Restoring Redwood Forests

Reforestation of the Welden and Lompico Parcels
2015 Annual Report

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Prepared for
The Sempervirens Fund
Los Altos, California

December 2015

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Introduction

To restore redwood forestlands, the Sempervirens Fund purchased two home sites located deep within the redwood forest, referred to as Lompico and Welden, and removed all existing structures. The Lompico site is located on the headwaters of Lompico Creek above the small town of Lompico and is located within the San Lorenzo River Watershed. The Welden site is located in the South Fork Watershed of Gazos Creek just northwest and downslope of the Chalks Ridge area and near the border between San Mateo and Santa Cruz Counties. Each developed site was about ½ acre or less, and had one or more structures.

The structures were demolished in the 2000s and a few years later a soil assessment was done and the sites were evaluated for their reforestation potential (Singer 2010, Singer 2009). These reports found unusual and extreme soil conditions to be present at each site. The Lompico site had the worst potential for revegetation as all topsoil had been removed by extensive grading and filling, and the remaining substrate consisted of pulverized construction debris and finely-ground rock. The capability of this “soil” to hold water or nutrients for plant use (i.e., available water-holding capacity and cation exchange capacity) was almost nil. Soil at the Welden site was better, although portions of the lot had been scraped down to bedrock and other portions had been piled fairly deep with loose fill. A worse problem was that the soils there were highly acidic, having a pH value of 4.3. Some trees cannot survive in a pH this low, and those that can survive will have their growth rate retarded.

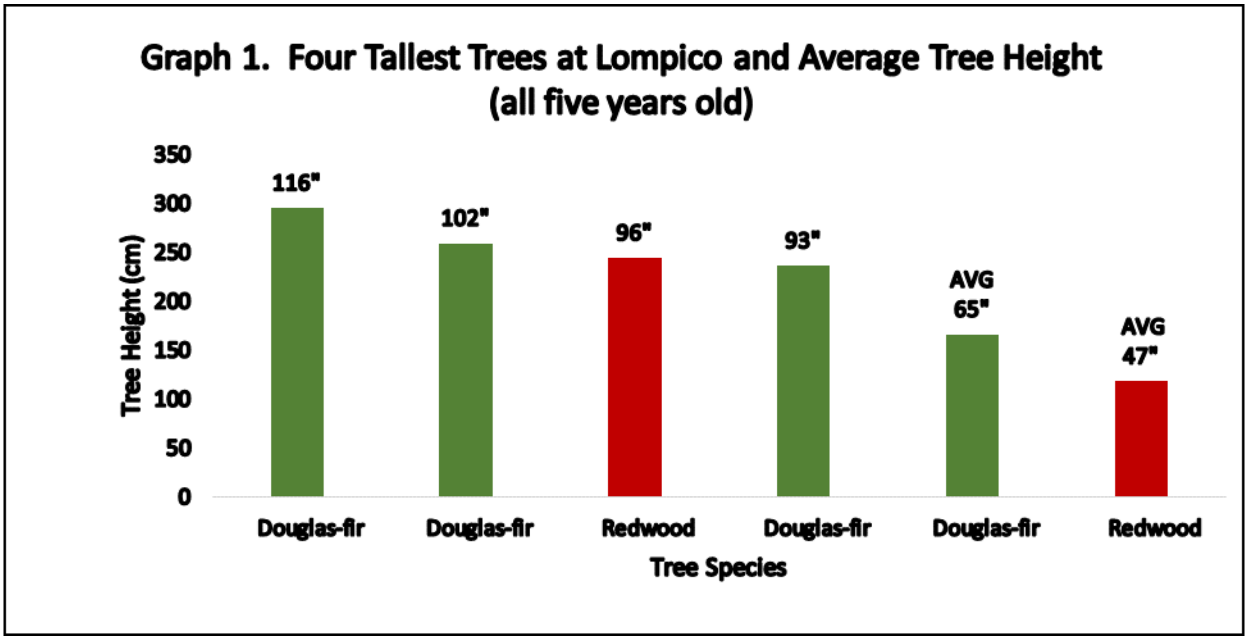
A reforestation plan using primarily redwood (*Sequoia sempervirens*) and Douglas-fir *Pseudotsuga menziesii)* was prepared for each site that used only local ecotype trees and included special measures to ameliorate the extreme soil conditions at each site. A presentation on the new and innovative planting techniques used was made at the 2011 Coast Redwood Forests in a Changing California conference (Singer, Schettler, and Hebert 2011). The Lompico site was planted in the fall of 2010 and the Welden site was planted in the fall of 2011. Both sites have been irrigated, weeded as necessary, and regularly monitored since then. Management and monitoring of the Welden site ended in October of 2015. This report describes the progress to date.

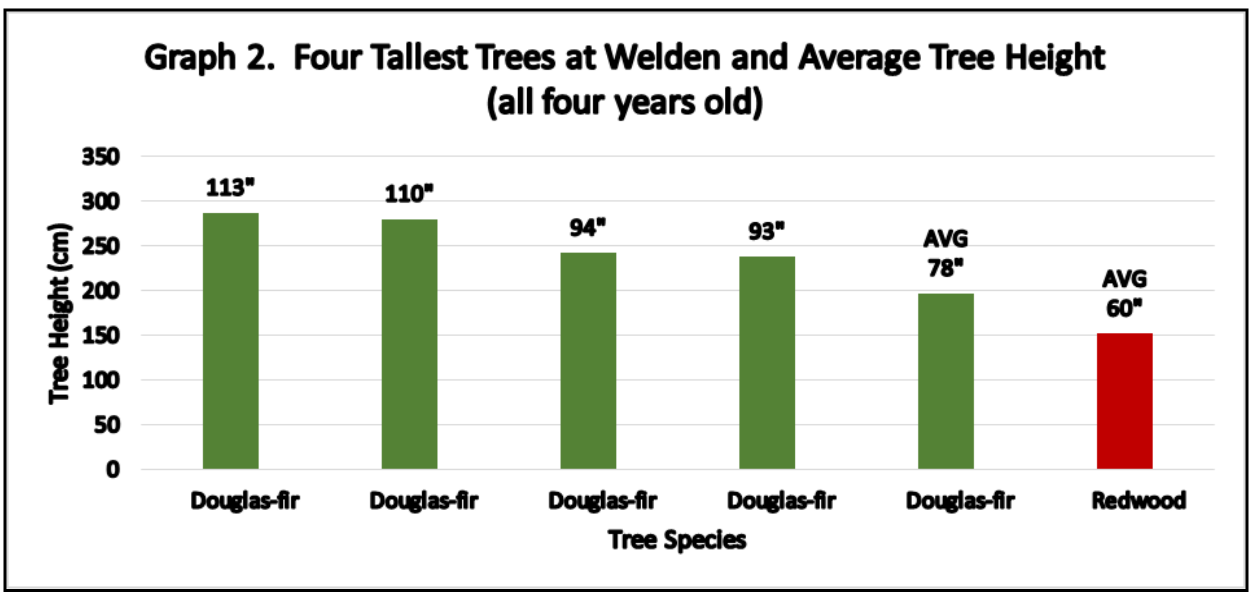
Overall Condition of Reforestation Efforts

The majority of trees at both the Lompico and Welden reforestation sites grew at least 15 cm (6") in height last year and several grew more than 45 cm (18”). Douglas-firs are growing faster than redwoods at both sites and both Douglas-firs and redwoods at Welden have significantly increased their growth rate this year. This is also true for redwoods at Lompico.

The four tallest trees at each site are shown in Graphs 1 and 2. It can be seen that two of the tallest trees at Welden, although one year younger, are taller than all but the tallest Doug-fir at

Lompico.   Douglas-firs at Welden are growing significantly faster than Douglas-firs at Lompico, likely because the soil conditions at Lompico were so bad. The average annual growth rate for all Douglas-firs at Welden was 39.9 cm (15.7") compared to Lompico, which was 30.2 cm (11.9").   The value for redwoods at Welden was 26.6 cm (10.5") while redwood growth each year at Lompico averaged 23.8 cm (9.3").   The yearly growth rate for each species at each site is shown in Table 1.

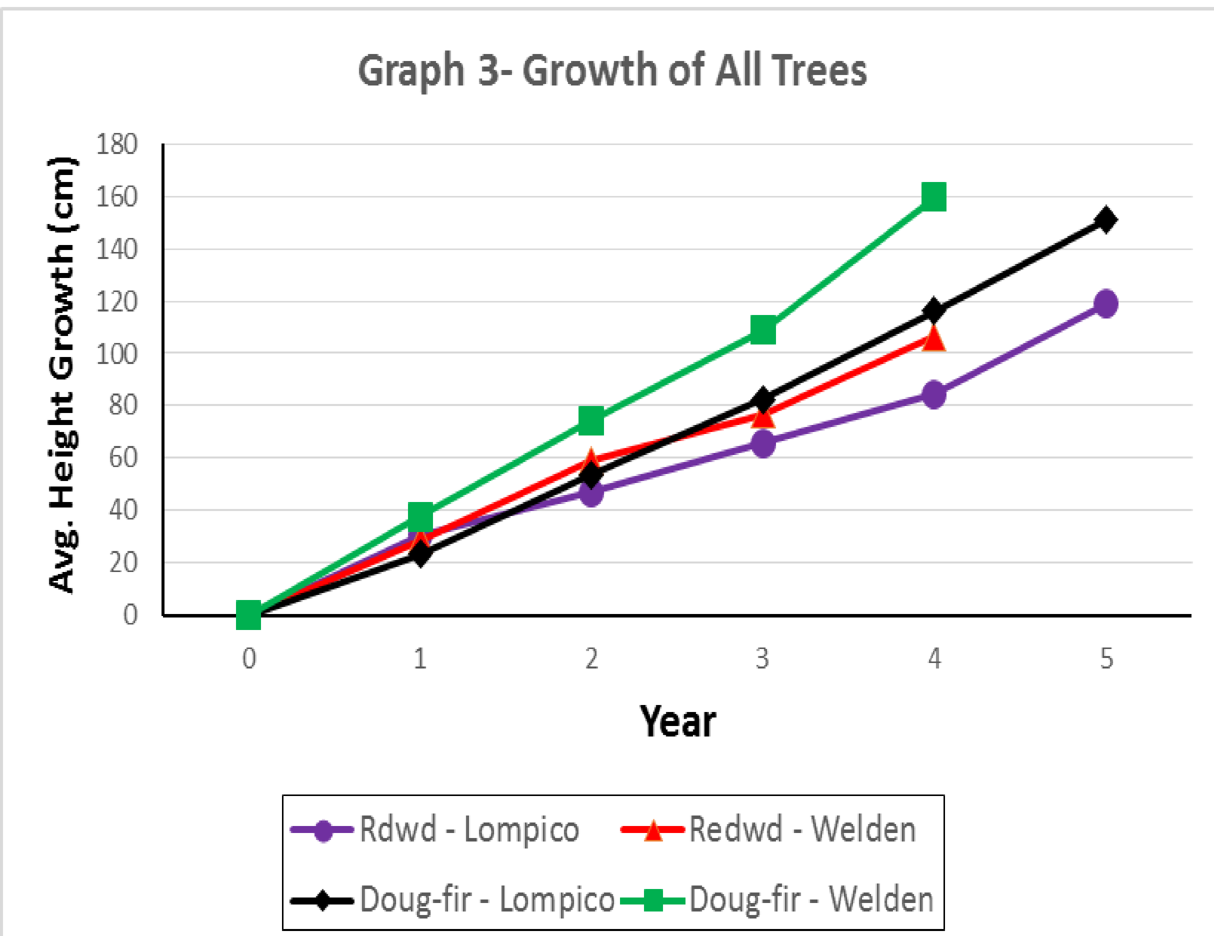




Graph 3 shows cumulative height growth for all trees broken down by species and site, although data from dead or dying trees was not included. (Note: Mortality rates are provided in Table 2).

Table 1. Average Yearly Growth of All Trees (Cm)

Year	Redwoods – Lompico	Redwoods- Welden	Douglas-firs – Lompico	Douglas-firs – Welden
0-1	30.5	28.6	23.4	37.8
1 – 2	16.6	30.6	30.2	36.7
2 - 3	18.5	17.6	28.9	34.3
3 - 4	18.9	29.6	33.8	50.8
4-5	34.3	--	34.5	--
Avg. Per Year	23.8 (9.3”)	26.6 (10.5”)	30.2 (11.9”)	39.9 (15.7”)



Two main findings are evident from Table 1 and Graph 3. The first is that Douglas-firs grow faster than redwoods. The second is that trees at Welden grew faster than trees at Lompico. These differences were discussed in last year's report and are not elaborated further here.

When one looks at individual tree growth rates and not the average growth rate of groups of trees, one finds that for most trees, individual growth rate varied from year to year. A tree might grow rapidly one season and then slowly the next season. Some trees that were growing slowly initially experienced rapid acceleration of growth in later years. Of the four tallest trees at both Lompico and Welden, three trees experienced big growth spurts in the 2015 growing season. One of these was the second tallest Douglas-fir at Welden which grew 84 cm (33") in 2015. This was the most growth of any tree that year. The reason for this uneven long-term growth rates is unclear. However, this pattern of growth is consistent with the hypothesis that a tree's growth rate would decrease as it used up the initial fertilizer in the planting hole, and would increase when its root system "found" and began to use other resources, then decrease again if new stressors were encountered.

Tree Mortality and Tree Health

Trees that died were excluded from Table 1 and Graph 3, but are shown in Table 2 below. Notice that at Welden, in addition to redwoods and Douglas-firs, five knobcone pines (*Pinus attenuata*), five Pacific madrones *(Arbutus menziesii*), and three California nutmegs (*Torreya californica*) were planted.

Table 2. Individual Tree Mortalities at Lompico and Welden

Site	Mortalities Summer 2011	Mortalities Summer 2012	Mortalities Summer 2013	Mortalities Summer 2014	Mortalities Summer 2015
Lompico	3 redwoods 3 Doug-firs Subtotal = 6	1 Doug-fir 1 replanted redwood Subtotal = 2	None Subtotal = 0	None Subtotal = 0	None Subtotal = 0
Welden	Not planted until the following fall	1 knobcone pine 1 madrone Subtotal = 2	1 Calif. Nutmeg 1 madrone Subtotal = 2	3 redwoods 1 Doug-fir Subtotal = 4	1 madrone Subtotal = 1

Over the course of the project, there have been 8 mortalities at Lompico and 9 mortalities at Welden (but of those only four were in redwoods or Douglas-firs). If one discounts the three madrones that died at Welden, since madrones are notoriously hard to transplant, the mortality rate at Welden would be lower, and especially the first year mortality rate, which was two instead of the six mortalities at Lompico. Not every dead tree was replaced and currently there are 33 living trees at Welden where 40 were originally planted. More replacement trees were planted at Lompico than at Welden and currently there are 48 living trees at Lompico (where 50 were originally planted).

The four trees that died in 2014 were on very poor quality micro-sites. The redwoods were planted on loose fill in a shaded location, and the Douglas-fir was planted into pulverized bedrock. Micro-sites are important and have a significant influence on tree growth and survival.

Beginning in the summer of 2014, some trees outgrew their 30-inch diameter anti-browse cages. When lateral branch growth was restricted and branch tips began to be deformed, the cage was removed. At Welden, four cages were removed in the fall of 2014 and four more in the spring of 2015. As a result, several trees were subject to minor browsing of their branch tips by deer. However no serious damage was done since the leader and upper branches were too high to be browsed. Nevertheless, this browsing episode showed the value of using the anti-browse cages. If smaller trees had not been protected, their growth could have been significantly impaired by deer browsing.

One un-caged tree at Welden received a different type of deer damage. A buck apparently used the trunk of a knobcone pine for antler rubbing, causing significant damage to the tree. Fortunately this was just a one-time event and the tree has largely recovered since then.

Gophers were not a problem at Welden, but did cause some problems at Lompico, leading to the loss of several seedlings during the first year or two.

There are two trees at each site that have shown little growth and remained small. These are all located on poor micro-sites and their future is uncertain. They seem to be on a holding pattern between life and death. Some will likely die in future years. However, monitoring over the length of the project has revealed that some of these stagnant trees may suddenly start growing rapidly – perhaps because their root system finally found a nutrient source or belatedly formed a mycorrhizal relationship. For example, one Douglas-fir at Lompico had zero height growth for three straight years, then grew 17 cm this last year.

<u>Welden and Lompico Project Conclusions - With an Emphasis on Welden</u>

The Welden reforestation project ended in the fall of 2015. On October 1, the last irrigation was applied to the trees and the entry road to the site was removed shortly thereafter.

Although the number of trees planted was too small and the site variability was too great to allow quantitative analysis of the results, there are some obvious findings and best management practices that can be stated. These are listed below.

1. Understand the physiology and ecology of tree growth – In designing a reforestation project, it is important to incorporate, as we did, two basic principles of tree seedling growth and establishment. These are:

(1) The act of planting and the first few years after planting comprise the most critical period in any revegetation project. Best management practices need to be applied during this

period as it is a crucial time for growth and establishment of the root network. A healthy root system will, in turn, create the conditions that will support long-term survival and growth.

(2) Once the tree reaches a certain age, perhaps 4 – 5 years old, the root network and mycorrhizal network should be well established, and the tree will acquire the capacity to alter its soil environment to better suit itself. So getting to this point is crucial.

2. Site soil evaluation -- Conducting a thorough soils analysis before developing a reforestation plan is money well spent. At Welden, the soils evaluation found the soils to be extremely acidic (pH = 4.3). Normal soil acidity levels would be 5.7 to 6.5, and at Lompico, the pH level was 6.0. Many plants cannot survive at a pH of 4.3, and those that do have their growth slowed. Knowing this allowed us to use soil amendments (shell flour, biochar) to modify the soil pH level. This allowed our planted trees to gradually adjust to these extremely acidic conditions. The use of local ecotype seed is also important in situations like this, and our use of same was likely another reason why our plantings were successful.

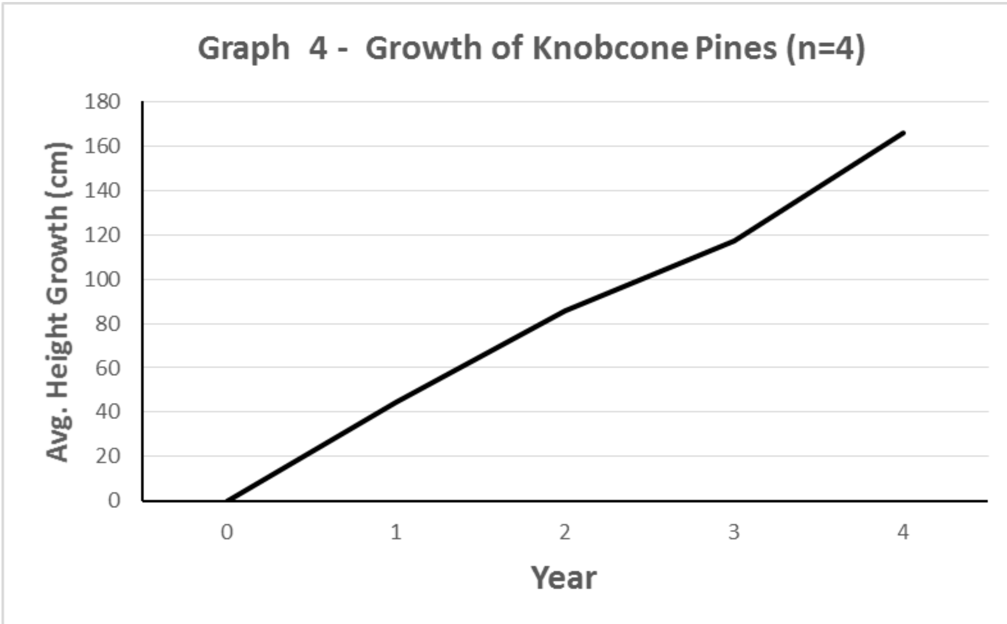
3. Ameliorate adverse soil conditions – The planting measures that we took were beneficial. These included: plant hole soil amendments (including biochar and mycorrhizal inoculants), species-specific mulching, use of delayed-access plant resource pockets, four-foot high anti-browse cages, weeding around the base of each tree, and especially, regular irrigation during the dry season.

Although irrigation was one of the most helpful measures, it should be noted that irrigation alone cannot overcome problems associated with soil acidity (as we had at Welden) and extremely low cation exchange capacity (which is the ability of soil to supply nutrients for plant growth) which we had at Lompico. Either one of these conditions, if untreated, could have led to total project failure. The planting methods and soil amendments used at Lompico are provided in the Appendix, and the methodology used at Welden was similar, with the exception of some important additional measures made to treat the soil acidity problem.

4. Match tree species with appropriate micro-sites - In addition to the use of planting hole and resource pocket soil amendments, the quality of the selected planting location micro-sites was also very important. Key factors were the presence or absence of native topsoil, the presence or absence (and condition) of the subsoil, the overall depth of the soil, and the proportion of direct sunlight to shade. It should be noted that under regular irrigation, sites exposed to full sunlight will produce the best tree growth.

The Welden site had a mix of good, mediocre, and poor planting micro-sites, as did Lompico – although good sites were rare at Lompico. The good sites tended to produce the fastest tree growth while the poor quality sites were known to have smaller trees, and were associated with most of the mortalities. Neither Douglas-fir nor redwood did well on the poor micro-sites, but knobcone pine was able to survive and even thrive on these sites once established (see Graph 4 which shows cumulative growth in height).

Matching of tree species' capabilities with micro-site conditions is a good practice, and is another reason to make a thorough site evaluation before planting.



5. Findings – Tree Survival and Density – A total of 30 redwoods and Douglas-firs were planted at Welden (including replacement trees) and 25 remain alive today for a survival rate of 83%. At the Lompico site, 56 redwoods and Douglas-firs were planted and 48 remain alive today for a survival rate of 86%. The density of surviving trees at each site is higher than would normally be found in a mature redwood forest, so if a few trees die after irrigation is stopped, the tree density will still be satisfactory. In addition, there is a very slow natural recruitment of Douglas-fir seedlings and redwood seedlings occurring on the edges at Welden, especially along the north edge of the property. This is a good sign that full recovery of the forest will occur in time.

6. Findings – Trees grew faster at Welden than Lompico, and Douglas-firs grew faster than redwoods at both sites - Both tree species grew well at Welden, and if one considers the poor site conditions at both sites, tree growth rates were exceptional. At Welden, over the four years of the project, the average annual growth rate for redwoods was 26.6 cm (10.5 inches) and for Douglas-firs it was 39.9 cm (15.7 inches). Welden also produced a Douglas-fir that was 9.4 feet tall (with an average annual growth rate of 2.4 feet), and a redwood that was 7.4 feet tall (meaning an average annual growth rate of 1.85 feet). At Lompico the average annual growth rate for redwoods was 23.8 cm (9.4 inches) and for Douglas-fir was 30.2 cm (11.9 inches). The tallest Douglas-fir at Lompico is an amazing 9.7 feet tall, meaning it grew at the rate of almost two feet per year. The tallest redwood was 8.0 feet tall.

Graph 3 shows that Douglas-firs grew faster than redwoods at both sites. Despite being one year younger, trees at Welden have outgrown trees at Lompico.

7. Findings – Fate of other tree species planted at Welden – Five knobcone pines were planted at Welden. One died and the other four are doing well (see Graph 4). In fact, all four of these trees are now over 5.0 feet tall. This species would be a good choice to use on poor planting micro-sites where little or no soil is remaining.

Also planted at Welden were 3 California nutmegs and 5 madrones, but these two species have not performed well. The madrones are prone to early mortality and three have died. Two California nutmegs have survived, but one of these is doing very poorly. Neither of these species seem to be well-suited for reforestation projects.

Conclusion

Reforestation of severely disturbed redwood stands can be accomplished with the suite of special planting techniques we developed and if a dry season maintenance regime of irrigation and weeding is implemented over the first few years.

References Cited

Singer, Steven, Suzanne Schettler, and Aaron Hebert 2011. A New Technique for Planting Redwoods on Severely Degraded Sites. Poster paper presented at the Coast Redwood Forests in a Changing California conference held in Santa Cruz, CA., June 21 – 23, 2011 (provided in the Appendix).

Singer, Steven. 2010. A Soils Investigation and Site Assessment for the Welden Parcel. Unpublished report prepared for the Sempervirens Fund. Steven Singer Environmental & Ecological Services, Santa Cruz, CA.

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Appendix

On following two pages – "A New Technique for Planting Redwoods on Severely Degraded Sites" which describes the planting methodology used at the Lompico site, and, on the second page, the drawing, "Redwood Planting Technique".

APPENDIX

A New Technique for Planting Redwoods on Severely Degraded Sites

Steven Singer, (Steven Singer Environmental and Ecological Services,SWSingerMS@aol.com), Suzanne Schettler, (Greening Associates), and Aaron Hebert, (the Sempervirens Fund).

We planted Coast Redwood (*Sequoia sempervirens*) and Douglas-fir (*Pseudotsuga menziesii)* on the Lompico project site, a one-half acre building demolition site in the Santa Cruz Mountains that had previously been subjected to cut-and-fill grading. Most areas of the site lacked any of the original soil and had a planting substrate that consisted of pulverized sandstone and construction rubble. This "urban soil" was compacted and was extremely deficient in organic matter and nutrients.

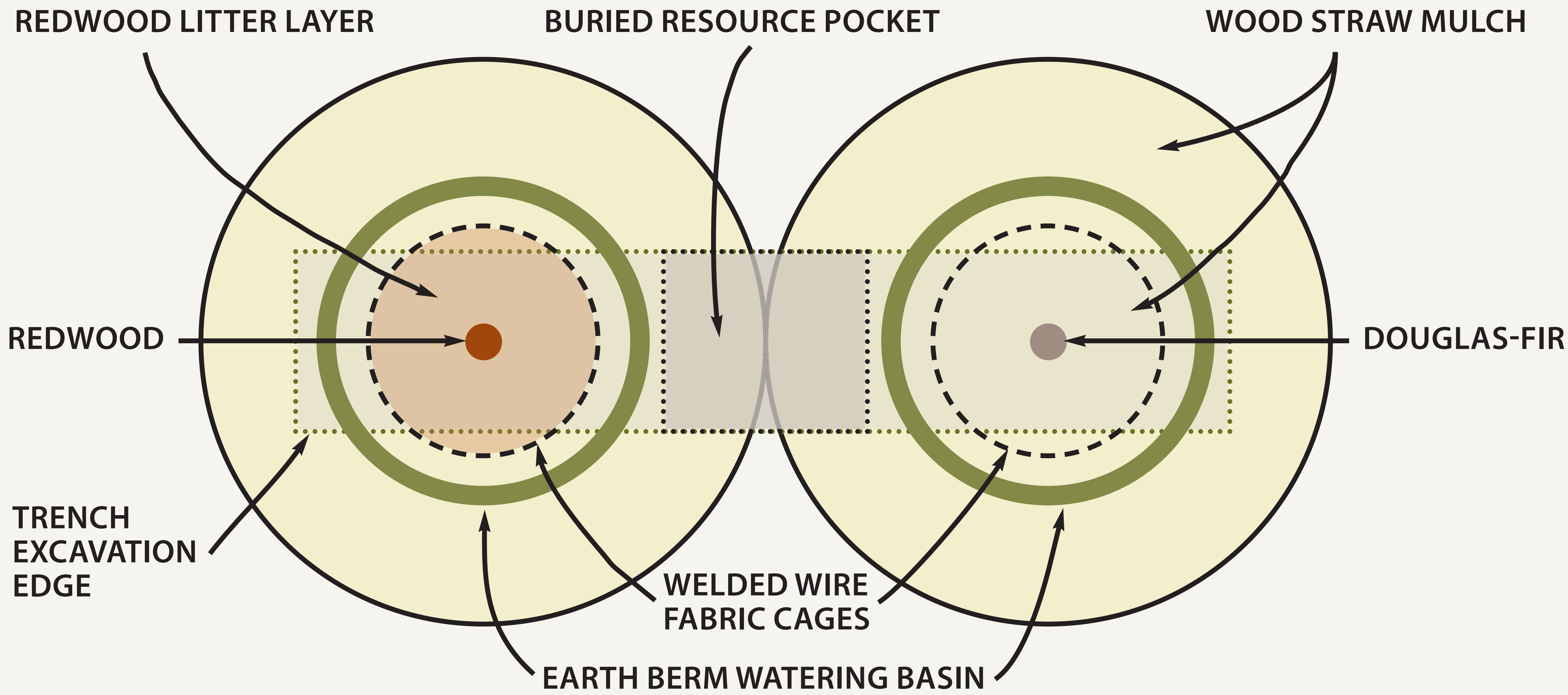
We planted 30 redwood seedlings and 20 Douglas-fir seedlings, grown from seed collected locally, in pairs six feet (1.82 m) apart in loosened soil. Fertilizer and forest soil mycorrhizal inoculum were added to each planting hole. Since the urban soil was unsuitable for tree growth, we augmented normal planting techniques by creating pockets of nutrients and organic amendments within reach of the expanding root systems of planted trees. Except for controls, each pair shared a 2.0 cubic foot (0.056 cubic meter) resource pocket that we placed midway between the two trees. The resource pocket consisted primarily of organic compost but with a layer of cottonseed meal (0.97 kg) below, and below that a layer of biochar (0.82 kg) (see diagram).

To encourage development of a normal forest litter layer, which is crucial for building fertile forest soil, we relocated a one-inch (2.54 cm) layer of redwood forest litter collected from the adjacent undisturbed forest around each redwood seedling in an 18-inch (45.7 cm) radius circle. To restore organic matter to the soil and provide a food source for fungi, we also used wood straw as surface mulch. The wood straw was placed in an 18-inch (45.7 cm) wide doughnut ring around the litter layer mulch. Douglas-fir seedlings were also centered within a 36-inch (91.4 cm) radius mulch circle, but it was composed entirely of wood straw (0.1 bale).

The main innovation of our treatment was to create nutrient resource pockets in the soil. An additional innovative measure that we used was to add biochar to the planting hole and surrounding soil. Biochar is a type of charcoal made by pyrolysis. This process does not release carbon dioxide, but instead locks up almost all the carbon in the biochar. Biochar has been shown to dramatically increase some types of plant growth while sequestering carbon in the soil. About 0.8 lbs (360 g) of biochar was mixed into the loosened soil around the planting hole, and 0.1 lbs (45.4 g) were added as a layer in the bottom of the planting hole.

This project was funded by the Sempervirens Fund, a non-profit 501(c)(3) organization whose mission is to protect and permanently preserve redwood forests, wildlife habitat, watersheds, and other important natural and scenic features of California’s Santa Cruz Mountains, and to encourage public appreciation and enjoyment of this environment.

PLAN VIEW – Redwood Planting Technique



SIDE VIEW –