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RESEARCH ARTICLE

Identification of Old-Growth Forest Reference Ecosystems Using Historic Land Surveys, Redwood National Park, California

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Abstract

Old-growth forests in the American West typically represent fragments of former, more extensive forests that were subjected to nineteenth and twentieth century land-clearing activities, such as logging. These present-day forest fragments are thought to be representative of the former landscape, and thus are capable of serving as living references for guiding restoration of logged forests. Yet how do we determine the extent to which existing old-growth stands represent the former forest, especially when little of the surrounding original vegetation remains? Historic land surveys conducted prior to significant logging can reconstruct the former forest at the stand level, thereby allowing an analysis of old-growth patches within the larger historic landscape. This study utilized original Public Land Surveys to assess the applicability of old-growth stands in Redwood National Park as reference ecosystems. A geographic information system (GIS) and statistical analysis of the nineteenth century forest found that vegetation communities, woody species composition, and ratios of dominant canopy species in unlogged patches were highly representative of the forests that were logged. Significance testing (H_o: $\mu_1 = \mu_2$) revealed *p*-values greater than 0.10000 in all measures of community and species composition, except for the higher abundance of oak in present-day old-growth (*p*-value = 0.0395). The results of this study suggest that the national park should increase efforts to protect old-growth reference ecosystems from further human impacts, and minimize ongoing degradation from edge effects by prioritizing restoration of adjoining second-growth forest.

Key words: coast redwood (*Sequoia sempervirens*), GIS, Public Land Survey.

Introduction

Reference ecosystems are critical components of planning and evaluating ecological restoration projects. They represent a single state or snapshot in the range of natural variability for the ecosystem in need of restoration (SER 2004). Thus, identification of the goals and objectives for restoration requires multiple lines of evidence, or multiple references, to understand ecosystem structure, composition, and functional processes (Foster et al. 1996; Moore et al. 1999; SER 2004).

This study fills in a significant gap in the knowledge of reference ecosystems for restoration of logged forests in Redwood National Park in northern California (41°N, 124°W): an assessment of old-growth forest based on a basin-wide reconstruction of ecosystems using historic land surveys. In conjunction with the analysis of aerial photographs (Best 1995), dendrochronology (Veirs 1982; Sugihara & Reed 1987), field surveys of the vegetation (Sugihara & Reed 1987; Lenihan 1990; Russell & Jones 2001), and qualitative historical accounts (e.g. Murdock 1921; Stover 1999), the original Public Land Surveys (PLS) contribute to the "composite description" of the basin necessary for restoration planning (SER 2004). Each one of these lines of evidence provides unique information regarding the ecosystem prior to damage, although the most effective restoration depends on understanding the range of historic variability. Thus, the original PLS field notes provide a better understanding of the forests that existed prior to logging, and thereby contribute to identifying restoration goals for second-growth forests in Redwood National Park.

Dendroecological reconstructions are limited in the national park to old-growth trees that remain standing today and the presence of intact stumps. Stumps and trees that were destroyed by tractor-logging cannot be sampled in a present-day field study. The earliest aerial photographs of the study area date to 1936—eighty-plus years after EuroAmerican settlement—and are incapable of stand-level reconstruction. Only the PLS record is capable of reconstructing the entire historic forest at the stand level. An extensive body of research has developed concerning the reliability and quality of vegetation reconstructions based on historic land surveys (e.g. Bourdo 1956; Galatowitsch 1990; Whitney 1990; Radeloff et al. 1999;

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Black et al. 2002; Bolliger et al. 2004; Wang 2007; Fritschle 2008, 2009). In Redwood National Park, the time period of the original PLS records is especially pertinent in identification of reference ecosystems because these surveys were conducted prior to widespread fire suppression, introduction of non-native species, and logging in the basin.

Using the original PLS field notes, Fritschle (2009) reconstructed the historic vegetation communities and spatial distributions of major woody species in the lower Redwood Creek basin of Redwood National Park. This study assesses the applicability of these historic communities and the remaining old-growth forest as reference ecosystems. The old-growth coast redwood communities found in the Little Lost Man Creek subbasin are considered highly representative of historic redwood-dominated communities in the park, and are studied in more detail. Using the PLS record as a basis for describing the historic nineteenth century forest, this study will answer the following questions: (1) What coniferous forest communities were logged in the lower Redwood Creek basin? (2) To what extent are the remaining old-growth coniferous forest communities representative of the historic forest? (3) Are the Little Lost Man Creek redwood forest communities representative samples of the redwood forests that were logged?

Nineteenth century surveyors noted species types according to common names rather than scientific nomenclature. Thus, the common names noted in the surveys are used throughout this paper.

Some second-growth stands in the park were reentered by timber companies and thus technically constitute third- and fourth-growth forest (Best 1995). For the sake of convenience, I will refer to all logged coniferous forests in the lower Redwood Creek basin as "second-growth."

Methods

The lower Redwood Creek basin in Redwood National Park was systematically surveyed under the auspices of the U.S. General Land Office beginning in 1875–1886. In the century following the original PLS, the lower Redwood Creek basin in Redwood National Park was subjected to extensive logging activities. Unlike many of the coast redwood (*Sequoia sempervirens*) forests further south in California, the more isolated Redwood Creek basin was not extensively logged until the mid-twentieth century (Bearss 1969; Best 1995). Prior to 1936, only 2% of the basin had been cleared, much of this was Sitka spruce (*Picea sitchensis*) forest near Orick. In 1954, 15% of the coniferous forests in the lower Redwood Creek basin had been logged. By the time most of the lower basin became national park land in 1978, 69% of the coniferous forests had been logged (Best 1995). Restoration of these second-growth forests to old-growth conditions has been identified as an important management concern in the national park (RNSP 2000; Sarr et al. 2004).

The restoration of second-growth coniferous forests in the lower Redwood Creek basin is a significant challenge for park scientists and managers. Timber companies aerially seeded and planted mostly Douglas-fir (*Pseudotsuga menziesii*) on clear-cut lands in the basin (RNP 1980; RNSP 2000). As a result, second-growth forests consist of very dense stands of small trees ranging from 5,000 to 25,000 trees per hectare, with a 10:2 overstory ratio of Douglas-fir to coast redwood (Muldavin et al. 1981; Veirs & Lennox 1981; Veirs 1986; RNSP 1999). This density of trees is two to three orders of magnitude higher than old-growth stands in the lower basin, which possess more redwood and typically have 25–90 large trees per hectare (Veirs 1982). In the overstory of old-growth stands in the park, redwood trees outnumber Douglas-fir trees ranging from 3:1 to 10:1 (RNSP 2000). Such high densities of Douglas-fir in second-growth forests effectively limit the growth of redwood. If these stands are left untreated, redwood may take as long as 100–200 years to start dominating the overstory (RNP 1980).

Although the old-growth stands in lower Redwood Creek suffer from the influence of edge effects resulting from adjacent logged forest (Russell & Jones 2001), park scientists believe that the old-growth forests found in the Little Lost Man Creek subbasin are largely representative of the historic coast redwood forests (RNP 1994) (Fig. 1). These forests are to be managed as the most "pristine" in the park (RNSP 2000). The subbasin comprises 957 ha, of which 89% (852 ha) remains as old-growth forest (RNP 1998).

To answer the questions posed in this study, the following analysis relied primarily on the processing of three geographic information system (GIS) datasets in ArcMap 9.1 (ESRI 2005):

- Line coverage of PLS-derived nineteenth century vegetation communities and species relative weights assigned to 1-mile section lines. Fritschle (2009) reconstructed the historical distribution of dominant woody species and vegetation communities in the lower Redwood Creek basin according to the original PLS record. Specifically, that analysis resulted in identification of six vegetation communities and the relative weights of species in the basin. Relative weights indicate the dominance of species within communities, but differ from more commonly employed importance values due to the absence of basal area data (Seischab 1990). Instead, relative weights derive from quantifying ranked lists of overstory and understory species noted at the end of every section mile (line summaries). For both the classification of communities and the calculation of relative weights, each 1-mile-long section line was treated as a sampling plot. Since each plot (section line) was approximately the same length (1.61 km), the average relative weight of species by community was derived from simply averaging the relative weights of all section lines within a community.
- 1:24,000 polygon coverage of present-day second- and old-growth coniferous forest created by Redwood National Park (RNP 1998).
- 1:100,000 polygon coverages of present-day vegetation alliances (USDA 2004, 2005).

To compare the historic coniferous forest with the present-day extent of old-growth and logged coniferous forest, PLS section lines were intersected with both the old-growth and logged polygons. The resulting GIS shapefiles included the

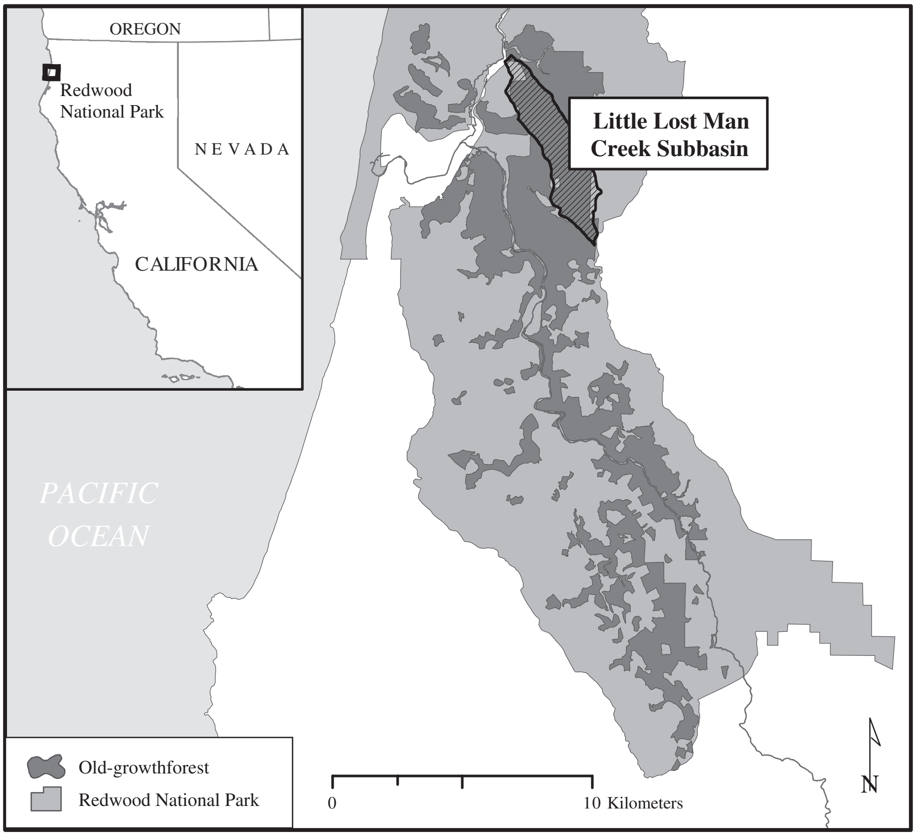

Figure 1. Old-growth forest stands, including the Little Lost Man Creek subbasin, in the lower Redwood Creek basin, Redwood National Park, California. Data sources: RNP (1998); NPS (2005).

original 1-mile-long PLS section lines divided into smaller segments within old-growth and logged coniferous forest. The composition of old-growth PLS-derived communities was determined by adding up the line segments lengths for each community type found in old-growth coniferous forest, dividing by the total length of old-growth line segments, and multiplying by 100%. Since the data were normally distributed according to normal probability and residual plots, two-tailed Student's t-tests were performed to assess significant difference between the historic and present-day old-growth forest communities. The relative weights of species within a community were also recalculated based on the length of line segments found in old-growth coniferous forest. When considering the entire study area of the lower Redwood Creek basin in Fritschle (2009), all section lines were approximately the same length (1 mile). Thus, the calculation of average relative weight for a species within a community required simply averaging all relative weights within a particular community. However, portions of these section lines were logged, resulting in differing lengths of old-growth section lines and requiring calculation of relative weights adjusted to the length of each line (Table 1).

To determine the degree to which the Little Lost Man Creek subbasin could serve as a reference redwood ecosystem required a definition of what constitutes "redwood forest" in lower Redwood Creek. Six coniferous forest alliances have been identified in the lower Redwood Creek basin: Pacific Douglas-fir (covers 4.4% of the lower basin), redwood–Douglas-fir (37.4%), Sitka spruce (1.4%), Sitka spruce–grand Fir (0.8%), Sitka spruce–redwood (5.1%), and redwood (50.8%) (USDA 2004, 2005). Alliances represent a more generalized classification of vegetation associations (Tart et al. 2005). The coniferous forest alliances were derived from remotely sensed data with a minimum mapping area of 6.25 ha and greater than 10% conifer cover (USDA 2004, 2005). Just over 90% of PLS section lines in the Little Lost Man Creek subbasin occur within the redwood alliance (a coniferous forest alliance with >50% redwood canopy cover). Redwood–Douglas-fir (9.3%) and Douglas-fir (0.3%) alliances encompass the remaining PLS lines (Fig. 2). Thus, the old-growth redwood forest in the subbasin was most appropriately compared to historic forests found within the redwood alliance. In the northern redwood range, this type of redwood-dominated forest exists on alluvial and colluvial soils along the coast and at maritime-influenced inland sites with elevations below 610 m (USDA 2004). Associated woody species include Douglas-fir, tanoak (*Lithocarpus densiflorus*), western hemlock (*Tsuga heterophylla*), California hazel (*Corylus cornuta californica*), salal (*Gaultheria shallon*), and Pacific rhododendron (*Rhododendron macrophyllum*). The

Table 1. Procedure for calculating average relative weights of community species in old-growth coniferous forest.

				Heavy Redwood-Fir Community					
Original Relative Weights				*Remaining Line Segments*		*Adjusted Relative Weights*			
FR	*HB*	*RW*	*SL*	*Length (m)*	*Percent*	*FR*	*HB*	*RW*	*SL*
33.30	0.00	66.70	0.00	1585.33	26.7	8.88	0.00	17.78	0.00
16.65	33.3	33.30	16.65	60.01	1.0	0.17	0.34	0.34	0.17
16.65	33.3	33.30	16.65	126.88	2.1	0.36	0.71	0.71	0.36
33.30	0.00	66.70	0.00	1655.36	27.8	9.27	0.00	18.56	0.00
33.30	0.00	66.70	0.00	1640.33	27.6	9.18	1.37	18.40	0.00
16.65	16.65	33.30	33.30	488.23	8.2	1.37	0.00	2.73	2.73
33.30	0.00	66.70	0.00	391.43	6.6	2.19	2.41	4.39	0.00
Original average relative weights for heavy redwood-fir community in entire study area						Adjusted average relative weights for heavy redwood-fir community in old-growth forest			
31.98	8.33	49.84	6.66			31.41	4.83	62.91	3.26

FR, fir; HB, huckleberry; RW, redwood; SL, salal.
Adjusted relative weights resulted from multiplying the original relative weight by the percent that line contributed to the total old-growth lines. For example, in the first section line listed above, the adjusted relative weight of fir was $33.30 \times 26.7\% = 8.88$. To find the adjusted average relative weight for a species within a particular community, the adjusted relative weights are added together. Thus, the average relative weight of fir within the old-growth heavy redwood-fir community is $(8.88 + 0.17 + 0.36 + 9.27 + 9.18 + 1.37 + 2.19) = 31.41$.

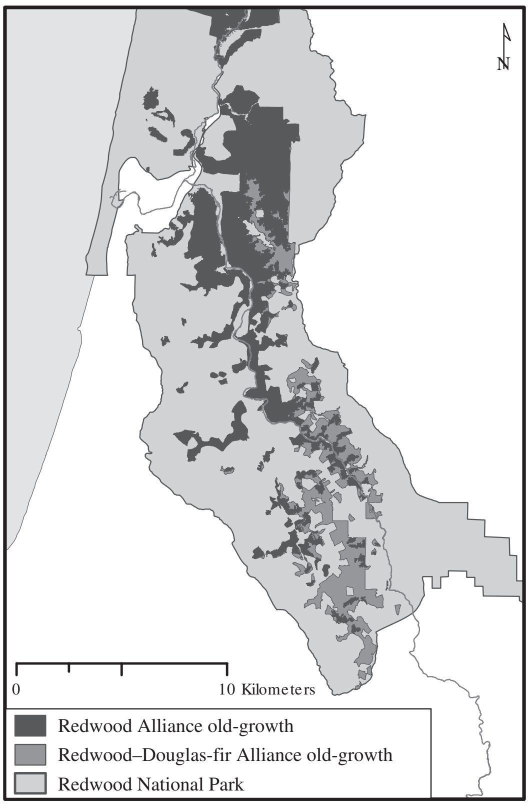

Figure 2. Redwood and redwood–Douglas-fir alliances in Lower Redwood Creek. Data sources: RNP (1998); USDA (2004, 2005); NPS (2005).

composition of PLS communities and species relative weights within the historic redwood forest and Little Lost Man Creek redwood forest were derived in the same manner as described earlier for present-day old-growth versus historic coniferous forest.

Results

Pre- and Post-Logging Coniferous Forest

Historic vegetation community section lines covered 193,817 m (approximately 120 miles) in the lower Redwood Creek basin (Table 2; Fig. 3). At the time of the original surveys, 46% of the lower Redwood Creek basin was comprised of fir-dominated communities; after logging nearly two-thirds of the original fir-dominated communities remained old-growth. Prior to logging, redwood- and oak-dominated communities accounted for 21 and 33%, respectively, of the vegetation communities in the basin. Roughly half of these communities were subsequently logged. The proportion of fir-, redwood-, and oak-dominated communities changed slightly between 1875 and the present-day: fir-dominated communities, which historically comprised 46% of the basin increased to 52% of the basin, redwood-dominated communities decreased from 21 to 20%, and oak-dominated communities decreased from 33 to 28%.

The most heavily logged communities were heavy redwood-fir and oak-fir-madrone. One-third of the heavy redwood-fir community and two-fifths of the oak-fir-madrone community remain in the basin today as old-growth forest. Originally, heavy redwood-fir represented 41% of the redwood-dominated communities in the basin and included the highest average relative weight of redwood. Currently, less than one-third of the redwood-dominated old-growth forest is composed of the heavy redwood-fir community. The oak-fir-madrone community included the highest average relative weight of fir. Thus, the communities that experienced the greatest amount of logging in the lower Redwood Creek basin had the greatest abundance (as measured by relative weights) of either redwood or fir. Communities with lower relative weights of these two species and a more equal mix of species experienced less logging.

Abundance of minor woody species such as *Vaccinium* spp. (huckleberry), *Acer* spp. (maple), and red alder were

Table 2. Public Land Survey communities (% area) and average redwood and fir overstory relative weights found in old-growth forest.

Community Type	*Area in Basin, 1875*	*Area in Basin as Old-Growth Forest, 1998*	*Proportion of Community That Remains Old-Growth*	*Average Overstory Fir Relative Weight*	*Average Overstory Redwood Relative Weight*
Fir-mixed conifer-mixed hardwood/chaparral	23.6	14.8	62.9	21.8	19.4
Fir-redwood-mixed hardwood	22.0	13.7	62.2	30.1	27.4
Fir-dominated communities (weighted average)	22.8	14.3	62.6	25.8	23.2
Fir-dominated communities (total)	45.6	28.5			
Heavy redwood-fir	8.7	3.0	34.4	26.6	48.3
Redwood-mixed conifer/chaparral	12.6	7.6	60.2	13.0	23.2
Redwood-dominated communities (weighted average)	10.6	5.3	49.6	18.7	33.7
Redwood-dominated communities (total)	21.3	10.6			
Oak-fir-madrone	15.6	6.4	41.1	41.5	0
Oak-pine-mixed conifer/chaparral	17.5	8.5	48.8	18.8	13.5
Oak-dominated communities (weighted average)	16.6	7.5	45.2	29.5	7.1
Oak-dominated communities (total)	33.1	14.9			
		Overall average:	54.1		

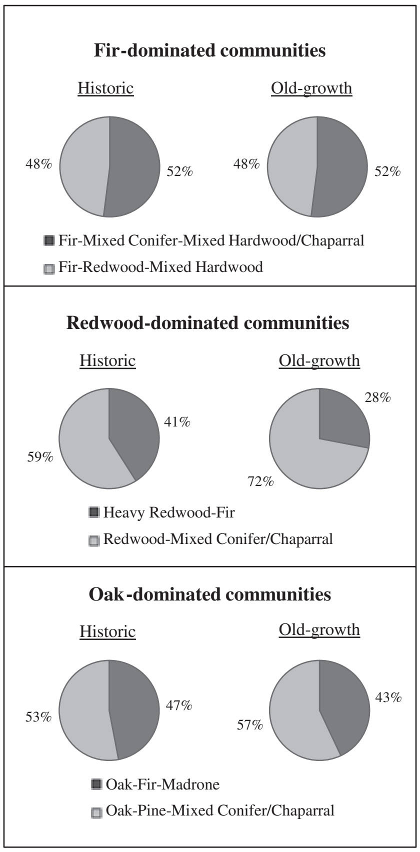

Figure 3. Breakdown of pre- and post-logging communities according to dominant woody species.

the most different, while the most dominant species—fir, redwood, and oak—were the most similar between the historic versus present-day old-growth coniferous forest (Table 3). On average, the heavy redwood-fir community possessed the greatest differences in relative weights of species between the old-growth and historic forest. In the old-growth heavy redwood-fir community, only redwood had a higher average relative weight compared to the historic forest. Except for oak (p-value $= 0.0395$), the increase or decrease in mean relative weight between the historic and old-growth forest was not significantly different. Similarly, the ratios of fir versus redwood average relative weights were not significantly different between the entire historic coniferous forest and the forests that now constitute logged and old-growth coniferous forest (Table 4).

Overall, these results suggest that while a significant amount of these communities was logged (p-value $= 0.00007$, H_o: $\mu_1 = \mu_2$), the proportions of communities within their dominant species type are not significantly different in the remaining old-growth forest (p-value $= 0.50000$, H_o: $\mu_1 = \mu_2$). In other words, the differences within the fir-dominated communities between historic coniferous forest and present-day old-growth coniferous forest are not significantly different. Similarly, the composition of all species, except oak, is not significantly different within communities.

Old-Growth Redwood Forest in the Little Lost Man Creek Subbasin

A comparison of redwood forest found throughout the lower Redwood Creek basin versus redwood forest in the Little Lost Man Creek subbasin yielded slightly higher average relative weight values in the subbasin for redwood, Sitka spruce, *Pinus* spp. (pine), red alder, California buckeye (*Aesculus californica*), chaparral (*Baccharis pilularis*), and huckleberry species (Table 5). Thus, the dominance of these species is slightly overrepresented in the subbasin compared to the redwood forest found throughout the lower basin in 1875–1886. Fir, oak, Pacific madrone (*Arbutus menziesii*), maple, *C. cornuta californica* (hazel), and salal are slightly less dominant in the subbasin. However, only the average

Table 3. Average relative weight of species by community, pre-logging coniferous forest (PC) versus uncut coniferous forest (UC).

Community	Fir		Redwood		Oak		Spruce		Pine		Alder		Madrone	
	PL	*UC*	*PL*	*UC*	*PL*	*UC*	*PL*	*UC*	*PL*	*UC*	*PL*	*UC*	*PL*	*UC*
Fir-mixed conifer-mixed hardwood/chaparral	30.5	29.7	26.8	25.5	17.5	19.2	15.3	14.7	0.4	1.1	4.0	3.3	0.8	1.0
Fir-redwood-mixed hardwood	30.8	31.1	28.0	24.5	20.4	22.1	0.0	0.0	0.6	0.0	0.0	0.0	5.5	6.1
Fir-dominated communities	30.7	30.4	27.4	25.0	19.0	20.7	7.7	7.4	0.5	0.6	2.0	1.7	3.2	3.6
Heavy redwood-fir	32.0	31.4	49.8	62.9	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0
Redwood-mixed conifer/chaparral	15.1	17.7	24.3	24.6	2.6	3.7	12.7	11.4	9.0	15.0	0.0	0.0	0.0	0.0
Redwood-dominated communities	23.5	24.6	37.1	43.8	1.3	1.8	6.3	5.7	4.5	7.5	1.3	0.0	0.0	0.0
Oak-fir-madrone	41.8	33.1	0.0	0.0	36.2	41.1	0.0	0.0	5.2	10.2	0.5	1.1	16.2	14.6
Oak-pine-mixed conifer/chaparral	20.6	24.0	15.1	17.4	20.0	20.3	0.5	0.8	25.0	23.9	0.0	0.0	1.1	1.7
Oak-dominated communities	31.2	28.5	7.6	8.7	28.1	30.7	0.2	0.3	15.1	17.1	0.3	0.5	8.7	8.1
Overall average RW	28.5	27.8	24.0	25.8	16.1	17.7	4.7	4.5	6.7	8.4	1.2	0.7	3.9	3.9
p-value	0.6917		0.4026		0.0395*		0.2447		0.1661		0.2722		0.8736	

Community	Maple		Buckeye		Hazel		Salal		Chaparral		Huckleberry	
	PL	*UC*	*PL*	*UC*	*PL*	*UC*	*PL*	*UC*	*PL*	*UC*	*PL*	*UC*
Fir-mixed conifer-mixed hardwood/chaparral	0.6	0.9	0.0	0.0	1.4	2.2	0.9	0.6	1.6	2.1	0.1	0.0
Fir-redwood-mixed hardwood	0.6	0.0	1.0	1.6	0.0	0.0	2.9	3.1	0.1	0.1	2.2	1.4
Fir-dominated communities	0.6	0.5	0.5	0.8	0.7	1.1	1.9	1.9	0.9	1.1	1.2	0.7
Heavy redwood-fir	0.0	0.0	0.0	0.0	0.0	0.0	6.7	3.3	0.5	0.0	8.3	2.4
Redwood-mixed conifer/chaparral	0.0	0.0	0.0	0.0	0.4	0.8	5.4	4.7	29.4	19.5	1.2	2.6
Redwood-dominated communities	0.0	0.0	0.0	0.0	0.2	0.4	6.1	4.0	14.9	9.7	4.8	2.5
Oak-fir-madrone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oak-pine-mixed conifer/chaparral	0.0	0.0	0.0	0.0	0.0	0.0	3.1	20.3	14.6	10.2	0.0	0.0
Oak-dominated communities	0.0	0.0	0.0	0.0	0.0	0.0	1.6	10.2	7.3	5.1	0.0	0.0
Overall average RW	0.2	0.2	0.2	0.3	0.3	0.5	3.2	5.3	7.7	5.3	2.0	1.1
p-value	0.5348		0.2815		0.1299		0.0818		0.1419		0.3437	

* Significant at the 0.05 level.

Table 4. Fir versus redwood average relative weight ratios by community in coniferous forest.

Community	*Pre-Logged Forest 1875–1886*	*Old-Growth Forest, 1998*	*Logged Forest, (cut 1945–1978)*
Fir-mixed conifer-mixed hardwood/chaparral	1.14	1.16	1.23
Fir-redwood-mixed hardwood	1.10	1.27	1.02
Heavy redwood-fir	0.64	0.50	0.61
Redwood-mixed conifer/chaparral	0.63	0.72	0.59
Oak-fir-madrone	No redwood	No redwood	No redwood
Oak-pine-mixed conifer/chaparral	1.36	1.38	1.62
Overall	0.97	1.01	1.01

Ratio values >1.0 indicate higher average relative weights of fir; values <1.0 indicate higher average relative weights of redwood; a value of 1.0 indicates the same average relative weight for both species. Pre-logged versus uncut p-value: 0.5653; pre-logged versus logged p-value: 0.5533;
old-growth versus logged p-value: 0.9317.

relative weight of oak was found to be significantly different (p-value $= 0.0462$, H_o: $\mu_1 = \mu_2$). A comparison of fir to redwood ratios revealed that redwood was significantly more important in the Little Lost Man Creek subbasin compared to the basin-wide redwood forest (p-value $= 0.0341$, H_o: $\mu_1 = \mu_2$) (Table 6).

The composition of communities in redwood forest between Little Lost Man Creek old-growth and the historic Redwood Creek basin redwood forest was not significantly different (p-value $= 0.4526$, H_o: $\mu_1 = \mu_2$). The largest differences in the proportion of communities within their dominant species types are the amount of redwood- and oak-dominated forest, 43 and 46% more important in the subbasin, respectively. Nonetheless, these differences are not significantly different. The composition of communities within the Little Lost Man Creek old-growth forest is representative of the historic redwood forest in the lower Redwood Creek basin.

In sum, the 852 ha of old-growth redwood forest in the Little Lost Man Creek subbasin is largely representative of the 11,708 ha of redwood forest found throughout the lower Redwood Creek basin; however, redwood is more dominant over fir in the subbasin.

Discussion

The results of this analysis suggest that the remaining old-growth coniferous forest in the lower Redwood Creek basin, including the old-growth redwood forest in the Little Lost Man Creek subbasin, is highly representative of the historic forest. The composition of communities and the average relative weights of species within those communities are not significantly different between the present-day old-growth forest and the logged forest. Thus, the coniferous forest in the

Table 5. Comparison of species average relative weights for lower Redwood Creek (RC) redwood forest versus Little Lost Man Creek (LM) old-growth redwood forest (%).

Community	Fir RC	Fir LM	Redwood RC	Redwood LM	Oak RC	Oak LM	Spruce RC	Spruce LM	Pine RC	Pine LM
Fir-mixed conifer-mix hardwood/chaparral	29.5	26.8	24.9	33.9	19.9	16.1	15.2	16.3	0.7	0.0
Fir-redwood-mixed hardwood	31.3	25.9	32.3	29.6	18.4	11.1	0.0	0.0	1.7	0.0
Fir-dominated communities	30.4	26.4	28.6	31.7	19.2	13.6	7.6	8.2	1.2	0.0
Heavy redwood-fir	28.6	27.1	56.6	54.2	0.0	0.0	0.0	0.0	0.0	0.0
Redwood-mixed conifer/chaparral	15.6	23.9	23.4	35.7	2.8	0.0	12.2	11.0	10.4	18.7
Redwood-dominated communities	22.1	25.5	40.0	45.0	1.4	0.0	6.1	5.5	5.2	9.4
Oak-pine-mixed conifer/chaparral	21.7	8.4	15.0	25.0	17.0	0.0	1.1	0.0	20.7	16.7
Overall average relative weight	25.3	22.8	30.4	35.7	11.6	3.9	5.7	7.0	6.7	10.4
p-value	0.1587		0.2562		0.0462*		0.4833		0.1326	

Community	Alder RC	Alder LM	Madrone RC	Madrone LM	Maple RC	Maple LM	Buckeye RC	Buckeye LM	Hazel RC	Hazel LM
Fir-mixed conifer-mix hardwood/chaparral	2.1	4.0	1.1	0.0	1.1	0.0	0.0	0.0	2.1	0.0
Fir-redwood-mixed hardwood	0.0	0.0	5.0	7.4	0.0	0.0	1.9	3.7	0.0	0.0
Fir-dominated communities	1.1	2.0	3.1	3.7	0.5	0.0	0.9	1.9	1.1	0.0
Heavy redwood-fir	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Redwood-mixed conifer/chaparral	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
Redwood-dominated communities	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Oak-pine-mixed conifer/chaparral	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Overall average RW	0.5	0.6	1.4	1.1	0.2	0.0	0.4	0.5	0.5	0.0
p-value	0.2218		0.2413		0.1870		0.1870		0.2902	

Community	Salal RC	Salal LM	Chaparral RC	Chaparral LM	Huckleberry RC	Huckleberry LM
Fir-mixed conifer-mix hardwood/chaparral	1.2	0.0	2.2	2.9	0.0	0.0
Fir-redwood-mixed hardwood	3.7	7.4	0.1	0.0	2.3	14.9
Fir-dominated communities	2.5	3.7	1.2	1.4	1.2	7.4
Heavy redwood-fir	5.9	12.5	0.1	0.0	8.5	6.2
Redwood-mixed conifer/chaparral	3.8	0.0	29.8	10.7	1.5	0.0
Redwood-dominated communities	4.9	6.2	14.9	5.4	5.0	3.1
Oak-pine-mixed conifer/chaparral	3.2	0.0	20.3	50.0	0.0	0.0
Overall average RW	3.6	2.8	10.5	12.2	2.5	3.0
p-value	0.4649		0.4809		0.2902	

* Significant at the 0.05 level.

lower Redwood Creek basin identified as effective old-growth (Russell & Jones 2001) can serve as a reference ecosystem for restoration of logged forests to old-growth conditions.

How might this evaluation of old-growth forests using the original PLS records affect ongoing park policies and ecological restoration activities? This question applies to both the parklands of Redwood Creek as well as to other parklands possessing representative old-growth forests. The implications for park policy and management are twofold.

First, if stands of old-growth are found to be highly representative of landscapes requiring ecological restoration, park policies should reflect the added importance of protecting these reference ecosystems. Protection should be geared toward as little human interference as possible in order to protect functioning, intact reference ecosystems. The task of national parks to balance visitor use and environmental protection can still be achieved as smaller fragments of old-growth forest serve the needs of interpretive programs and visitor enjoyment. Although access and visitor development of these reference ecosystems should be limited, the old-growth stands can be intensively studied to inform specific objectives in second-growth restoration.

In Redwood Creek, park managers have taken this step for the redwood alliance forest. The Little Lost Man Creek subbasin, as this study has shown, contains highly representative old-growth redwood forest. The subbasin has been designated a Research Natural Area subzone of the primitive zone within the national park (RNSP 2000). Research Natural Areas in the national parks are permanently designated for the purpose of observation, monitoring, and long-term environmental research in areas typifying an ecological community type (NPS 2004). The results of the PLS analysis found that other old-growth forest alliances in the basin are also highly representative of the former forest. Although less extensive in area and more fragmented, Redwood–Douglas-fir alliance old-growth in the southern half of the park warrants enhanced protection and further study as a reference ecosystem. Twenty percent of old-growth in the lower Redwood

Table 6. Fir versus redwood average relative weight ratios by community in redwood alliance forest.

Community	Redwood Forest in Entire Redwood Creek Basin	Redwood Forest in Little Lost Man Creek Subbasin
Fir-mixed conifer-mixed hardwood/chaparral	1.19	0.79
Fir-redwood-mixed hardwood	1.01	1.01
Heavy redwood-fir	0.51	0.51
Redwood-mixed conifer/chaparral	0.73	0.67
Oak-fir-madrone	No redwood	No redwood
Oak-pine-mixed conifer/chaparral	0.67	0.33
Overall	0.82	0.63
p-value	0.0341*	

Ratio values >1.0 indicate higher average relative weights of fir; values <1.0 indicate higher average relative weights of redwood; a value of 1.0 indicates the same average relative weight for both species.
* Significant at the 0.05 level.

Creek basin is found within this alliance (RNP 1998; USDA 2004, 2005).

The second implication for park policy and management activities relates to prioritizing restoration of second-growth forest stands. Since the protection of reference ecosystems is paramount to restoring second-growth stands, it follows that stands surrounding reference ecosystems should be restored first. In Redwood Creek, formerly clear-cut stands are directly adjacent to old-growth forest, resulting in up to a 50% reduction in effective old-growth (Russell & Jones 2001). Thus, to protect the reference ecosystems from further edge effects, the first objective in second-growth restoration should deal with the edges along the old-growth forest. Key biotic and abiotic variables should be identified for forest edges that will change the forest structure to reflect, for example, old-growth microclimatic, soil moisture, and disturbance regimes. The identification of key variables allows us to identify those organisms and abiotic processes most likely to encourage further structural and processes development (Moore et al. 1999). In Redwood Creek, buffering the reference ecosystems in such a manner would likely involve furthering the work that the park has identified as management objectives, specifically thinning the thickets of Douglas-fir and exotic species, reintroducing fire, and planting native species (RNSP 2000).

Unlike many studies that have used the PLS to reconstruct historic vegetation, significant stands of old-growth forest still exist in the lower Redwood Creek basin. This allows us to gauge how representative current old-growth is compared to the historic forest.

The PLS reconstruction provides a historical reference for forests that no longer exist today, thus it can contribute to ongoing restoration and management decisions. Future work in restoration of coast redwood forests would benefit from a field study mimicking the original PLS in old-growth forest to better gauge the strengths and limitations of this reconstruction, similar to the work by Manies and Mladenoff (2000) in northern Wisconsin. Although that study made significant contributions to understanding PLS records, especially in relation to scales and methodologies for creating presettlement vegetation maps, forests in the Pacific Northwest differ substantially in the terrain surveyors had to traverse, the types of species and ecosystems found, and the historical context of the surveys, including differing sets of instructions and problems with land fraud. Such a study would also assist in uncovering biases that may exist in the PLS record for this region and enable more direct comparisons with other field-based studies of redwood forests.

Implications for Practice

- A GIS analysis of historic land surveys, such as the original PLS, can be used to determine the degree to which remnant old-growth patches are representative of the former forest (reference ecosystems). This analysis can also identify ecosystems that occupied a specialized, narrow niche in the historic landscape.
- Identification of representative old-growth patches can aid in the triaging of landscape protection and restoration, prioritizing protection of highly representative patches and restoration of adjacent damaged ecosystems to buffer further damage to the representative ecosystem.

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