FINAL REPORT

An Evaluation of Potential Effects on Old-Growth Redwoods from Implementation of the Richardson Grove Operational Improvement Project

TREE DECISIONS

September 16, 2013

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TREE DECISIONS

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I. EXECUTIVE SUMMARY

My professional opinion is that no significant detrimental impact on old-growth redwoods *(Sequoia sempervirens)* would result from implementing the Richardson Grove Operational Improvement Project.

This opinion is based on:

- 3 decades of experience evaluating redwoods as a practicing and consulting arborist (see Appendix A);
- extensive review of the scientific literature on coast redwood biology, ecology, and resilience;
- multiyear examination of old-growth redwoods at Richardson Grove State Park, including a helicopter overflight session to evaluate tree crowns;
- consultation with California Department of Transportation (Caltrans) engineers and biologists;
- site review to evaluate potential impacts on every old-growth redwood tree affected by the project, using revised maps and cross sections of work supplied by Caltrans;
- review of filed legal documents and the Final Environmental Impact Report/Environmental Assessment (FEIR/EA) (Caltrans 2010); and
- assessment of the avoidance and minimization measures[1] required by Caltrans.

II. DISCUSSION

A. Origins of the Redwood Highway

The Redwood Highway is a 350-mile section of U.S. Highway 101 (U.S. 101) that runs from San Francisco to Crescent City, California, and passes through stands of old-growth coast redwoods. The section of the Redwood Highway that winds through Richardson Grove State Park was constructed around 1915 and was first surfaced around 1927, probably using gravel and oil (Caltrans 2010a; Hawk 2004). The road was narrow, with challenging curves, and was not paved until the 1930s (Hawk 2004). Sections of U.S. 101 along the Eel River in Humboldt County were destroyed in 1964 by severe floods and then were rebuilt (see Appendix B, photographs 5 and 6).

Richardson Grove State Park is one of the oldest redwood state parks in the North Coast area and borders the South Fork of the Eel River. Visitors can hike among majestic old-growth

[1] The terminology used in the FEIR/EA is “avoidance, minimization, and/or mitigation measures.” “Avoidance and minimization measures” is the more technically correct term for addressing tree impacts, because the impacts are not significant.

redwood trees that are more than 1,000 years old; some of the trees are more than 300 feet tall. The park is open year round and offers hiking, camping, swimming, seasonal fishing, and wildlife viewing (California State Parks 2011a).

B. Scope of the Richardson Grove Operational Improvement Project

This project requires modifications along a 1.05-mile length of U.S. 101 that runs through Richardson Grove State Park. Old-growth redwoods grow close to the highway on both sides. Proposed roadway improvements to U.S. 101 would include minor realignments and shoulder widening to create smoother curves, including superelevations ("banking") to minimize large-vehicle off-tracking conflicts (Caltrans 2010b, 2010c).

The project's primary modifications to the existing landscape would include a triangular cut slope and a crescent-shaped fill slope near the south end of the grove and a cut slope near the north end of the project limits outside Richardson Grove State Park (Caltrans 2010d).

The project includes changes to six drainage culverts beneath the highway: four culverts would be replaced, one of which is outside of the park at the northern end of the project; one culvert would have a downdrain installed; and one culvert would be extended. In addition, a soldier pile wall would be constructed outside of the park at the northern end of the project, with a section of gabion wall at each end. The piles for the soldier pile wall require 30-inch-wide holes, placed 8 feet apart and up to 20 feet deep. The bottom of the soldier pile wall may be buried between 2 and 9 feet.

The design of the project took the protection of trees into account. Effects on adjacent trees have been minimized by creating small increases in road height rather than severing roots, and by selecting a thinner roadbed layer to minimize the depth of soil replacement (Caltrans 2010e). U.S. Department of Transportation (DOT) design exceptions include reduced requirements for line of sight, road shoulder widths, and minimum horizontal clearance to fixed objects, so no old-growth redwoods would be removed. This project would add less than 5% of hardened surface (roadbed) to the existing hardened surface within the structural root zone (Caltrans 2010f, 2010g, 2010h).

C. Arborist Review of the Project

I reviewed the following resource materials provided by Caltrans:

- "Old-Growth Redwoods in Project," a set of revised maps of all the trees whose root zones are within proposed areas of project activity (Appendix C).

- "Individual Tree Analysis," a description of the proposed work, tree protection measures, and the results of the field evaluation for each old-growth redwood in the project area (Appendix D).

- Litigation Documents and the FEIR/EA (Caltrans 2010).

I visited the project site in May 2009 on behalf of Save-the-Redwoods League and submitted a brief evaluation to them in June 2009. I conducted site visits again on behalf of Caltrans in September 2011, October 2011, November 2011, and January 2012, reviewing tree mapping, reviewing construction plans, and evaluating trees in consultation with Caltrans personnel. On December 27, 2011, I executed a verified declaration of my opinion of project effects that was filed the following day with the United States District Court. Most recently, in February 2013, I walked with a Caltrans biologist and Caltrans engineer through the section of U.S. 101 that is included in the proposed project and evaluated trees again in the context of revised mapping.

We examined the areas around all old-growth redwood trees (totaling 116, five located outside park boundaries) where some part of their root health zone fell within areas of proposed project activity. (The root health zone is a circular area with the tree trunk at the center and a radius equal to five times the tree trunk diameter measured 4.5 feet above ground level.) Of these 116 trees, 75 would be subject to project activity within their structural root zone (a circular area with the tree trunk at the center and a radius equal to three times the tree trunk diameter measured 4.5 feet above ground level).

The scale shown below was developed to quantify the projected effect of the project on individual trees. The scale is based on my experience as an arborist, field review, consultation with Caltrans personnel, and a review of the scientific literature as noted by references in this report.

Each tree was rated according to the predicted effects of root disturbance on tree health as would be evidenced by a change in the appearance of needles (leaves). If a substantial percentage of a tree's roots are disrupted or destroyed, the tree’s ability to absorb and transport moisture to its leaves may decrease. Moisture reduction can be so insignificant that foliage effects are visually undetectable (Ratings #0 through #3); or effects may be observable as temporarily desiccated needles or partial needle loss (Rating #4).

After severe root disruption, a coast redwood may be unable to absorb sufficient water to keep the uppermost part of the tree alive. The tree may form a "spike top" of dead wood (a lasting effect), but the remainder of the tree would remain healthy and the tree’s survival would not be threatened (Rating #5).

Should extreme and lasting disruptions occur, such as the destruction of numerous major buttress roots or severe and widespread compaction throughout the tree's circumference, the tree's survival could be at risk (Rating #6).

Effect of Root Zone Disturbance on Tree Health	
Rating	Effect
0	No effect.
1	Effect of root zone disturbance is extremely minor with no decline in foliage density or tree health.
2	Effect of root zone disturbance is very slight with no decline in foliage density or tree health.
3	Effect of root zone disturbance is slight with no decline in foliage density or tree health.
4	Effect of root zone disturbance may be a short-term visible reduction in foliage density that is still well within the adaptive capabilities of the tree.
5	Effect of root zone disturbance may be a reduction in root health sufficient to cause lasting visible dieback of wood in the uppermost crown; tree survival is not threatened.
6	Effect of root zone disturbance may be severe enough to threaten survival of the tree.

The following factors were taken into account:

- Visual examination of tree condition
- Proximity of the tree to U.S. 101
- Proximity of proposed work to the base of the tree
- Extent of potential root disturbance or removal
- Extent of new soil compaction
- Proposed avoidance and minimization measures for each tree

To illustrate how the ratings were applied: trees that were rated 0 (no effect) would have negligible activity within the root health zone; trees rated 1 (extremely minor effect) would have a minor amount of disturbance throughout the root health zone; trees with a rating of 2 (very slight) would have work closer to the base of the tree or in a larger proportion of the root health zone; and trees that were rated 3 (slight) would be subject to more activity within their structural root zones than trees rated 1 or 2.

Caltrans identified and mapped all affected trees in a document entitled "Old-Growth Redwoods in Project" (Appendix C). This document will also be available on the Richardson Grove Operational Improvement Project Web page: http://www.dot.ca.gov/dist1/d1projects/richardson_grove/. Appendix C consists of twenty

24-inch by 36-inch layout drawings of U.S. 101 as it progresses through the length of the project area. I reviewed the final version of this document, dated September 6, 2013.

Based on the evaluation, I reached the following conclusions[2]:

- For 18 of the trees (rated 0), the project would have no effect (Tree Nos. 17, 23, 31, 50, 65, 76, 78, 79, 80, 95, 98, 108, 110, 111, 113, 114, 115, and 116).

- For another 24 trees (rated 1), the project activity would have an extremely minor effect, with no decline in foliage density or tree health (Tree Nos. 6, 18, 28, 29, 40, 43, 44, 45, 47, 48, 54, 57, 60, 66, 71, 74, 84, 85, 88, 91, 97, 102, 107, and 109).

- For 53 of the trees (rated 2), the effect of the proposed project would be very slight, with no decline in foliage density or tree health (Tree Nos. 1, 2, 3, 8, 9, 10, 14, 15, 16, 19, 22, 24, 26, 27, 32, 33, 34, 35, 36, 37, 38, 39, 41, 42, 51, 52, 53, 56, 58, 59, 61, 62, 63, 64, 67, 68, 69, 70, 72, 73, 75, 81, 89, 90, 92, 93, 94, 96, 99, 100, 101, 103, and 117).

- For the remaining 21 trees (rated 3), the effects would be slight, with no decline in foliage density or tree health (Tree Nos. 4, 5, 7, 11, 12, 13, 20, 21, 25, 46, 49, 55, 77, 82, 83, 86, 87, 104, 105, 106, and 112).

No trees would have activity within their root zones that would rate an effect beyond a "3," and in no case would root disturbance have a significant detrimental effect on the health or stability of old-growth redwoods.

Caltrans compiled descriptions of the proposed work, tree protection measures, and the results of the field evaluation for each old-growth redwood (Appendix D, "Individual Tree Analysis"), which I reviewed most recently on September 12, 2013. The individual tree analysis will also be available on the Richardson Grove Operational Improvement Project Web page, at http://www.dot.ca.gov/dist1/d1projects/richardson_grove/.

Three proposed activities warrant additional discussion: culvert replacement, excavation of a triangular cut slope, and construction of a soldier pile and gabion wall. The FEIR/EA indicates that roots larger than 2 inches in diameter may be removed as necessary in these areas (Caltrans 2010i).

Culverts would be replaced within the structural root zones of three old-growth redwoods within the park (Tree Nos. 12, 13, and 15; Appendix C). Outside of the park, a culvert would be replaced within the structural root zones of trees 104 and 105.

The culverts would be backfilled with Portland Cement Concrete (PCC), which is similar to the backfill already in place around existing culverts. Using PCC halves the width of the trench normally required to lay a 24-inch culvert, reducing it from 2 feet on either side to 6 inches, and thereby minimizing the area of root disturbance. Because of the limited total area of root

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[2] Although there is a total of 116 trees, a tree is numbered 117; during field checking of tree maps, Tree No. 30 was determined to be a second trunk of tree No. 29, and was dropped from the list.

disturbance, the resilience of coast redwoods, and the use of avoidance and minimization measures, culvert replacement would not threaten the trees' health or stability.

During excavation of the triangular cut slope (at Postmile 1.36), roots would be removed within the structural root zone of one old-growth redwood, Tree No. 13. The area around the tree is well hydrated at the base of a thickly vegetated slope with a visible watercourse and many ferns. Excavation would be limited to an area at least 12 feet from the north side of the trunk. Roots larger than 2 inches in diameter would almost certainly be encountered; such roots would be cut cleanly with a sharp instrument to promote effective compartmentalization (the formation of chemical and anatomical barriers to infection). The area of soil excavation and root removal is too small to significantly diminish the availability of water to the tree. The remaining undisturbed roots would continue to absorb and distribute water throughout the circumference of the tree crown. Death or injury to individual roots of a coast redwood does not lead to corresponding one-sided trunk or branch death in the crown of the tree (Perry 1992). (See Appendix E.)

At the northernmost end of this project, outside Richardson Grove State Park, a soldier pile wall and gabions would be placed below road level on the east side of U.S. 101. Gabions (strong mesh enclosures containing rocks) are compressible, would be installed to fortify the widened roadway, and would be placed adjacent to Tree Nos. 104 and 106.

None of the proposed highway alterations is of sufficient magnitude to threaten the health or stability of any old-growth redwood. There is no reason to expect that the crown of any old-growth redwood would exhibit signs of stress such as branch dieback, needle loss, or needle desiccation. In each case, disturbances would be confined to a small percentage of the area occupied by roots, would be effectively limited by the proposed avoidance and minimization measures, and would be well within the adaptive capabilities of the trees.

D. Condition of Old-Growth Redwoods in the Project Area

No more eloquent and unbiased source of knowledge about old-growth redwood resilience exists than the trees alongside U.S. 101 in Richardson Grove. More than 90 years of highway traffic, including the passage of more than 15 million cars and trucks over the redwoods' root zones during the past decade (Caltrans 2010a, 2010j), has had no discernible significant detrimental effect on the trees. Any fair critique of the Richardson Grove Operational Improvement Project must address and account for the absence of discernible decline.

During my field visits to Richardson Grove over the past 4 years, including an aerial evaluation of the canopy by helicopter in 2011, I have observed that the old-growth redwoods alongside U.S. 101 appear to be in vigorous health. Only three old-growth trees along the highway in Richardson Grove (Tree No. 20 at Postmile 1.37 and Tree Nos. 89 and 90 at Postmile 1.69) show evidence of substantial prior detrimental impacts attributable to root destruction. During construction work on U.S. 101 decades ago, these three trees were subjected to extreme severance of multiple large-diameter buttress roots. The scars from this destruction are still visible at the bases of the trees. Although spikes (dried-out treetops) still extend above the crowns of these three trees as evidence of severe moisture stress from decades ago, their canopies appear to be vigorous and healthy today (see Appendix B, Photographs 7, 8, 9, and 10).

None of the proposed highway modifications in the Richardson Grove Operational Improvement Project requires severing any buttress roots on old-growth redwoods.

A change within the structural root zone does not equate to a significant impact. The roots of mature redwoods extend in all directions and well beyond the structural root zone. The issue is not just whether roots would be disrupted to some extent, but whether adjacent old-growth redwoods can successfully adapt, compensate, and remain in vigorous health. Research on coast redwoods has demonstrated the extraordinary resilience of old-growth redwoods in response to externally induced changes to their root systems (see discussion below). The vigorous condition of the old-growth redwoods in Richardson Grove alongside U.S. 101 is an external manifestation of their successful resiliency.

E. General Characteristics of Tree Root Systems

Tree roots can provide anchorage, absorption and conduction of water and minerals, storage of carbohydrates, production of hormones, and sites for resprouting. They are opportunistic and will proliferate where environmental conditions such as water, soil oxygen, and nutrient availability are favorable (Perry 1982). Root growth patterns vary widely between trees of different species growing under diverse environments. Lateral woody roots extend outward from the tree base and provide anchorage and support for the tree (Schnelle et al. 1989).

Depending on tree size or species, the lateral roots often decrease in diameter at a distance within 2 meters of the trunk base at sites called "zones of rapid taper" (Helliwell 1989). Lateral roots branch into smaller secondary roots that continue to bifurcate. More than 90% of the root mass will be found in the top meter of soil (Gasson and Cutler 1990; Harris et al. 2004).

Lateral roots can extend far beyond the dripline (the circumference of the tree crown) to a distance of two or three times the radius of the canopy. Open-grown tree roots can spread generally to about three times the distance to the dripline and perhaps farther for forest trees (Gilman 1990), and roots frequently encompass a generally circular area about four to seven times the area beneath the tree's crown (Perry 1992; Hagen 2001). Sinker roots extend straight or obliquely downward from primary and secondary lateral roots and increase stability (Mattheck 1994).

Fine roots originate along the basic root framework. They advance outward, down, and most frequently up toward the soil surface (Perry 1982), and greatly increase the tree's underground surface area for acquisition of water and dissolved minerals from the soil. Fine absorbing roots are found primarily beyond the dripline (Schnelle et al. 1989). The surface area of a tree's roots can be greater than the surface area of its leaves, and when roots are associated with beneficial symbiotic fungi called mycorrhizae, the effective absorptive surface of the finer roots can be amplified 100 times or more (Perry 1992).

Self-grafting between separate roots of a single tree occurs in most, and probably all, of the forest tree species of commercial importance (Graham and Bormann 1966). Roots may grow across each other and continue to grow radially until pressure develops at the point of contact. Each root develops a ridge of tissue, the intervening bark is eventually broken down, and vascular continuity is established (Graham and Bormann 1966).

The shape of an individual root system is also heavily influenced by site conditions (Costello 2012; Stokes and Mattheck 1996). The downward extent of tree roots can be limited by site-specific influences such as mechanical impedance, low oxygen levels, and dry subsoils (Stone and Kalisz 1991).

Frequent injury to and death of roots from many agents is ongoing throughout the life of a healthy tree, and new roots often form rapidly after injuries (Perry 1992). Root pruning stimulates roots to regenerate at or just behind the cut (Wilson 1970).

When a tree's root, trunk, or branch tissue is disrupted by pruning cuts or other wounds, microorganisms begin to infect the site. The tree responds by forming chemical and physical "walls" (barriers) around the wound to slow or prevent the spread of disease or decay. This process is called compartmentalization (Shigo 1977, 1986).

In a study of the effects of root severance on four species of deciduous hardwoods, different roots were severed at one of four locations: at the root flare or at distances of 1, 2, or 3 meters from the trunks. Five years later, the roots were excavated and examined. Severed roots of all sizes showed only minimal decay. The author concluded that, unlike in branches where leaving a stub can lead to more extensive decay, severing the roots did not cause substantial deterioration from root decay, and the minimal decay after 5 years posed no threat to the long-term health and stability of these four species (Watson 2008). Roots are strong compartmentalizers (Shigo 1986; Watson 2008).

F. Specialized Adaptations of Coast Redwoods

1. The Extraordinary Resilience of Coast Redwood Root Systems

Coast redwoods are surprisingly capable of compensating for disruptions to their root systems, as described by several researchers in the excerpts shown below.

Stone and Vasey (1962a:13) comment that "The mature redwood is apparently able to overcome the loss of a large portion of its root system by rapidly regenerating a new root system. What continues to surprise us is that so much of the root system can be removed without any noticeable reduction in vigor."

Sturgeon (1964:8, 11, 16, 17, 18) comments as follows about coast redwoods:

> The coast redwood species *(Sequoia sempervirens)* is rather remarkable in its ability to adapt to soil conditions, to sprout profusely, to respond to increased light, and to survive and grow under certain stresses imposed by man. …
>
> Coast redwood resists well attack by natural agents and adjusts remarkably well to changes in the environment, especially by growing of new roots and new foliage. …

> Roads of various qualities have been built through stands of redwoods...all in Humboldt County. A few trees along these roads and highways have had portions of their bases removed for road development over the past 40 years or more. Asphalt or concrete paving, which obviously is laid over the root zone of many trees adjoining the roadways, has not generally affected the vigor of these trees. A very few trees bordering the paved highway have defects that could be attributable to loss of effective root area. However, in most instances there are other apparently contributory factors to reduced vigor, such as fire effects and poor site quality. …
>
> Trees marginal to unpaved roads must suffer loss of effective root zone. Redwood trees have fibrous feeder roots at levels of one to two feet below the soil surface. Compaction caused by road building would reduce the effectiveness of such roots. However, redwood trees are remarkably aggressive and seem to compensate for such depreciating factors and maintain an outward appearance of vigor. In fact, trees on highway margins in relatively dense stands develop deeper crowns on the side where the opening for the highway provides more light than on forested sides. …
>
> Judging from the absence of significant loss of vigor in trees bordering the highways, coast redwood is evidently not seriously affected by paving where it does not cover more than half the trees' root zone.

Standish (1972:53, 54) adds:

> Meinecke's work in 1929 conclude(d) that the continued high visitor use of Coast Redwood areas should eventually lead to a decline in the tree's general health. If the tree's annual ring increments are a good indication of the tree's health, then this present study has failed to confirm Meinecke's theory. …
>
> Essentially there was no significant difference between the different areas in the growth of Coast Redwood, and there is no evidence that shows any correlation of visitor use to growth pattern changes.

McBride and Jacobs (1978:22, 33) comment as follows:

> The comparison of radial growth differences failed to show a significant difference between the two groups of trees. The results of this experiment did not provide any evidence that tourist trampling and subsequent soil compaction have caused reduced radial growth or lowered tree vigor. …
>
> Soil compaction was not demonstrated to reduce radial growth of redwoods. No correlation between the proximity of trails to individual trees and the vigor of these trees as expressed in ring width could be established. Trail construction should not be limited by a fear of adversely influencing the trees.

Stone and Vasey (1962b:2–3) described the effects of soil removal that disturbed redwood roots at Humboldt Redwoods State Park:

> Old-growth redwoods on alluvial flats in Humboldt Redwoods State Park had two feet of soil mechanically removed by a bulldozer over a radius of 40 feet around each of 4 redwoods with diameters ranging from 28 to 84 inches, and heights of 150 to 300 feet. …
>
> The soil was spread back in place immediately after removal, thus creating a two-foot-deep layer of soil entirely free of live roots. The treatment destroyed 30 to 40 per cent (by volume) of the existing root system of each tree including most of the 'feeder' roots. Root re-entry into the 'new layer' of soil was rapid. (Two years later), 40 per cent had been replaced at the zero to three inch depth, while at the 6 to 9 inch depth, 52 per cent had been replaced. All these roots were healthy and growing vigorously. Thus, redwood roots are able to reoccupy the soil mass rapidly with new roots, despite the loss of as much as 40 per cent of their old root systems. …
>
> Crowns of the treated trees were examined. No apparent change took place. Dieback did not occur and the crowns remained green and healthy. Radial growth of the treated trees was also examined. Using root growth, diameter growth, and crown condition as criteria of tree health, no noticeable decline in health was apparent two years after root removal.

Lastly, Stone (1965:8) comments:

> We found that within four years after removal of 90% of the feeder root system a replacement root system comparable to the original one had been regenerated by vertical upward growth of roots from below.

2. Stability and Anchorage

Relatively few tree species rely on a strengthened primary central root called a taproot to achieve long-term anchorage and stability. Coast redwoods do not have taproots (Fritz 1934). Resistance to windthrow can be increased substantially by small increases in rooting depth (Fraser 1962). Tree stability generally depends on the shape and size of aboveground parts, and especially on the type of root system. To prevent mechanical failure of a tree, external loading forces such as wind must be distributed down the tree and into the ground (Mattheck 1994). Strong and widespread lateral roots, as employed by coast redwoods (Fritz 1929; Olson et al. 1990; USFS 1908), disperse aboveground loading forces to soil and provide traction to resist uprooting (Coutts 1983; Ennos 1993; Mattheck 1994; Stokes and Mattheck 1996). One California forestry professor wrote that "I followed one major root some 150 feet from the main trunk till it disappeared and often 100 foot lengths are not uncommon with roots of 1–2 inch diameter at that point," and that "redwood roots graft onto other redwood roots and grow strongly together creating therefore a matrix like steel reinforcing bars in concrete. This means that pressures are distributed over the entire forest floor" (Becking 1979).

3. Buttress Flares and Lignotubers

Many trees effectively increase basal trunk diameter by creating buttresses (Ennos 1994). The coast redwood has developed a specialized organ of regeneration and carbohydrate storage called a lignotuber, which can develop into a massive swelling at or just below ground level. It continues to expand throughout the life of the tree and is generally covered with shoot buds. If the trunk is injured, the lignotuber can release shoots and generate new roots to increase the vigor and stability of young and old trees (Del Tredici 1998, 1999). Sequoia lignotubers also store carbohydrates and mineral nutrients, and can function as a kind of "clasping organ" to anchor trees growing on steep slopes (Del Tredici 1998, 1999).

4. Recovery from Periodic Flooding

In 1933, a coast redwood more than 1,200 years old fell in Richardson Grove State Park. Emanuel Fritz, a professor from the School of Forestry at the University of California, Berkeley, examined the tree's massive rootball and confirmed the extraordinary ability of this species to respond to heavy siltation by creating new root systems that grow upward into new sediment. In his own words (Fritz 1934):

> The main grove stands on a “flat” or high river bench built up by past floods. Seven great floods and a number of minor ones occurring during the life of this tree deposited enough silt to raise the ground level more than 11 feet. Each time the base of the tree was partially buried but was able to adapt itself to the new level by originating a newer and higher root system.
>
> A heavy flood, a thousand or more years ago, left a heavy deposit of silt, perhaps 30 inches deep. The root system continued to function but a new system was eventually formed to fit the higher ground level. …Each time a new set of roots was formed and the trunk below ceased its diameter growth. …Roots pointing outward occur as aftermath of floods. They are an attempt by the tree to readjust its root system to the new soil level. …The 1933 root system is approximately 300 years old.
>
> Other trees in Richardson Grove have similar subsurface trunks, as may be noted by examining the trees that have large fire scars. The exposed central trunk in each case exhibits straight grain at the ground line instead of the usual outward flare of the butts.

5. Ability to Withstand Low-Light Conditions

Small redwoods in an old-growth forest may have been suppressed by massive overstory trees for more than 400 years, but still maintain the ability to accelerate growth rates when older trees fail and light becomes available (Fritz and Averill 1924; Olson et al. 1990).

6. Fire History and Effects

Native Americans are reported to have used periodic burning to increase the efficiency of food gathering and to clear the understory for easier travel (Fritz and Averill 1924; Gilligan 1966). Fire history researchers have reached widely varying estimates of fire return intervals (FRI) in different old-growth coast redwood forests (Veirs 1982; Finney and Martin 1989). Wide disparities in FRI estimates have been attributed to changes in past land uses before and during settlement of the redwood region (Stuart 1987), variation in forest type from mesic (relatively moist) coastal forests to drier inland stands (Veirs 1982), and the difficulty of accurately assessing and cross-dating fire scars because of indistinguishable and discontinuous annual growth rings that are commonly encountered in coast redwoods (Fritz and Averill 1924; Fritz 1940).

The basal bark of a coast redwood trunk is thick and fire resistant, but periodic fires can decrease fire resistance sufficiently to kill the cambium layer (living tissue beneath the bark) (Fritz 1931; Isenberg 1943). Redwoods can live for many centuries with substantial fire scars, as evidenced by charring and fire cavities on old-growth trees throughout Richardson Grove.

7. Resistance to Insects and Decay

Coast redwoods have no important tree-killing insect or disease enemies (Fritz 1931). Fire injuries become entrance courts for infection by wood-rotting fungi (Finney and Martin 1989; Fritz 1931; Kimmey and Lightle 1955; Kimmey 1958). Two major types of decay have been identified: a brown cubical rot caused by *Poria sequoiae* and a white ring rot caused by *Poria albipellucida* (Kimmey and Lightle 1955). *Poria sequoiae* is not a "tree-killing" disease, but is a very important factor when it contributes to structural weakening of a tree (Fritz 1931).

Most decay in coast redwoods is associated with fire wounds in the lower portion of the bole and dead or broken treetops (Fritz and Bonar 1931; Kimmey and Lightle 1955). Entrance courts appear to be the same for both fungi. Broken branches were not identified as entry points for decay-causing fungi (Kimmey and Lightle 1955).

Old-growth coast redwoods are valued for their decay resistance. Highly decay-resistant wood has been found to be about five times more prevalent in old-growth redwoods than in young-growth coast redwoods, mainly in the butt log heartwood nearest the sapwood (Clark and Scheffer 1983; Piirto 1985).

In tests to determine decay resistance to ground contact, about 94% of old-growth coast redwood trees had outer heartwood that was either resistant or very resistant to decay. Differences in the decay resistance of coast redwood can be attributed to differences in extractive content (the nonstructural compounds in wood) (Anderson 1961; Clark and Scheffer 1983).

8. Development of Spike Tops

Earlier fires sometimes swept up the trunks of coast redwoods on weathered bark shreds and killed the tops of trees that had thinner layers of insulating bark than their lower trunks (Fritz 1931). A contributing cause of spike tops is a partial destruction of basal cambium from fire and the consequent reduction of water-conducting sapwood, which reduces the availability of moisture to keep the top of the tree alive (Fritz 1931). Injury to the tops of coast redwoods is sometimes traceable to girdling by rodents (Fritz and Averill 1924).

Moisture stress can account for many of the spike tops that are visible in older coast redwoods (Stone 1965). During transpiration (water loss through needles), water moves upward through the xylem (water-conducting tissue) under negative pressure. When tension becomes too great, the water conduit is vulnerable to cavitation (formation of an air pocket that disrupts the continuity of a water column) (Sperry 1989; Zimmermann 1983).

Coast redwoods are relatively inefficient at regulating the rate of transpiration through their needles (limited stomatal control) (Burgess and Dawson 2004). With increasing tree height, gravity and friction exert potentially greater disruptive effect on a water column (Ambrose et al. 2009). Nonetheless, redwoods apparently have large safety margins within their xylem structure for protection from cavitation even under severe drought conditions. This is a successful adaptive strategy for a species growing in an environment with abundant winter rainfall, summer fog, and coast-moderated temperatures throughout the year (Ambrose et al. 2009).

9. Fog Drip and Direct Foliar Absorption

Redwood roots obtain water from the water table, precipitation, and fog drip; needles (redwood leaves) obtain moisture directly from rain, dew, or fog. In one study, between 8% and 34% of the water used by coast redwoods in coastal forests of northern California during the summer months was attributable to fog precipitation that had dripped from foliage into the soil (Dawson 1996).

Another study demonstrated that tree crown fog interception by coast redwoods compensated for the negative effect of gravity on upward water conduction that accompanies increasing tree height (Simonin et al. 2009). The abundant and closely arranged needles can take in a great deal of moisture directly from fog, dew, and rain, which supplements water that is obtained from roots (Limm et al. 2009; Simonin et al. 2009).

10. Specialized Xylem Structure for Effective Uptake of Water

The spiraling of water-conducting elements in trees can be analyzed to determine the pathways of water ascent. Dyes injected into conifers, including coast redwoods, will ascend by way of tracheids (specialized water-conducting cells) in a path similar to the arrangement of the tracheids (Hendrickson and Vité 1960; Kozlowski and Winget 1963).

In coast redwood trees, aqueous dyes ascend in zigzag patterns, which indicate that tree roots lift water and dissolved minerals (sap) in a diffuse manner that serves all of the branches and leaves (Perry 1992). This pattern of sap ascent is called "interlocked." Water in the various layers of sapwood is transported alternatively from one direction to the opposite. Injected dye will spread out as it ascends the tree, and can be identified in cross-sectional wood "wafers" that are obtained from the tree above the site of dye injection (Rudinsky and Vité 1959).

This pattern of sap ascent gives the coast redwood two ecological advantages: moisture is distributed completely over the upper crown, and the tree has great adaptability to environmental changes (Rudinsky and Vité 1959). Death or injury to individual roots of a coast redwood does not lead to corresponding one-sided trunk or branch death in the crown of the tree (Perry 1992). (See Appendix E.)

G. Avoidance and Minimization Measures to Avoid Root Damage

Vigorous old-growth redwoods have vast, multilayered root systems that extend well beyond their canopies. Roots proliferate where the resources of life are available (Perry 1992).

For purposes of this project, the structural root zone is described as a circular area with the tree trunk at the center and a radius equal to three times the tree trunk diameter measured 4.5 feet above ground level (California State Parks 2011b). It contains the majority of the tree's large supporting structural roots that provide stability (Costello et al. 2003; Helliwell 1989; Mattheck 1994; Smiley at al. 2002; Smiley 2009; Urban 2008). Structural roots within this area would have to be severely disrupted or destroyed for the health or stability of a vigorous old-growth redwood to be substantially compromised.

Decades ago, the very large buttress roots (in the structural root zone) of Tree Nos. 20, 89, and 90 in Richardson Grove were severed on one side for construction of U.S. 101, causing the death of the uppermost part of the trees ("spike tops") from the sudden disruption of available moisture. The trees' crowns remain vigorous, although the spike tops are still visible (see photographs 7–10 in Appendix B). No buttress roots of old-growth redwoods would be severed during the Richardson Grove Operational Improvement Project.

The root health zone is defined as a circular area with the tree trunk at the center and a radius equal to five times the tree trunk diameter (Smiley et al. 2002). Project activities occurring in the root health zone but not in the structural root zone (that is, between three and five times the distance from the center of the trunk) would be farther from the large supporting roots, the buttress flare, and the trunk of the tree, and would affect only a very small percentage of nonstructural roots. Research on root regeneration by coast redwoods has demonstrated the extraordinary ability of coast redwoods to regenerate new roots even after up to 90% of the "feeder" (absorbing) roots have been destroyed (Stone 1965; Stone and Vasey 1962a, 1962b). Therefore, disruption or even destruction of a very small percentage of nonstructural roots in this outer area of the root health zone would have no significant effect on tree health or stability. Proposed activity within the structural root zone was evaluated closely for potential effects on health or stability. This project incorporates detailed measures to protect old-growth trees during construction of highway improvements, and each is discussed below.

1. Avoiding Unnecessary Compaction

Extreme soil compaction can be one of the most critical threats to the health and survivability of trees. Soil compaction can reduce oxygen diffusion and moisture availability to roots, limit drainage, encourage the proliferation of undesirable soil microorganisms, and reduce a tree's capacity to respond favorably to many kinds of biotic and abiotic stress.

Although old-growth redwoods are resilient trees with multiple adaptive capabilities, their resilience can be overwhelmed by extreme environmental stress. The minor increase in compacted area created by these limited highway modifications would not create such stress. Research has consistently demonstrated that soil compaction over a small percentage of a vigorous old-growth redwood's root structure would not, in itself, have any significant detrimental or life-threatening effects (Gothier 1980; Hartesveldt et al. 1975; McBride and Jacobs 1978; Standish 1972; Stone 1965; Stone and Vasey 1962a, 1962b; Sturgeon 1964).

Nonetheless, unnecessary soil compaction should and would be avoided. Heavy equipment for road excavation, trenching, and construction would operate from the paved roadway, and would not park on undisturbed soil beneath the canopies of old-growth redwoods. DOT design exceptions for this project allow roadway shoulders to taper with steeper slopes to reduce the area of coverage on native soil. The small amount of additional compaction resulting from implementation of this project would be insignificant to the health and stability of the old-growth redwoods.

2. Limited Severance of Roots

Locations within the park where roots larger than 2 inches in diameter would be severed, if encountered, are limited to the sites proposed for culvert replacement (near Tree Nos. 12, 13, 15, 104, and 105), and the cut slopes (Appendix C). If a root 2 inches or larger in diameter must be severed, it would be cut cleanly with a sharp instrument.

In the FEIR/EA (Caltrans 2010), the word "cut" described a procedure to be used in proximity to old-growth redwoods. "Cut" is an engineering term used to describe the removal of soil to a specified depth; it does not refer to the cutting of roots.

Should roots larger than 2 inches in diameter be encountered during excavation within the structural root zone of old-growth redwoods in the park, they would be incorporated into the base material for the roadway. None of the proposed highway modifications would interfere sufficiently with old-growth root systems to lead to branch dieback or a visible reduction in foliage density.

3. Pneumatic Soil Excavation

Soil within the structural root zone of old-growth redwoods would be removed with hand tools such as picks and shovels, or by using handheld pneumatic devices, or a combination of the two (Caltrans 2010e, 2010l, 2010m).

Pneumatic excavators would be used to prevent damage to tree roots, to preserve roots larger than 2 inches in diameter, and to enable roots to be incorporated into the structural section of the roadway (Caltrans 2010n, 2010o). Small roots would be cut cleanly to encourage rapid compartmentalization (Watson 2008).

Pneumatic excavators are hand-held devices that are connected by hoses to air compressors. A high-pressure stream of air is tunneled through a nozzle that breaks dense soil into finer particles and effectively removes soil without causing significant damage to roots. If soil moisture is adequate, even compacted soils can be removed from root systems with virtually no damage (Smiley 1999). When root preservation is a key objective for "high-value" trees, use of the pneumatic soil excavation technique is recommended (Gross and Julene 2002).

4. Cement-Treated Permeable Base

Soil would be removed and replaced as necessary with an aggregate mix called cement-treated permeable base (CTPB). This material was selected for this project because it requires approximately 6 inches less in application depth than other common road aggregates, is permeable, and requires only consolidation (a lesser degree of compaction) adjacent to roots within the structural root zone. CTPB allows for greater oxygen diffusion and water percolation than a conventional subbase material (Caltrans 2010l, 2010p, 2010q).

5. Brow Logs

Brow logs are approximately 12-inch-diameter redwood poles, about 10 feet in length, that would be stacked against the base of a single redwood (Tree No. 83) parallel to the existing roadway, so that the roadway shoulder could be extended without requiring tree removal. The brow logs would be connected to each other with internal rebar, would serve as a buffer between the tree trunk and new soil, and would prevent soil from accumulating against the trunk base (Caltrans 2010p).

The presence of wood against the thick bark of old-growth redwoods is a natural and noninjurious event. In old-growth redwood forests, including Richardson Grove, large branches and smaller trees commonly fall or roll against the uphill sides of redwoods and soil accumulates uphill of the standing tree. In this project, the soil and aggregate against the brow logs would be compacted. The limited additional compacted soil near the tree would be smaller in surface area than if brow logs were not used.

6. Supplemental Irrigation

Wind can cause tree leaves, including redwood needles, to become somewhat desiccated (drier) if the leaves are unable to replace lost moisture. In Richardson Grove, a very high percentage of the needles of old-growth redwoods are in the upper crowns of the trees, far above the moderate wind currents generated by vehicular traffic on U.S. 101.

This project is not expected to significantly increase traffic (Caltrans 2010r, 2010s, 2010t, 2010u). Speed limits through Richardson Grove were lowered in 2008 from 40 to 35 miles per hour (Caltrans 2010v, 2010w, 2010x) and sections are now posted at 30 miles per hour.

During the drier months of June to September, a tanker truck would spray water weekly to a distance of 25 feet from the roadway in an amount equal to a one-half-inch depth in areas where excavation has occurred within the structural root zones of redwoods 30 inches or greater in diameter (Caltrans 2010q). This supplemental irrigation would be available to wide areas of absorbing roots to offset any decrease in moisture availability that may be attributable to minor root disturbance.

The combination of minor root disturbance, supplemental irrigation, concentration of needle mass in the upper redwood canopy, and absence of increased traffic volume or speed eliminates undue concern about needle desiccation.

7. Monitoring and Quality Control

All avoidance and minimization measures are summarized in the project's Environmental Commitments Record, which would track compliance through project completion, including postconstruction mitigation and monitoring activities. Protection measures have been incorporated into the plans and specifications for constructing the project; state inspectors would be on-site during construction to ensure they are carried out. A certified arborist would also be on-site to ensure that avoidance and minimization measures are adhered to during soil excavation, culvert work, and placement of aggregate mix within structural root zones (Caltrans 2010y, 2010z).

III. CONCLUSION

The life of any redwood is a succession of adaptations to environmental changes. The old-growth coast redwoods along U.S. 101 in Richardson Grove show no significant visible decline after tens of millions of vehicles have crossed over their structural root zones for more than 90 years.

Research has consistently verified that coast redwoods are extraordinarily resilient, provided that their roots and leaves obtain adequate moisture from the water table, precipitation, and fog. Nothing in the Richardson Grove Operational Improvement Project would significantly diminish the ability of these old-growth redwoods to obtain water. The proposed construction would add less than 5% of hardened surface (roadbed) to the existing hardened surface within the structural root zone (Caltrans 2010f, 2010g, 2010h). The avoidance and minimization measures described in the FEIR/EA (Caltrans 2010aa, 2010bb) would prevent significant detrimental impacts (Caltrans 2010cc).

In my professional opinion, based on the consistent research findings on redwood resilience, the current vigorous health of the subject trees, the confined areas of root disturbance, the design of the roadway modifications to minimize effects on trees, and the extensive construction avoidance and minimization measures, this project would not have any significant detrimental effect on the old-growth redwoods of Richardson Grove.

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