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Understory Recovery in Coast Redwood Communities: A Case Study Comparing a Naturally Recovering and an Actively Managed Forest

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Abstract

Restoration of late seral features in second growth *Sequoia sempervirens* (coast redwood) forests is increasingly important, as so little of the original old-growth remains. Natural recovery is an effective method restoring many late seral features, and does not require the additional disturbance of active management. In order to better understand management impacts on redwood understory abundance and composition, data were collected in naturally recovering stands and in stands that were actively managed with the explicit intent of promoting old-growth characteristics. Ten 10 m diameter plots with three 2 m diameter nested sub-plots were randomly sampled in two sites within each management type. Results indicate that tree canopy cover, native species cover and richness, richness of coast redwood associated species, and the cover of *Trillium ovatum* (western wake robin) were significantly higher in naturally recovering versus actively managed stands. In addition, several coast redwood associated understory species were exclusively recorded in the naturally recovering stands including: *Asuram caudatum* (wild ginger), *Prosartes hookeri* (hooker's fairybells), *Maianthemum racemosum* (false solomon seal), *Scoliopus bigelovii* (fetid adder's tongue), *Viola sempervirens* (redwood violet); while only one such species was recorded exclusively in the actively managed stands: *Trientalis latifolia* (pacific star flower). Natural recovery appeared to support understory recovery more effectively than active forest management in this case.

Keywords

Restoration, Natural Recovery, Active Management, Old-Growth, Late-Seral

1. Introduction

Primeval *Sequoia sempervirens* (coast redwood) forests once covered an estimated 800,000 ha along the west coast of the United States (Noss, 1999). Today, approximately 5% of the original redwood forests remain. The rest is composed of post-harvest second growth forests, including both actively managed stands and preserves where natural processes have been allowed to reassert themselves. With so little of the original old-growth remaining, there is growing interest in restoring characteristics associated with old-growth to these maturing second growth stands. While old-growth is traditionally defined by an absence of a logging history (Peterken, 1996; Frelich & Reich, 2003), various stand characteristics are associated with old-growth including relatively low density, structural complexity, and shade tolerant understory communities (Van Pelt & Franklin, 2000; Helms, 2004; Spies & Duncan, 2009).

Silvicultural techniques have traditionally been used to manage forests for timber production, with the primary goal of producing a regular crop of large straight trees (Nyland, 2016). In recent years, active timber management techniques such as variable density thinning have been promoted as a tool for restoring old-growth characteristics (O'Hara et al., 2010; Berrill et al., 2013). While these techniques have been shown to be effective in increasing the growth rate of remaining trees in the short run, the impact of these treatments on non-commercial plant species is not well understood.

The re-establishment of herbaceous understory species associated with coast redwood forests is of particular concern because many of these species are sensitive to logging, and may provide metric for assessing the recovery coast redwood forest community as a whole (Loya & Jules, 2008; Russell & Michels, 2010). In addition, much of the plant diversity in the coast redwood forest is found in the understory (Gilliam, 2007). The decline of redwood associated understory species, such as *Asuram caudatum* (wild ginger), *Maianthemum racemosum* (false solomon seal), *Oxalis oregana* (redwood sorrel), *Polysticum munitum* (pacific sword fern), *Prosartes hookeri* (hooker's fairybells), *Scoliopus bigelovii* (fetid adder's tongue), *Trientalis latifolia* (pacific star flower), *Trillium ovatum* (western wake robin), and *Viola sempervirens* (redwood violet) following logging events has been well documented, and has been correlated to other forest metrics such as reduction in canopy cover and the establishment of non-native species (Meier et al., 1995; Gilliam, 2007; Loya & Jules, 2008; Russell, 2009; Russell & Michels, 2010; Russell et al., 2014; Petersen & Russell, 2017).

The diversity of the coast redwood understory tends to recover fairly quickly following logging in forests that are allowed to recover naturally, due to the resilient nature of the dominant canopy species *S. sempervirens* (Gerhart, 2006). The abundance and cover of understory associated species can be slower to recover however (Loya & Jules, 2008; Russell & Michels, 2010). In addition, individual species appear to recover at different rates, suggesting varying sensitivities to logging. Keyes and Teraoka (2014), for example, found that total understory cover in old-growth and second growth did not vary significantly between old growth and second growth stands, but the that Importance Values of key redwood associates, including *Oxalis oregana* Nutt. and *Trillium. ovatum*, were significantly higher in old-growth stands. The authors argue that their results support the notion of active restoration in the form of variable tree thinning, but do not consider the potential impacts of additional logging operations on natural processes of forest recover.

The objective of this study was to determine how understory species composition and richness varied between a naturally recovering second growth coast redwood forest compared to a second growth coast redwood forest that was actively managed for the expressed purpose of promoting old-growth characteristics.

2. Methods

Two sites were used to compare differences in herbaceous understory species between managed and naturally recovery coast redwood forests in the southern part of their range. For the purpose of this study, a "managed forest" is defined as one where harvesting is currently used to manipulate stand density and characteristics. Whereas a "naturally recovering" forest is defined as one that has received no harvest treatments since historic logging ceased.

Characterized by a Mediterranean climate, the Santa Cruz Mountains typically experience warm dry summers and cool wet winters. Annual precipitation for study sites average roughly 110 cm. Study sites were located in the Fall Creek Unit of Henry Cowell Redwoods State Park in Felton, California, USA (37.0494˚N - 37.0899˚N, 122.0816˚W - 122.1383˚W) and Soquel Demonstration State Forest in Los Gatos, California, USA (37.0711˚N - 37.0923˚N, 121.8631˚W - 121.9378˚W). The Fall Creek Unit was heavily logged between the 1870's and 1919 to provide firewood for the lime industry. Logging ceased after the lime quarry was shut down in 1919. The land was gifted to the California State Park system in 1972. The forest has been protected from logging since that time, and has been allowed to recover naturally. Soquel Demonstration Forest was selectively harvested from the late 1880's-1920's, with heavy harvesting taking place in the 1920's and 1930's. The property was transferred to CAL FIRE (formerly the California Department of Forestry and Fire Protection) in 1990 for management as a demonstration forest, and selective harvesting has been ongoing since that time (Bernheisel, 2014).

Study sites in Soquel Demonstration Forest were located within the boundaries of two timber harvest plans that were selectively harvested in 2012. Low-intensity timber management activities were being used to "promote old-growth characteristics" in both these sites (Bernheisel, 2014). Topographic maps and geological data were used to select two sites in the Fall Creek Unit that closely resembled the geographic features present for the sites located in Soquel Demonstration Forest.

The vegetation on both sites was consistent with that which is found in the southern range of the coast redwood region. *Sequoia sempervirens* and *Psuedotsuga menziesii* (Douglas-fir) dominated the canopy with the sub canopy being composed of *Notholithocarpus densiflorus* (tanoak), *Acer macrophylum* (big leaf maple), and *Umbellularia californica* (California Bay Laurel).

Ten 10 m (157 m^2) circular tree plots were randomly selected within the Fern Gulch timber harvest plan (THP) area and ten additional tree plots were randomly selected within the Rim THP area of the Soquel Demonstration Forest. A total of twenty 10 m circular tree plots were randomly selected from two sites within the boundaries of the Fall Creek Unit (**Figure 1**). Each plot was at least 10 m from neighboring plots, 10 m from special habitats, and 200 m from paved roads to limit edge effect (Russell & Jones, 2001). Herbaceous and shrub understory species were sampled in three 2 m circular subplots within each of the forty tree plots, using the ocular estimation techniques described in previous studies (**Figure 2**) (Loya & Jules, 2008; Russell & Michels, 2010; Russell et al., 2014).

2.1. Data Collection

Plots were located in the field by randomizing distance on access trails, as well as distance off of access trails. Data for this study were collected in late April 2018. General stand characteristics were recorded at plot center for each tree plot including; elevation, aspect (using an azimuth compass), slope (using a clinometer), and canopy cover (using a spherical densitometer). Within each tree plot species richness, abundance, and diameter breast height (DBH) were recorded for all tree species over 1 m in height with a DBH > 10 cm. Trees with multiple trunks were counted as separate individuals if the split occurred below breast height. Trees were included in the count if >50% of the trunk was within the plot boundaries.

Three nested sub-plots were located evenly spaced along a transect within each tree plot. All herbaceous and shrub species < 5 m in height within each sub-plot were identified and ocular cover estimates were made. In the event an identification could not be made in the field, samples were collected for later identification using the Jepson Manual (Baldwin et al., 2012).

2.2. Data Analysis

All data analyses were conducted using IBM SPSS statistical software. Descriptive analyses were used to explore the potential differences between the two management styles for all sample variables. Paired two sample t-tests, Mann Whitney U paired t-tests, and ANCOVA were used to test for significant differences between the two management styles. For data that were not normally distributed, which included, the percent cover and richness of herbaceous

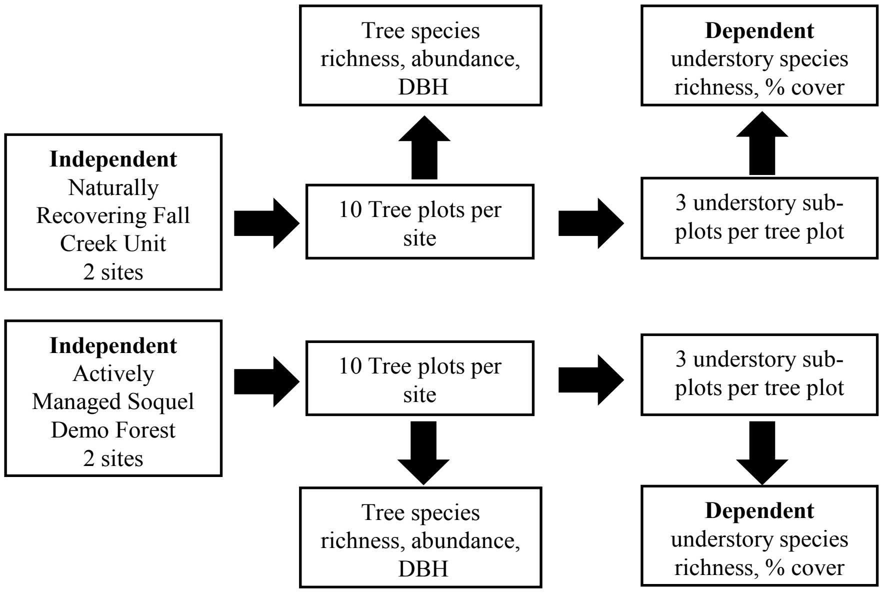

Figure 1. Study design for comparison between naturally recovering and managed second growth coast redwood stands in Santa Cruz County, USA.

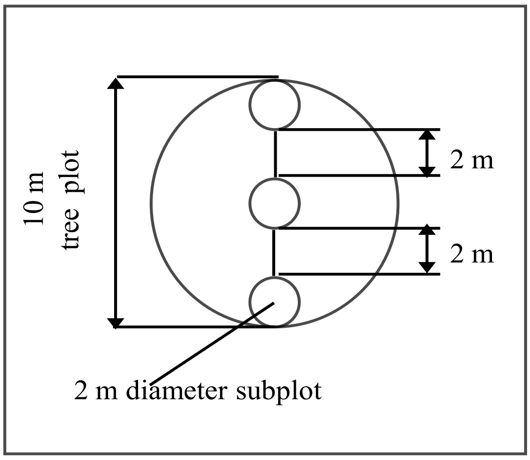

Figure 2. Placement of 2 m diameter nested understory plots within each 10 m diameter tree plots in managed and naturally recovering coast redwood forests in the southern part of the range.

understory species, the percent cover and richness non-native species, and the percent cover of understory woody shrubs, a Mann-Whitney U paired t-test was used. Two separate t-tests were used to test for significant differences between the four sites in the two parks when grouped according to proximity to the ridge top. ANCOVAs were used to compare various predictors for understory richness and cover between the two management styles including; basal area, canopy cover, elevation and aspect.

3. Results

A total of thirty-seven species were observed including seven tree species, sixteen herbaceous understory species, nine understory shrub species and five non-native species (**Table 1**). Though forest structure and composition varied between the management practices, average basal are did not differ significantly. Native species cover, native species richness, native shrub cover, native shrub species richness, and tree canopy cover all differed significantly between actively managed and naturally recovering sites (**Table 2**).

3.1. Understory Cover

A paired t-test for native species cover supported the finding that there was substantially more native understory cover in the naturally recovering stands at the Fall Creek Unit than in the actively managed Soquel Demonstration Forest, $t(37.3) = -6.73$, $p < 0.001$ (**Figure 3**). A Mann-Whitney U test indicated that this difference was primarily due to a difference in native shrub species cover between the managed ($Mdn = 1.33$) and naturally recovering ($Mdn = 13.5$) plots, $U = 25$, $p < 0.001$. ANCOVAs indicated that these findings were still statistically significant when predictor variables were considered. Two separate paired two sample t-tests indicated that when sites were grouped according to proximity to ridge top, the naturally recovering Fall Creek Unit had significantly more native understory cover than the actively managed Soquel Demonstration Forest for plots both near, $t(15.19) = -5.2$, $p < 0.001$, and far, $t(12.59) = -4.79$, $p < 0.001$.

Table 1. Understory species observed in a naturally recovering, and an actively managed coast redwood forest in the southern range of *Sequoia sempervirens*.

Species Observed		
Native herbaceous understory species	**Native shrub understory species**	**Native tree species**
Aralia californica (elk clover)	*Ceanothus thrsiflorus* (blueblossom)	*Acer macrophylum* (big leaf maple)
Asuram caudatum (wild ginger)	*Corylus cornuta* (hazelnut)	*Arbutus menzessii* (madrone)
Galium aparine (bedstraw)	*Frangula californica* (coffeeberry)	*Notholithocarpus densiflorus* (tanoak)
Lonicera hispidula (hairy honeysuckle)	*Rosa gymnocarpa* (wood rose)	*Psuedotsuga menziesii* (Douglas fir
Maianthemum racemosum (false solomon seal)	*Rubus parviflorus* (thinmbleberry)	*Quercus agrifolia* (coast live oak)
Oxalis oregana (redwood sorrel)	*Rubus ursinus* (Ca blackberry)	*Sequoia sempervirens* (*coast redwood*)
Polystichum munitum (sword fern)	*Toxicodendron diversilobum* (poison oak)	*Unbellularia californica* (bay laurel)
Prosartes hookeri (hooker's fairybells)	*Vaccinium ovatum* (huckleberry)	
Pteridium aquillinum var. pubeseen (bracken fern)		**Non-native species**
Satureja douglasii (yerba buena)		*Cirsium vulgare* (bull thistle)
Scoliopus bigelovii (fetid adder's tongue)		*Conium maculatum* (poison hemlock)
Trientalis latifolia (pacific star flower)		*Hedera* sp. (ivy)
Trillium ovatum (pacific trillium)		*Melissa officinalis* (lemon balm)
Viola sempervirens (redwood violet)		*Myosotis latifolia* (forget me not)
Woodwardia fembriata (giant chain fern)		

Table 2. Mean, standard error and p-values for stand structure and composition in the actively managed Soquel Demonstration Forest and the naturally recovering Fall Creek Unit. Significant findings (p < 0.05) are denoted with an (*).

	Actively Managed		Naturally Recovering		
	Mean	*S.E.*	*Mean*	*S.E.*	*p-value*
Native species cover	6.71	1.30	33.31	4.09	0.000*
Non-native species cover	1.03	0.97	0.33	0.03	0.583
Native herb species cover	4.77	1.33	15.99	4.39	0.277
Native shrub species cover	1.91	0.52	17.32	3.35	0.000*
Native species richness	3.65	0.47	5.95	0.62	0.005*
Non-native species richness	0.30	0.15	0.10	0.07	0.565
Native herb species richness	2.00	0.27	2.70	0.43	0.183
Native shrub species richness	1.65	0.35	3.25	0.43	0.012*
Canopy cover	71.40	1.95	83.25	1.61	0.000*
Basal area (m^2)	0.010	0.002	0.011	0.002	0.914

*indicates significant findings ($p < 0.05$).

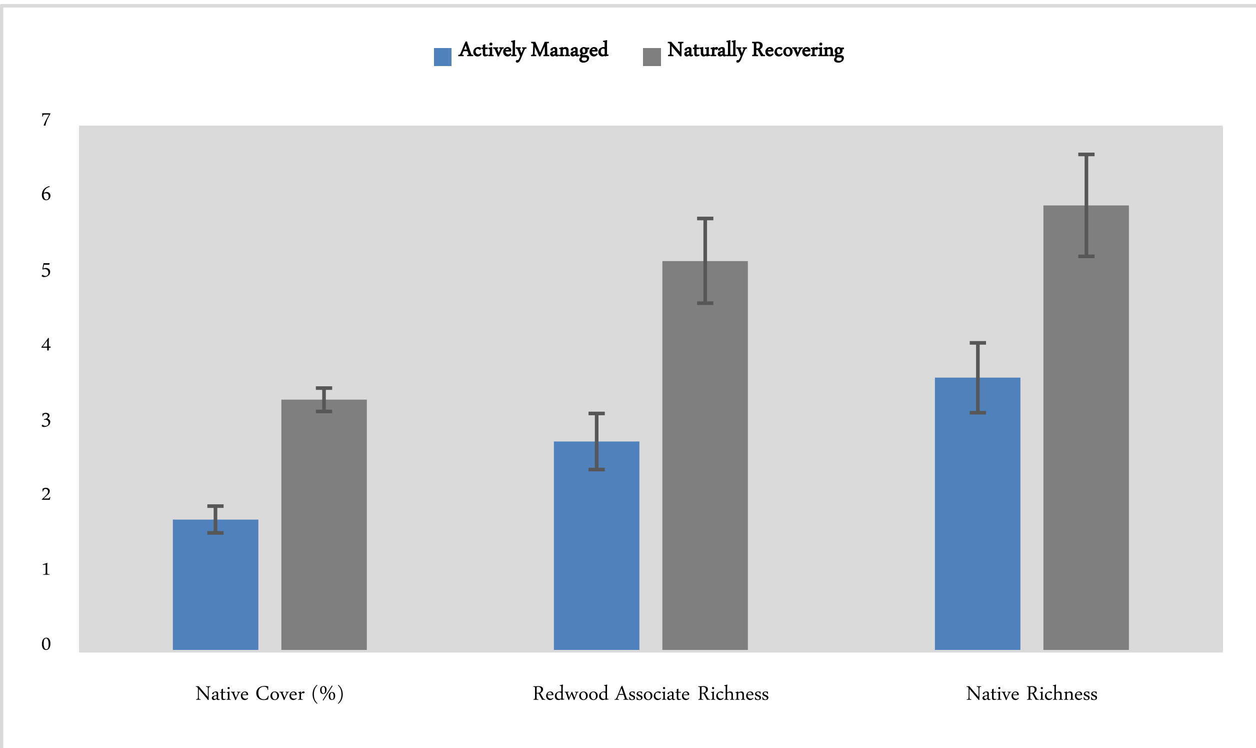

Figure 3. Comparisons for mean (±SE) native species cover percent ($p < 0.001$), mean (±SE) redwood associated species richness ($p = 0.001$) and mean (±SE) species richness for all native understory species ($p = 0.005$) on managed versus naturally recovering plots.

3.2. Understory Species Richness

A paired two sample t-test indicated that there was substantially more native species richness on the plots located in the Fall Creek Unit than in Soquel Demonstration Forest, $t(35.34) = -2.97$, $p = 0.005$ (**Figure 3**). A Mann-Whitney U test indicated that this difference was primarily due to a difference in the native understory shrub species between the managed (*Mdn* = 1.50) and naturally recovering plots (*Mdn* = 3.00), $p = 0.012$. Though Fall Creek had higher percent cover and richness for native herbaceous understory species (**Table 1**), Mann Whitney tests indicated that no statistically significant difference was found between management styles ($p = 0.227$, $p = 0.183$).

3.3. Redwood Associates

Several coast redwood associated species were observed including *Trillium ovatum*, *Oxalis oregana*, *Asuram coudatum*, and *Polystichum munitum* (**Table 3**). A paired t-test indicated that there were significantly more redwood associated species present on plots in Fall Creek then Soquel Demonstration Forest, $t(35.51) = -3.56$, $p = 0.001$. When individual species were considered, substantially more *Trillium ovatum*, ($p = 0.028$) occurred on plots in Fall Creek then in Soquel Demonstration Forest (**Table 4**).

4. Discussion

The process of natural forest recovery supports the development of understory communities in a variety of forest types, with longer periods without logging providing the greatest benefit (Halpern & Spies, 1995; Meier et al., 1995; Yamagawa & Ito, 2006). Herbaceous understory species are often dependent on the microclimate conditions created by closed canopy, and are therefore particularly sensitive to active timber management (Meier et al., 1995; Kahmen & Jules, 2005; Yamagawa et al., 2006). The results of our study support these findings, with tree canopy cover, native species cover, native species richness, and the richness

Table 3. Redwood associated understory species encountered at Fall Creek 1 (FC1), Fall Creek 2 (FC2), Soquel Demonstration Forest Fern Gulch (SDF), and Soquel Demonstration Forest Rim (SDR).

	Naturally Recovering		Actively Managed	
	FC1 presence	FC2 presence	SDF presence	SDR presence
Asuram caudatum (wild ginger)	X	--	--	--
Maianthemum racemosum (false solomon seal)	X	--	--	--
Oxalis oregana (redwood sorrel)	X	--	X	X
Polystichum munitum (sword fern)	X	--	X	--
Prosartes hookeri (hooker's fairy bells)	--	X	--	--
Scoliopus bigelovii (fetid adder's tongue)	X	--	--	--
Trientalis latifolia (pacific star flower)	--	--	--	X
Trillium ovatum (pacific trillium)	X	X	X	--
Viola sempervirens (redwood violet)	--	X	--	--

Table 4. Mean, standard error and p-values for most commonly observed redwood associates in the actively managed Soquel Demonstration forest and the naturally recovering Fall Creek Unit.

	Actively Managed		Naturally Recovering		
	Mean	*S.E.*	*Mean*	*S.E.*	*p-value*
A. caudatum	0.00	0.00	0.41	0.27	N/A
O. oregana	2.83	1.08	11.88	3.73	0.174
P. munitum	1.28	0.56	2.18	0.70	0.414
T. ovatum	0.02	0.02	0.46	0.21	0.028*

of coast redwood associated species found to be significantly higher in naturally recovering versus actively managed stands.

As predicted in the literature (Keyes & Teraoka, 2014), the recovery of understory species was highly variable. For example, *Trillium ovatum,* a species known to be sensitive to logging (Kahmen & Jules, 2005), was found to be significantly less abundant in the actively managed stands versus the naturally recovering stands. Several other species associated with the coast redwood community were absent entirely from the actively managed plots (*Asuram caudatum*, *Prosartes hookeri*, *Maianthemum racemosum*, *Scoliopus bigelovii*, and *Viola sempervirens*), while others were present (*Trientalis latifolia* and *Oxalis oregano*).

The use of timber management tools to promote understory recovery is somewhat counter-intuitive, particularly in coast redwood forests where stand replacing disturbances are extremely rare. This forest type is best suited to a gap-phase succession model, and as Meier et al. (1995) stated, "logging results in less-than-optimal conditions for forest-floor herb reproduction by modifying microhabitats on the forest floor and by temporarily eliminating gap-phase succession." In addition, Halpern and Spies (1995) suggest that logging practices (especially short rotation prescriptions) tend to preclude the development of old-growth characteristics, and may result in reduction in species diversity over the long run. The use of mechanical thinning techniques, for example, may be effective in engineering stand density and individual tree growth in the short run (O'Hara et al., 2010), but these practices can be detrimental to shade dependent understory species (Keyes & Teraoka, 2014). Timber management, for whatever purpose, has the tendency to reduce populations of rare herbaceous species (Meier et al., 1995). In addition, successional conditions following logging can further limit the recovery of sensitive understory plants.

The sensitivity of herbaceous understory plants could provide opportunities for the development of a suit of bio-indictors that could be used as a metric for the assessment of forest recovery. Such bio-indicators have been successfully assessed using arthropods (Schmidt et al., 2013). With additional data collection in recovering coast redwood forests, species such as *Trillium ovatum* may present themselves suitable indicators of developing late-seral conditions.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Baldwin, B. G., Goldman, D., Keil, D. J., Patterson, R., Rosatti, T. J., & Wilken, D. H. (Eds.) (2012). *The Jepson Manual: Vascular Plants of California* (2nd ed.). Berkeley, CA: University of California Press.

Bernheisel, A. (2014). *Soquel Demonstration State Forest General Forest Management Plan.* California Department of Forestry and Fire Protection. http://calfire.ca.gov/resource_mgt/downloads/Soquel/SDSF_GFMP_2014.pdf

Berrill, J. P., Beal, C. B., LaFever, D. H., & Dagley, C. M. (2013). Modeling Young Stand Development towards Old-Growth Reference Condition in Evergreen Mixed-Conifer Stands at the Headwaters Forest Reserve, California. *Forests, 4,* 455-470. https://doi.org/10.3390/f4020455

Frelich, L. E., & Reich, P. B. (2003). Perspectives on Development of Definitions and Values Related to Old-Growth Forests. *Environmental Reviews, 11,* 9-22. https://doi.org/10.1139/a03-011

Gerhart, M. (2006). *Expanding the Legacy of Research at the Fritz Wonder Plot, Big River, California: A Report to Save-the-Redwoods League.* Mendocino, CA: Mendocino Land Trust.

Gilliam, F. S. (2007). The Ecological Significance of the Herbaceous Layer in Temperate Forest Ecosystems. *BioScience, 57,* 845-858. https://doi.org/10.1641/B571007

Halpern, C. B., & Spies, T. A. (1995). Plant Species Diversity in Natural and Managed Forests of the Pacific Northwest. *Ecological Applications, 5,* 913-934. https://doi.org/10.2307/2269343

Helms, J. A. (2004). Old-Growth: What Is It? *Journal of Forestry, 102,* 8-12.

Kahmen, A., & Jules, E. S. (2005). Assessing the Recovery of a Long-Lived Herb Following Logging: *Trillium ovatum* across a 424-Year Chronosequence. *Forest Ecology and Management, 210,* 107-116. https://doi.org/10.1016/j.foreco.2005.02.018

Keyes, C. R., & Teraoka, E. K. (2014). Structure and Composition of Old-Growth and Unmanaged Second-Growth Riparian Forests at Redwood National Park, USA. *Forests 5,* 256-268. https://doi.org/10.3390/f5020256

Loya, D. T., & Jules, E. S. (2008). Use of Species Richness Estimators Improves Evaluation of Understory Plant Response to Logging: A Study of Redwood Forests. *Plant Ecology, 194,* 179-194. https://doi.org/10.1007/s11258-007-9283-z

Meier, A. J., Bratton, S. P., & Duffy, D. C. (1995). Possible Ecological Mechanisms for Loss of Vernal-Herb Diversity in Logged Eastern Deciduous Forests. *Ecological Applications, 5,* 935-946. https://doi.org/10.2307/2269344

Noss, R. F. (1999). The Redwood Forest: History, Ecology, and Conservation of the Coast Redwoods. Washington DC: Island Press.

Nyland, R. D. (2016). *Silviculture: Concepts and Applications* (3rd ed., pp. 383-405).

Long Grove, IL: Waveland Press.

O'Hara, K. L., Nesmith, J. C. B., Leonard, L., & Porter, D. J. (2010). Restoration of Old Forest Features in Coast Redwood Forests Using Early-Stage Variable-Density Thinning. *Restoration Ecology, 18,* 125-135. https://doi.org/10.1111/j.1526-100X.2010.00655.x

Peterken, G. F. (1996). *Natural Woodland: Ecology and Conservation in Northern Temperate Regions*. Cambridge: Cambridge University Press.

Petersen, A. K., & Russell, W. (2017). *A Comparison of Stand Structure and Composition Following Selective-Harvest at Byrne-Milliron Forest* (pp. 247-258). Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Russell, W. (2009). The Influence of Timber Harvest on the Structure and Composition of Riparian Forests in the Coastal Redwood Region. *Forest Ecology and Management, 257,* 1427-1433. https://doi.org/10.1016/j.foreco.2008.12.014

Russell, W. H., & Jones, C. (2001). The Effects of Timber Harvesting on the Structure and Composition of Adjacent Old-Growth Coast Redwood Forest, California, USA. *Landscape Ecology, 16,* 731-741. https://doi.org/10.1023/A:1014486030462

Russell, W., & Michels, K. (2010). Stand Development on a 127-Yr Chronosequence of Naturally Regenerating *Sequoia sempervirens* (Taxodiaceae) Forests. *Madroño, 57,* 229-241.

Russell, W., Sinclair, J., & Michels, K. (2014). Restoration of Coast Redwood (*Sequoia sempervirens*) Forests through Natural Recovery. *Open Journal of Forestry, 4,* 106-111. https://doi.org/10.4236/ojf.2014.42016

Schmidt, F. A., Ribas, C. R., & Schoereder, J. H. (2013). How Predictable Is the Response of Ant Assemblages to Natural Forest Recovery? Implications for Their Use as Bioindicators. *Ecological Indicators, 24,* 158-166. https://doi.org/10.1016/j.ecolind.2012.05.031

Spies, T. A., & Duncan, S. L. (2009). Searching for Old-Growth. In T. A. Spies, & S. L. Duncan (Eds.), *Old-Growth in a New World: A Pacific Northwest Reexamination* (pp. 3-11). Washington DC: Island Press.

Van Pelt, R., & Franklin, J. (2000). Influence of Canopy Structure on the Understory Environment in Tall, Old-Growth, Conifer Forests. *Canadian Journal of Forest Research, 30,* 1231-1245. https://doi.org/10.1139/x00-050

Yamagawa, H., & Ito, S. (2006). The Role of Different Sources of Tree Regeneration in the Initial Stages of Natural Forest Recovery after Logging of Conifer Plantation in a Warm-Temperate Region. *Journal of Forest Research, 11,* 455-460. https://doi.org/10.1007/s10310-006-0229-4

Yamagawa, H., Ito, S., Mitsuda, Y., & Fukuzato, K. (2006). Effects of Topography and Management History on Natural Forest Recovery in Abandoned Forest after Clear-Cutting in Miyazaki, Japan. *Journal of Forest Research, 11,* 99-106. https://doi.org/10.1007/s10310-005-0192-5