseeding to allow for good soil/seed contact and water infiltration.
- The hydromulch slurry should float down from the arched stream, as opposed to being shot directly at the ground to prevent disturbance of the soil and broadcast seeds.
- Preventive measures must be taken to avoid damage to existing native vegetation, container plants, and cuttings (e.g., spraying and covering plants with mulch, breaking stems or branches with hoses). In the event that hydromulch does end up coating existing plants it must be removed the same day to prevent loss of plant growth and productivity.
- Hydroseeding helps protect seed from being blown away by the wind or eaten, and helps trap limited moisture in the soil to promote germination of the seed. The hydromulch can also help provide some erosion control in the areas it is applied by dissipating water over a slope. However, on more than several sites heavily applied hydromulch appeared to accelerate erosion in cases where water was not able to uniformly penetrate the mulch. This caused water to sheet into openings or at the bottom of sites, which then caused rilling and sediment discharge down the slope.
- Based on observations alone it is difficult to say whether imprinting was more effective than hydroseeding because after year one canopy cover was roughly the same (5-15% cover). Both techniques have different advantages. Imprint seeding provides greater soil-seed contact and small troughs for water infiltration that protect and encourage germination. Hydroseeding provides a protective coat on top of the seed that discourages predation and

losses to wind. The best seeding technique, which has yet to be tested on the ANF, is probably a combination of both imprinting and hydroseeding. In other words, after recontouring and decompaction, imprint the site to create pockets in the soil to catch seed and water and then hydromulch over the imprinted area. This would, of course, require the site to be accessible to heavy equipment and reachable by hydromulch hose.

- As with imprinting all hydroseeding effort should be performed before the first fall rains (September-October) so that seeds will be exposed to as much precipitation and other dormancy breaking conditions as possible.

Container Planting Techniques—

After any necessary site preparation is completed container planting may occur. If container plantings are utilized in tandem with a seeding technique it is best to perform the seeding method first, so that the containers are not disturbed.

Methods—

As described in the "Guidelines for Choosing a Plant Palette and Collecting Native Plant Materials" paper of this General Technical R, seeds for container plants should be harvested from areas within 5-10 miles of the restoration site, usually within the same HUC 6 level watershed. Eight of the restoration areas have been planted with container plants, amounting to around five acres total. All planting stock was grown in a southern California nursery for at least nine months and usually closer to one year. Almost all of the container plants used on the restoration sites were in one gallon pots with about a six inch rooting depth. Before transport to the restoration site, container plants were certified free of weeds, disease and invasive insect species.

The container plant quantities and species were specified in the individual restoration site plant palettes. Prior to digging, the locations of the container plants were marked (typically by pin flags) to space the plants in natural-looking patterns. Considerations for the microclimate requirements for each species were also taken into account. On average, plants were installed on 5-7-foot centers for shrubs, with closer spacing for bunch grasses and wider spacing for larger shrubs and trees. All container plants were planted in accordance with the following specifications:

- Chaparral container plants should be planted in the fall/early winter (October1-December 15).
- All planting holes should be augured (although no wheel-mounted augers shall be permitted) or hand dug, have vertical sides with roughened surfaces, and be one and one-half (1.5) times the diameter and twice the depth of the plant's container
- Any roots wrapped around the sides of the containers should be pulled loose from the root balls. Plants should be planted with the roots untangled and laid out in the planting holes to promote good root growth and prevent the plants from becoming root bound
- Roots should be adequately protected at all times from the sun and/or drying winds
- After excavation and before planting, the planting holes should be filled approximately 25% with thoroughly broken up native topsoil and filled with water. Holes should be allowed to drain thoroughly between fillings to reduce settling

- Plants should be set in the thoroughly drained planting holes so that the crowns of the root balls are 0.5 inch above finished grade when backfilled with soil. The soil around the planting should be tamped down sufficiently to eliminate any air pockets in the soil. The root crowns of the plants should not be depressed.
- A watering basin 24 inches in diameter should be constructed around each plant. The basin should be constructed by creating a berm above grade. The soil inside and outside of the basin should be at the same level. The basin should not be a depression in the soil.
- Deep pipes may also be placed next to (within 2-4 inches of the root ball depending on species) the container plant at the time of outplanting. (The deep pipe irrigation method is described below in the "Maintenance" section).
- Each plant should be individually watered at the time of planting with sufficient water to reach the lower roots. Special care must be taken to prevent the soil from washing away from the roots and the root crown from being buried with soil.
- If the plant species is one that is frequently browsed by herbivores (*e.g.* California sagebrush (*Artemisia californica*), California buckwheat (*Eriogonum fasciculatum*), rabbitbrush (*Ericameria nauseousus*), herbivory cages should be placed over the container plant. Herbivory cages should be constructed of chicken wire or similar material that will prevent herbivores from chewing through to the plant. Cages will be a minimum of 2 feet above ground. Cages should be removed before they hinder plant growth.

Lessons Learned—

- Optimal planting periods of chaparral species on the ANF vary by elevation and weather patterns. Most outplantings occurred in early December. This was adequate timing in poor rain years, but not ideal in good rain years because the plants missed several fall rain events, meaning more supplemental watering was needed. Two restoration sites over 5000 ft in elevation that had containers put out in late December and early January were not successful, most likely due to frost kill and a lack of adequate acclimatization prior to planting. In normal or above average rain years it appears to be best to outplant in mid to late October before the first fall rains for all elevations. In poor rain years it may be best to outplant from late October to early November at elevations over 5000 ft., but to wait till mid-November for lower elevations.
- Container plants in the standard nursery "one gallon" pots (~6 inches in depth) are not the ideal planting size for arid restoration. This is because the root system of plants in these short pots is typically not adequate to support the robust above ground foliage grown in the nursery in extremely dry outplanting conditions. In the future the ANF plans to use more deep rooted plants, which should be grown in tree pots (~14 inches tall). The goal will be to have fully developed roots filling the container with a good root-to-shoot ratio (approximately 3:1). Better developed roots with less above ground foliage to support should be more successful and require less watering (which is often exorbitantly expensive).

- Container plants should have had at least a month of exposure to outdoor conditions similar to the climate of the restoration site to ensure that hardening off (or acclimatization) has occurred.
- Repellents to prevent herbivory are not recommended as they have not proven to be an effective deterrent.
- Literature shows that tree/shrub shelters greatly enhance the growth of plants by providing increased moisture and watering ease and protection from wind, and sunlight and heat radiation (Bainbridge 2007; Steinfeld et al. 2007). The ANF has not yet used tree shelters for chaparral species, but they are proposed for upcoming restoration sites, especially those sites receiving chaparral oak and tree plant species.
- Increase container plant numbers by at least 20% to ensure an adequate number of plants will survive.
- Covering the water basin around container plants with mulch or wood fibers increases moisture retention.
- Restoration sites with container plants outperformed all seeded sites, with container plant areas reaching an average of approximately 30-40% cover by the first year (gaining ~10% each year after in normal rain years). This most likely is due to 1) the lack of reliance on inconsistent field germination; 2) the inherently larger canopy cover containers supply and 3) the reduced weed proliferation from the increased competition for light and nutrients that containers provide.
- It is best to use long lived perennials, species that require specialized seed treatments for germination (e.g. heat, smoke, scarification), and/or late seral species in the container planting palette, as these species are often hard to establish by hydroseeding or imprinting and can typically only be reintroduced to a site in a timely manner (less than 10 years) by plantings. Annuals, short lived perennials, species with high seeding germination rates and early seral species are all more efficiently and cost effectively restored in the field by seeding techniques.

Restoration Maintenance Techniques

After the initial seeding or container plant installation maintenance activities are needed to ensure successful restoration. The maintenance techniques of watering and weed control are described below. Watering is only done for container plantings on the ANF, but it can be used for seeded areas if funding is adequate. Weed control is essential on all restoration sites, regardless of the site preparation done or the seeding/planting technique employed.

Watering—

Methods—Supplemental irrigation is necessary to ensure successful establishment and growth of container plants. Seeded areas were never watered in any of the restoration sites. The frequency and amount of watering depends on the type of irrigation utilized, the plant species, site accessibility and funding. The two types of watering techniques utilized are described below:

- Deep pipe watering: Deep pipes are vertical plastic pipes (typically 2 inches in diameter and 14 inches in height) with holes drilled in them at different depths that are inserted next to container plants to allow irrigation water into the deep root zone. This improves water delivery to the plants' roots and minimizes water evaporation and weed growth. A cap or screen is put over the top of the pipe to discourage wildlife and debris from entering. Deep pipes can be filled by a water truck hose, watering can, or a drip emitter with pulsed irrigation from a remote storage tank or water truck hookup. On the ANF only one site has had deep pipes installed and they were watered by a water truck hose. The schedule for the deep pipe watering should be as follows: In the first year after planting, container plants watered (typically 1-2 liters) twice per month every month of the year if no rain event occurs. The rain event should measure at least 1 inch to obviate the need for supplemental water. In the second year after planting, container plants should be watered twice per month, if no rain event occurs, between May and October. In the third year after planting, container plants should be watered once every two months starting in June and ending in October. In the fourth year after planting, container plants should not need to be watered, unless it is an extremely dry year.

- Surface watering: Watering is done using a hose or PVC pipe connected to a water truck or water storage tank. Water is applied using a shower head-type nozzle capable of providing low –pressure application to prevent erosion or damage to the plantings and planting basins. On the ANF seven restoration sites were surface watered by hoses hooked up to water trucks. The schedule for surface watering utilized the same schedule described for deep pipe watering only plants should receive 1-2 gallons per plant during each watering event. More water is needed in surface watering in order to ensure percolation down to the root systems.

Lessons Learned:

- On the one restoration site fitted with deep pipes the watering schedule outlined above was followed for the first five months after installation, but in the middle of summer watering stopped and the plants died in less than a month. However, prior to the cessation of watering, the plants seemed to be faring well. In addition, literature shows that deep pipe watering has been three times more effective at increasing plant survival growth than surface watering (Bainbridge 2007, Steinfeld et al. 2007). In the future the ANF plans to test more deep pipe watering to see it is indeed more effective and cost efficient than surface watering.
- At least one deep pipe should be installed for each container plant; otherwise plants do not receive enough water.
- Do not water when there is a chance of freezing. This is especially harmful to newly planted plants that are not fully acclimatized.
- Take care to not overwater. Most chaparral species are accustomed to low water availability and can die from prolonged overwatering. Of the "workhorse" container plants listed in Table 1 this seems to most affect yucca.
- For long, linear restoration sites consider utilizing the mainline irrigation technique, which involves setting up a PVC main waterline down the length of the restoration site with valves every 50-100 feet to allow for hose or drip access to all container plants. On the ANF this was recently installed over

1000 feet of a restoration site and has more than adequate water pressure when hooked to a water truck.

- The watering schedule described above is a best case scenario. However, even though it has provided the best success rates (close to 70-80% survival) on four of the restoration sites, container plantings on three other sites have received roughly half as much watering and have a 50-60% survival rate. Given that watering installation and maintenance is the biggest cost in container plant restoration, the ANF is currently trying reduced watering schedules on several new sites to see if less water application is economically efficient.

Table 1—Workhorse container plant species for chaparral ecosystems restoration on the Angeles National Forest, California.

Species	Common name
Adenostoma fasciculatum	chamise
Arctostaphylos glandulosa, A. glauca	Eastwood manzanita, bigberry manzanita
Artemisia californica, A. tridentata	California sagebrush, big sagebrush
Atriplex canescens	four-wing saltbrush
Cercocarpus betuloides	birchleaf mountain mahogany
Encelia actonii, E. californica, E. farinosa	encelia
Ericameria nauseousus	rabbitbrush
Eriodictyon crassifolium	yerba santa
Eriogonum fasciculatum	California buckwheat
Hesperoyucca whipplei	chaparral yucca
Malacothamnus fasiculatus, M. fremontii	chaparral mallow
Peritoma arborea	bladderpod
Salvia apiana, S. mellifera, S. leucophylla	white, black and purple sage
Sambucus nigra ssp. *caerulea*	elderberry

Weeding—

***Methods*—**Weeding of non-native plant species was a key maintenance component for all restoration sites. All non-native plant species were targeted for removal, but especially invasive species (see Table 2 for a listing of the most common weed species removed). Weeding was accomplished by one of three methods: hand-pulling, mechanical or herbicide removal. The three methods are described in detail below

- Hand-pulling: Removal was accomplished by taking out the entire plant (roots, stems, flowers, seeds) by hand. Hand removal often included the use of trowels or other digging equipment to remove roots. Hand-pulling of sites was typically done four to five times in a growing season (late February through mid-June, depending on elevation), since some plants resprouted and different species germinated at different times.
- Mechanical: Removal was done by weed whipping or cutting the tops/seed heads off non-natives before they produced viable seed. This was typically done at least three-four times in a growing season as the root system of non-natives is not touched.

- Herbicide: Removal was completed by spraying non-natives with a Forest Service approved herbicide using a foliar, cut stump, or basal bark method (depending on the species, plant stature and time of year). Approved herbicides were glyphosate, triclopyr, chlorsulfuron, imazapyr and clopyralid. Herbicides were only used when weather conditions were conducive to effective uptake of the herbicide by the targeted species (e.g., sunny, dry, and when plants are actively growing) and when wind conditions were such that herbicide drift was nonexistent (at or below the threshold for continuous wind speeds as specified on the product label). Applications of herbicide did not occur 24 hours prior to or following precipitation events. Where riparian areas were present, only water-safe herbicides and surfactants were utilized. All herbicide used was applied in accordance with State and federal regulations and mitigation measures specific to the restoration site. Restoration sites typically were treated two to three times during the growing season to catch newly germinating weeds.

Table 2—Most common non-native plant species removed from restoration sites on the Angeles National Forest, California

Species	Common name
Avena barbata, A. fatua	wild oats
Bromus diandrus	ripgut brome
Bromus hordeaceus	smooth brome
Bromus madritensis ssp *rubens*	red brome
Bromus tectorum	cheat grass
Centaurea solstitialis	yellow star-thistle
Centaurea melitensis	tocalote
Erodium botrys, E. cicutarium	filaree
Festuca myuros	rattail fescue
Hirschfeldia incana	shortpod mustard
Lactuca serriola	prickly lettuce
Medicago polymorpha	bur clover
Melilotus officinalis, M. alba	sweetclover
Nicotiana glauca	tree tobacco
Polypogon monospeliensis	rabbitfoot grass
Salsola tragus	Russian thistle
Schismus barbatus	Mediterranean grass
Sisymbrium altissimum, S. irio	mustard
Spartium junceum	Spanish broom
Stipa miliacea	smilo grass
Festuca myuros	rattail fescue

Lessons Learned:

- It is crucial to conduct weeding several times during the growing season, well before seed is produced, regardless of the weed removal method chosen. Hand pulling and mechanical weeding should be carried out at least 4-5 times and herbicide applications at least 3 times per season to ensure that all non-natives are removed. Timing depends on the precipitation and temperatures of the growing season for a particular year, but in general, the best times appear to be early February, following up in mid-March, then early April and a finishing round in late April/early May. Weeding must be maintained for several years. In areas with weed coverages less than 15-20%, weeding may only be required for three years (if conducted at the correct times so that seed is not produced). However, in areas that had greater than 20% weed cover or that did not receive proper weeding at the correct timing, removal may be necessary for six to ten years.

- Care must be taken with herbicides to not impact nearby natives. This can be difficult, especially when restoration has just begun and newly germinating plants are small and close together. Early herbicide application in February is key as many natives have not yet germinated, but many non-natives are actively growing.
- Hand-pulling and mechanical weeding techniques were the only means of removal on the restoration sites until 2012. This four year period of hand/mechanical weeding provided ample time to show that the efficacy of these techniques was typically low. This was due to 1) the lengthy time and manpower it took to remove the non-natives by hand (typically herbicide removal took a half to a quarter of the time and manpower); 2) the inability to adequately remove roots, which led to resprouting; and 3) the propensity for weed whipping to also harm nearby natives and actually spread weed seed if not done at the right time of the season. Because herbicide is so much quicker to apply, it typically kills the entire plant and there are ways to mitigate harm to nearby natives, it is the most efficient and effective means of weed removal.
- Of all the restoration techniques weeding is by far the most important. Several sites on the ANF have recovered native vegetation in a few years without any seeding or container plants if the non-native cover is kept lower than 5%. When weeding has not been done at the correct time of year or at all native recovery has been stunted (less than 15-20% coverage) or non-existent, no matter how much seeding or container planting has been completed.
- It is important to remove all non-native invasive species. This applies to common weeds like cheatgrass (*Bromus tectorum*), shortpod mustard (*Hirschfeldia incana*) or filaree (*Erodium* spp.), which have the most potential to overrun/outcompete natives, especially in seeded areas.
- In areas that have over 25% cover of non-natives consider only weeding for the first year of restoration, especially if the plan is to seed the area. This is called a "grow/kill cycle", which allows for the first large flush of weeds to germinate followed by removal over one growing season, thus depleting the amount of weed seed in the seed bank. This will give the native seed applied the following year to have less competition and a better chance of survival. It is also easier to apply herbicide the first year without the concern of herbicide drift to natives. If the non-native cover is particularly high it may be beneficial to go through two "grow/kill cycles."

Conclusions

The most important factors influencing the success of chaparral restoration are the adequacy of planning, weather patterns, hydrology and soil conditions, pre-project invasive plant infestations, availability of materials and personnel, and, as always, cost. The highest performing restoration sites on the ANF have been those that either had a low presence of non-natives beforehand or had aggressive weed control in the first two/three years of restoration, combined with the use of adequate amounts of genetically appropriate, early seral native plants introduced to the site as container plants at the correct time in the early fall and watered consistently. Hydroseeding and imprinting can be effective restoration techniques as well in sites with less than 25% preexisting weed cover, if adequate amounts of PLS seed (around 30 pounds) are applied before the first fall rain (September-October) and the soil is decompacted and furrowed (has pockets/depressions where water can collect).

In the future, the ANF will continue to test new techniques or combinations of techniques, timing, and maintenance schedules in order to determine the most efficient and effective chaparral restoration methods. However, it must always be recognized that every potential restoration site is different and possesses its own unique microclimate and site attributes, meaning that a restoration technique may perform well in some locations, but not as well in others that may seem very similar. Research to statistically quantify and compare the efficacy of these different restoration techniques under a wide variety of site conditions is needed, so that land managers can rely on more than anecdotal or qualitative data to make the most informed restoration decisions.

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