



Vegetation Community Monitoring

Species Composition and Biophysical Gradients in Klamath Network Parks

Natural Resource Report NPS/KLMN/NRR—2021/2236





The production of this document cost \$25,743, including costs associated with data collection, processing, analysis, and subsequent authoring, editing, and publication.

ON THIS PAGE

Photo of vegetation monitoring crew working in an old-growth redwood site.
Photo by NPS

ON THE COVER

Sampling at Whiskeytown National Recreation Area
Photograph by: Sean B. Smith, Klamath Network

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Natural Resource Report NPS/KLMN/NRR—2021/2236

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March 2021

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Smith, S. B., P. J. van Mantgem, and D. Odion. 2021. Vegetation community monitoring: Species composition and biophysical gradients in Klamath Network parks. Natural Resource Report NPS/KLMN/NRR—2021/2236. National Park Service, Fort Collins, Colorado.
<https://doi.org/10.36967/nrr-2284769>.

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Abstract

The Klamath Network of the National Park Service consists of six park units located in northern California and southern Oregon. The Network began implementing a vegetation monitoring protocol in 2011 to identify ecologically significant vegetation trends in the parks. The premise of the protocol is that multivariate analyses of species composition data is the most robust early detection means for identifying vegetation change over time. Here we present these community metrics, based on our initial sampling efforts. We use these metrics to establish a baseline for comparison in future trend analysis, and to evaluate the adequacy of the protocol for meeting the Network's objectives of detecting temporal changes across contrasting vegetation types.

The park landscapes were subdivided into three strata: Matrix (low- to mid-elevation upland habitats), Riparian (within 10 meters of a perennial stream), and High-Elevation (above a predefined elevation, park specific). Across the three strata, we established a total of 241 permanent plots at random locations to measure complete species composition and cover. We describe baseline biophysical conditions and relate them to the data obtained from all 241 plots using ordination analyses. The unconstrained gradient analyses were moderately robust at illustrating the relationships among plots and correlating them to environmental gradients. We also prepared species accumulation curves representing gamma diversity, which showed overall species richness, and also illustrated how well the observed vs. expected richness values of each stratum were captured by the sampling. Most park/strata were well sampled; for others, we found that additional samples would improve how well the protocol captures the vegetation composition within park/strata. Specifically, all sample frames at Whiskeytown and the High-Elevation sample frames at Lassen were not well sampled. Comparisons of alpha diversity values showed High-Elevations had the lowest diversity, while Riparian areas were by far the most diverse across all parks. The Matrix stratum at Oregon Caves National Monument was also especially diverse and had the highest Matrix alpha diversity we observed in all parks. We suggest that after three rounds of sampling, the Network perform analyses to identify possible ways to improve statistical power. These options include adding sites or lengthening the sampling interval. Results of these analyses could support protocol modifications. This report on vegetation composition is the first in a series of analysis and synthesis reports. Future analysis and synthesis reports will analyze structure and function.

Acknowledgments

We thank the many field crews who collected the field data. Rob Klinger and Kathryn McEachern provided helpful comments on an earlier version of this report. This work was supported by the National Park Service and the U.S. Geological Survey's Ecosystems Mission Area. This product has been peer reviewed and approved for publication consistent with USGS Fundamental Science Practices (<http://pubs.usgs.gov/circ/1367/>). Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Introduction

The National Park Service manages 417 national park units (<https://www.nps.gov/aboutus/national-park-system.htm>) across the U.S. for the purpose of preserving their natural and cultural resources. In pursuit of this goal, the National Park Service in 1998 initiated a long-term Inventory and Monitoring program to monitor the “vital signs” of ecosystem health (<https://www.nps.gov/im/vital-signs.htm>). The monitoring program is hierarchical; the parks have been partitioned into 32 networks (<https://www.nps.gov/im/networks.htm>). The goal of the Inventory and Monitoring program is to “develop scientifically sound information on the current status and long term trends in composition structure and function of park ecosystems...” (Fancy et al. 2009).

National parks, like other protected areas, are an important conservation tool to protect biodiversity (Rodrigues et al. 2004). Often relatively undisturbed, protected areas provide natural laboratories where collection of baseline and trend data can be used to explore the patterns and drivers of plant diversity, and serve as reference sites to compare the biology of more disturbed landscapes (Fancy et al. 2009; Grime and Pierce 2012).

In this report, we examine vegetation monitoring data from six park units arrayed across the Klamath Region, a hot spot for temperate plant diversity in North America (Whittaker 1960; DellaSala et al. 1999; Vander Schaaf et al. 2004; Burge et al. 2016; Baldwin et al. 2017). Baseline data were collected with a standardized protocol, *Monitoring Vegetation Composition, Structure, and Function in the Parks of the Klamath Network* (Odion et al. 2011), creating an unparalleled opportunity to quantitatively analyze vegetation patterns to serve management and provide broad insights for floristic conservation in this region. In addition to this vegetation baseline summary, we assess adequacy of the Klamath Inventory and Monitoring Network vegetation community monitoring protocol for capturing the status and trends in vegetation composition and structure in the Klamath Network (Figure 1) (Sarr et al. 2007; Odion et al. 2011).

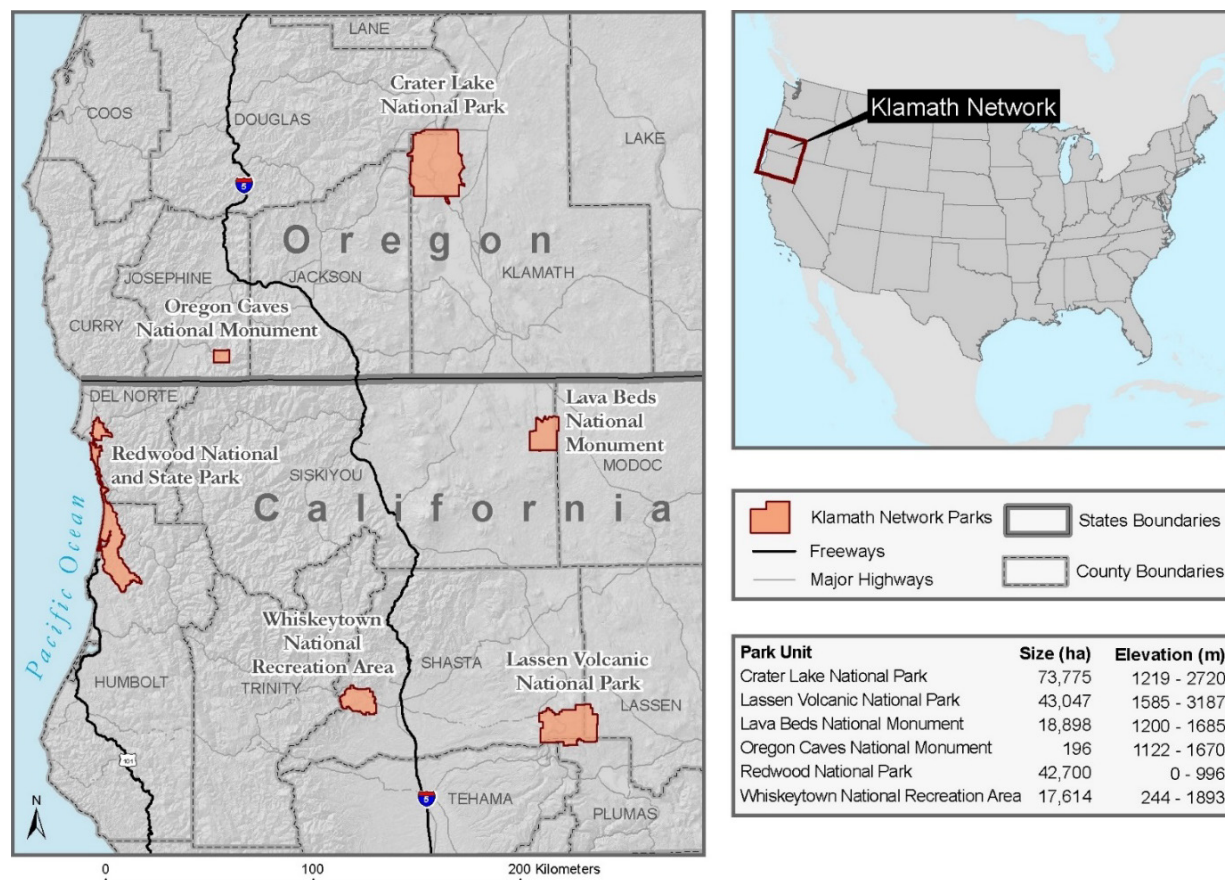
The Klamath Network

The Klamath Network contains 6 parks: Crater Lake National Park (Crater Lake), Lava Beds National Monument (Lava Beds), Lassen Volcanic National Monument (Lassen), Oregon Caves National Monument and Preserve (Oregon Caves), Redwood National and State Parks (Redwood), and Whiskeytown National Recreation Area (Whiskeytown). The parks vary dramatically in size (196 ha to 73,775 ha, See inset table in Figure 1). Note that in 2014 the area of Oregon Caves was expanded from 196 to 1,843 ha, after the development of the vegetation monitoring protocol.

The parks span a land area of complex topography in the geologically ancient Klamath-Siskiyou Ecoregion in the west (containing Redwood, Oregon Caves and Whiskeytown), and the younger, volcanic Cascades-Modoc Ecoregion to the east (containing Crater Lake, Lassen and Lava Beds) (Sarr et al. 2007) (Figure 1). The six parks of the Klamath Network are arrayed across a transitional area between maritime, continental, and Mediterranean air masses in western North America (Mitchell 1976; Sarr et al. 2015). Maritime influences decline with distance from the ocean (westward to eastward), so that precipitation decreases and annual temperature variations increase. Summer droughts, a distinguishing feature of Mediterranean climates, are modulated by summer fogs

along the coast, while interior areas at low elevations (Whiskeytown) experience extremely high summer temperatures.

Vegetation of the two subregions (described in detail in Appendix A) ranges from temperate rainforests with enormous, world-record-height trees along the coast at Redwood, to barren shrublands on infertile soils and rock in the sagebrush desert of Lava Beds. Elevation extends from sea level at Redwood, to above timberline in Crater Lake and Lassen (Figure 1). The parks of the Klamath Network also differ in geologic and paleobotanical history. The Klamath Region has both ancient and young, heterogeneous, geology. Floristically, the parks capture elements of the southern Oregon and northern California Coast Ranges, the Sierra Nevada, Cascade Range, and Great Basin, all near the northern end of the California Floristic Province (Sarr et al. 2015). The central significance of the Klamath Region as a floristic center of diversity, speciation, endemism and as a glacial refugium in western North America has been recognized in the classic papers by Whittaker (1960, 1961), Stebbins and Major (1965), and more recently by Burge et al. (2016) and Baldwin et al. (2017). The center of this area in the Siskiyou Mountains has “a greater diversity of forest communities, in a more complex vegetation pattern, than any comparable area of the West.” (Whittaker 1960).



Objectives

This report is the first analysis and synthesis of vegetation monitoring data collected under the Klamath Network vegetation monitoring protocol. For reference, the overall protocol has four objectives, abbreviated here:

1. Describe the composition, structure, and function of vegetation communities.
2. Quantify temporal and spatial change.
3. Sample communities of special concern (alpine and riparian).
4. Co-locate sampling sites with bird and stream monitoring to evaluate interrelationships.

In this report we address the first element of protocol objective #1 by calculating and presenting baseline metrics for vegetation composition. Future analysis and synthesis reports will cover structure and function. We start with vegetation composition because the protocol was built on the premise that much of the information and insight about temporal change in vegetation will be contained in multivariate analyses of vegetation composition in relation to elevation and climatic gradients (Odion et al. 2011). Multivariate approaches can be complemented by univariate analyses of compositional data such as species richness, diversity, and evenness in relation to environmental gradients. These multivariate approaches can be used to efficiently explore composition data derived from univariate analysis and identify progressive changes in vegetation and the underlying biophysical trends. Changes in vegetation composition can provide compelling evidence that a meaningful ecological event has occurred, or an ecological threshold has been exceeded (Anderson and Thompson 2004).

Thus, our specific objectives for this report are to

1. Characterize baseline vegetation composition in Klamath Network parks using metrics such as species richness, diversity, and evenness.
2. Conduct preliminary analyses to relate species composition to environmental gradients.
3. Make recommendations on sampling design and data analysis.

In future reports, we will use these baseline metrics to address the second objective of the protocol: detecting temporal and spatial change in vegetation composition (objective #2; Odion et al. 2011). Specifically, the baseline results in this report will set us up to then address three components of objective #2: 1) quantifying changes in relative abundance of species, 2) quantifying changes in beta diversity (species identity and relative abundance), and relate compositional turnover to environmental gradients, and 3) quantifying changes in alpha and gamma diversity (species richness and evenness).

Methods

Vegetation

We compiled vegetation descriptions from comprehensive documents prepared as foundational to the Network (Sarr et al. 2007) (Appendix A). Appendix B provides links to the park vegetation map products.

We also prepared lists of the 15 most abundant vascular plant species, by growth form, in the 241 plots we established for this vegetation monitoring protocol, (Appendices C–H). We followed the USDA PLANTS (USDA, NRCS 2020) definitions of Growth Habits: Forb/herb – vascular plant without significant woody tissue above or at the ground; Graminoid – grass or grass-like plants; Shrub – perennial, multi-stemmed woody plant; Tree – perennial, woody plant with a single stem; Vine – twining/climbing plant with relatively long stems. One exception we made to the USDA PLANTS growth form definitions is that we eliminated subshrubs and used local observations to lump them into either Forb/herb or Shrub. Additionally, for each park, we classified species into Plant Functional Types based on leaf type and deciduousness for woody species, and annual vs. perennial composition for herbs and graminoids.

We also classified sites to the alliance level following the California Native Plant Society (CNPS 2019) classification. If a direct match was not found, we used park vegetation maps (Appendix B) to match sites to National Vegetation Classification Standard (NVCS) alliances. We used the species name of each alliance to determine Growth Habit. When an alliance name had two species listed, we used name with highest overall cover from our site. We also used the alliance species name to add duration of the species: annual or perennial, and classified perennial plants as either evergreen or deciduous.

Biophysical Parameters

For this report we selected data from the PRISM Climate Group (PRISM 2015) (data last accessed 5/14/2019) to determine core climate variables to relate to vegetation. PRISM is a climate analysis system that utilizes point data, digital elevation models (DEM), and other spatial datasets to develop gridded estimates of climatic parameters (Daly et al. 1994). For each plot we extracted 30-year ‘normals’ (1981–2010) at an 800 m spatial resolution to identify mean temperature (°C) and precipitation (mm) for the entire calendar year, as well as average winter (Dec, Jan, Feb) minimum temperatures, average summer (Jun, Jul, Aug) maximum temperatures, and average summer maximum vapor pressure deficits (hPa).

Field Sampling Design

We conducted plot-based sampling following a standardized protocol developed by Odion et al. (2011). The following restrictions were applied to the sampling layout: 1. Areas more than 1 km from a road or trail were excluded to reduce travel time; 2. Areas within 100 m from the road and trail network were excluded to minimize human impacts to vegetation (except at Whiskeytown); 3. Steep slopes (>30°) and other areas too dangerous to sample (sharp lava rock, talus, and scree slopes) were excluded. At Whiskeytown, we were forced to limit our sample frame to >50 m and < 200 m from roads and trails as a safety precaution due to illegal *Cannabis* cultivation. The *Cannabis*

cultivation restrictions at Whiskeytown did not appear to eliminate any habitat types. The sampling frames for each park are shown in (Figure 2A–F). They were divided into Matrix (low to mid-elevation upland habitats), Riparian, (within 10 meters of a perennial stream), and High-Elevation strata (above a predefined elevation, park specific), as defined in Odion et al. (2011) (next section). Overall, there were 13 separate park/stratum combinations. Within each stratum, spatially balanced, *random* sample sites were selected using the Generalized Random Tessellation Stratified algorithm, a true probability design (Stevens and Olsen 2004). Table 1 shows the number of plots that fit into each park’s sample frame. The Matrix stratum as a whole had many more plots than the others (131 plots out of 241). The highest number of plots in any sample frame (30) was in the Matrix at Lava Beds. Conversely, only 10 Matrix plots were sampled at Oregon Caves. Only 14 Riparian plots were sampled at Lassen, while only 10 were sampled in the High-Elevation stratum at Lassen and Whiskeytown.

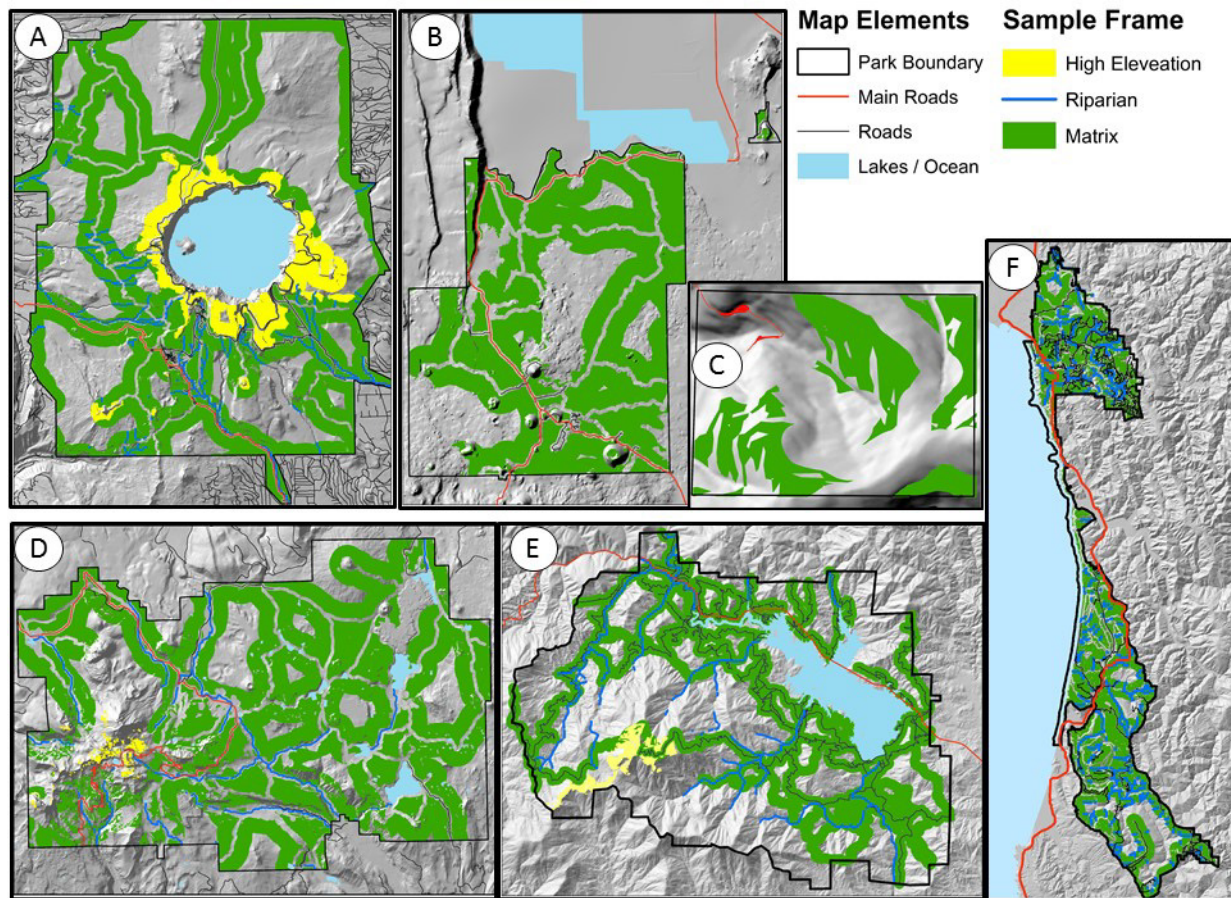


Figure 2. Map showing parks and vegetation monitoring sampling frames used for the Klamath Network’s vegetation monitoring protocol. Matrix stratum (green), Riparian stratum (Blue), and High-Elevation stratum (yellow) for all six park units of the Klamath Network: A = Crater Lake National Park, B = Lava Beds National Monument, C = Oregon Caves National Monument and Preserve, D = Lassen Volcanic National Park, E = Whiskeytown National Recreation Area, and F = Redwood National and State Park.

Table 1. Number of plots in the Klamath Network vegetation monitoring protocol by stratum type, and the total number of species (gamma diversity), and total number of tree, shrub, herb, graminoid and vine species found in each stratum in each park.

Park	Counts	Matrix	Riparian	High Elevation	All
Crater Lake	Number of plots	26	20	20	66
	Number of species	78	246	57	287
	Number of tree species	9	9	5	12
	Number of shrub species	13	30	5	36
	Number of herb species	41	142	29	169
	Number of graminoid species	15	64	18	69
	Number of vine species	0	1	0	1
Lava Beds	Number of plots	30	0	0	30
	Number of species	133	–	–	133
	Number of tree species	3	–	–	–
	Number of shrub species	17	–	–	–
	Number of herb species	99	–	–	–
	Number of graminoid species	14	–	–	–
	Number of vine species	0	–	–	–
Lassen	Number of plots	18	14	10	52
	Number of species	96	276	46	323
	Number of tree species	10	8	4	11
	Number of shrub species	20	28	6	38
	Number of herb species	49	168	21	193
	Number of graminoid species	17	72	15	81
	Number of vine species	0	0	0	0
Oregon Caves	Number of plots	10	0	0	10
	Number of species	112	–	–	112
	Number of tree species	12	–	–	–
	Number of shrub species	18	–	–	–
	Number of herb species	69	–	–	–
	Number of graminoid species	12	–	–	–
	Number of vine species	1	0	0	–
Redwood	Number of plots	26	21	0	47
	Number of species	145	191	–	243
	Number of tree species	10	11	–	13
	Number of shrub species	21	29	–	33

Table 1 (continued). Number of plots in the Klamath Network vegetation monitoring protocol by stratum type, and the total number of species (gamma diversity), and total number of tree, shrub, herb, graminoid and vine species found in each stratum in each park.

Park	Counts	Matrix	Riparian	High Elevation	All
Redwood (continued)	Number of herb species	84	104	–	140
	Number of graminoid species	27	44	–	54
	Number of vine species	3	3	–	3
Whiskeytown	Number of plots	21	15	10	46
	Number of species	197	228	66	333
	Number of tree species	11	17	5	19
	Number of shrub species	45	37	19	65
	Number of herb species	101	110	34	174
	Number of graminoid species	33	54	8	65
	Number of vine species	7	10	–	10
All Parks	Number of plots	131	70	40	241
	Number of Species	556	654	133	891

The following describes the strata:

Matrix Stratum

The Matrix vegetation stratum includes all areas across the parks not otherwise classified as Riparian, or High-Elevation. In a wide-ranging collection of sites such as the Klamath Network it is reasonable to expect that Matrix stratum will vary among parks. The Matrix stratum contained several different vegetation types, primarily composed of low- to mid-elevations and Tree, Shrub, Forb/herb, Graminoid, or Vine dominated (see Table 2 below for a complete list). Every park had a Matrix stratum.

Riparian Stratum

This stratum consists of areas 10 m on either side of perennial streams and seeps. Perennial stream coverages were derived from USGS National Hydrography Dataset (<http://nhd.usgs.gov>), and confirmed by park resource staff. Riparian sampling frames were developed for Crater Lake, Lassen, Whiskeytown, and Redwood. Due to the small size of our sampling area and steep terrain, Oregon Caves did not have suitable riparian habitat. No riparian habitat exists at Lava Beds. At Redwood, we rejected some riparian sites based on inability to safely fit plots within steep and narrow stream corridors. Plots at Redwood are therefore biased toward less steep and rocky terrain.

High-Elevation Stratum

High-Elevations only occur in Lassen, Crater Lake, and Whiskeytown. They were defined to include predominantly subalpine zones (Odion et al. 2011). Sites are between 2100–2400 m at Crater Lake and 2500–2800 m at Lassen. High-elevation habitat at Whiskeytown, the small area near the summit of a mountain peak known as Shasta Bally, is lower than at Crater Lake and Lassen. It ranges from

1524 m to 1890 m. The lower limits of the High-Elevation stratum were determined by inspecting aerial imagery to identify the lowest subalpine forests. To efficiently pursue multiple monitoring goals, ten high elevation vegetation monitoring sites were co-located with whitebark pine (*Pinus albicaulis*) monitoring sites at both Crater Lake and Lassen (McKinney et al. 2012). Whiskeytown lacks whitebark pine. McKinney et al. (2012) required all 50 x 50 m whitebark pine sites to have at least one live whitebark pine ≥ 1.37 m in height. We also established 10 sites in the Crater Lake High-Elevation stratum not co-located with whitebark pine sites.

Table 2. Mean percent of plots with different alliance level Plant Functional Types for the Matrix, Riparian, and High-Elevation strata in each park sampled in 2011–2013 by the Klamath Network using its vegetation monitoring protocol. Mean number of species shown with standard error in parentheses.

Park/Stratum	Plant Functional Type	% of total plots	# plots	Mean # Species
Crater Lake/Matrix	Conifer (Evergreen)	96	25	13.2 (1.3)
	Shrub (Deciduous)	4	1	15.0 (–)
Crater Lake/Riparian	Conifer (Evergreen)	57	15	66.9 (2.2)
	Graminoid (Perennial)	8	2	59.5 (0.5)
	Shrub (Deciduous)	8	2	75.5 (3.5)
	Forb/Herb (Perennial)	4	1	45.0 (–)
Crater Lake/High-Elevation	Conifer (Evergreen)	55	11	17.2 (2.2)
	Graminoid (Perennial)	20	4	15 (3.6)
	Forb/Herb (Perennial)	20	4	16.3 (2.2)
	Shrub (Evergreen)	5	1	22.0 (–)
Crater Lake Total	10	–	–	–
Lava Beds/Matrix	Shrub (Evergreen)	57	17	35.5 (2.1)
	Graminoid (Annual)	17	5	29.0 (5.1)
	Broadleaf (Evergreen)	10	3	35.3 (4.3)
	Conifer (Evergreen)	7	2	45.5 (1.5)
	Graminoid (Perennial)	7	2	38.0 (2)
	Shrub (Deciduous)	3	1	36.0 (–)
Lava Beds Total	6	–	–	–
Lassen/Matrix	Conifer (Evergreen)	83	15	16.3 (2.0)
	Shrub (Evergreen)	17	3	15.0 (1.2)
Lassen/Riparian	Conifer (Evergreen)	71	10	64.9 (5.2)
	Shrub (Deciduous)	21	3	65.3 (8.4)
	Forb/Herb (Perennial)	7	1	70 (–)
Lassen/High-Elevation	Conifer (Evergreen)	40	4	13.3 (2.9)
	Forb/Herb (Perennial)	60	6	13.7 (2.1)
Lassen Total	7	–	–	–

Table 2 (continued). Mean percent of plots with different alliance level Plant Functional Types for the Matrix, Riparian, and High-Elevation strata in each park sampled in 2011–2013 by the Klamath Network using its vegetation monitoring protocol. Mean number of species shown with standard error in parentheses.

Park/Stratum	Plant Functional Type	% of total plots	# plots	Mean # Species
Oregon Caves/Matrix	Conifer (Evergreen)	100	10	49 (2.0)
Oregon Caves Total	1	–	–	–
Redwood/Matrix	Conifer (Evergreen)	65	17	24.4 (2.4)
	Broadleaf (Evergreen)	27	7	18.9 (1.6)
	Graminoid (Perennial)	8	2	35.5 (3.5)
Redwood/Riparian	Broadleaf (Deciduous)	43	9	50.4 (3.1)
	Conifer (Evergreen)	47	10	41.9 (4.6)
	Broadleaf (Evergreen)	5	1	67.0 (–)
	Graminoid (Perennial)	5	1	49.0 (–)
Redwood Total	8	–	–	–
Whiskeytown/Matrix	Broadleaf (Evergreen)	57	12	41.5 (5.4)
	Shrub (Evergreen)	19	4	24 (6.5)
	Conifer (Evergreen)	19	4	30.3 (2.5)
	Broadleaf (Deciduous)	5	1	40.0 (–)
Whiskeytown/Riparian	Broadleaf (Evergreen)	53	8	63.6 (7.1)
	Broadleaf (Deciduous)	20	3	51 (3.6)
	Conifer (Evergreen)	13	2	43.5 (1.5)
	Vine (Deciduous)	13	2	54.0 (6.0)
Whiskeytown/High-Elevation	Conifer (Evergreen)	70	7	18.9 (4.6)
	Shrub (Evergreen)	30	3	13.0 (1.0)
Whiskeytown Total	10	–	–	–

Field Sampling Methods

We sampled each plot once between 2011–2013: Redwood and Lava Beds, 2011; Whiskeytown and Lassen, 2012; Oregon Caves and Crater Lake, 2013. The field crews sampled each permanent plot using a multiscale 20 x 50 m (0.1 ha) plot. In Matrix and High-Elevation strata, a 20 x 50 m plot design was employed (Figure 3A–B). In the Riparian stratum, depending on stream sinuosity and safety concerns, either two 10 m x 50 m belts were established on each side of the stream, or one 10 m x 100 m was established on one side of the stream (Figure 4A–B). All 0.1 ha plots were subdivided into predetermined and permanent 10 m x 10 m modules. Some Riparian 10 x 10 m modules were slightly less than 100 m² due to the parallelogram module shape caused by stream sinuosity. Such changes in plot shape have not been demonstrated to materially affect the outcome of species diversity studies, so long as total area is equivalent (Keeley and Fotheringham 2005).

In each 0.1 ha plot, the field crew recorded all species present. These data were used in species richness analyses. All other analyses used species abundance data from ocular cover estimates all species in 4 of the 10 x 10 m modules (Figures 3A, 3B, 4A–B). Module level abundance values were collected by two-observers, reaching unanimous decision on ocular cover estimates to the nearest 1%, (100 m² plot, 1 m² equals 1%). For a scale of reference each 10 x 10 m module has a 1 x 1 m (1 m²) and a 3.16 x 3.16 m (10 m²) submodule established. These are used for a scale of reference while determining cover values, and are especially helpful in estimating covers for herbaceous species and small shrubs.

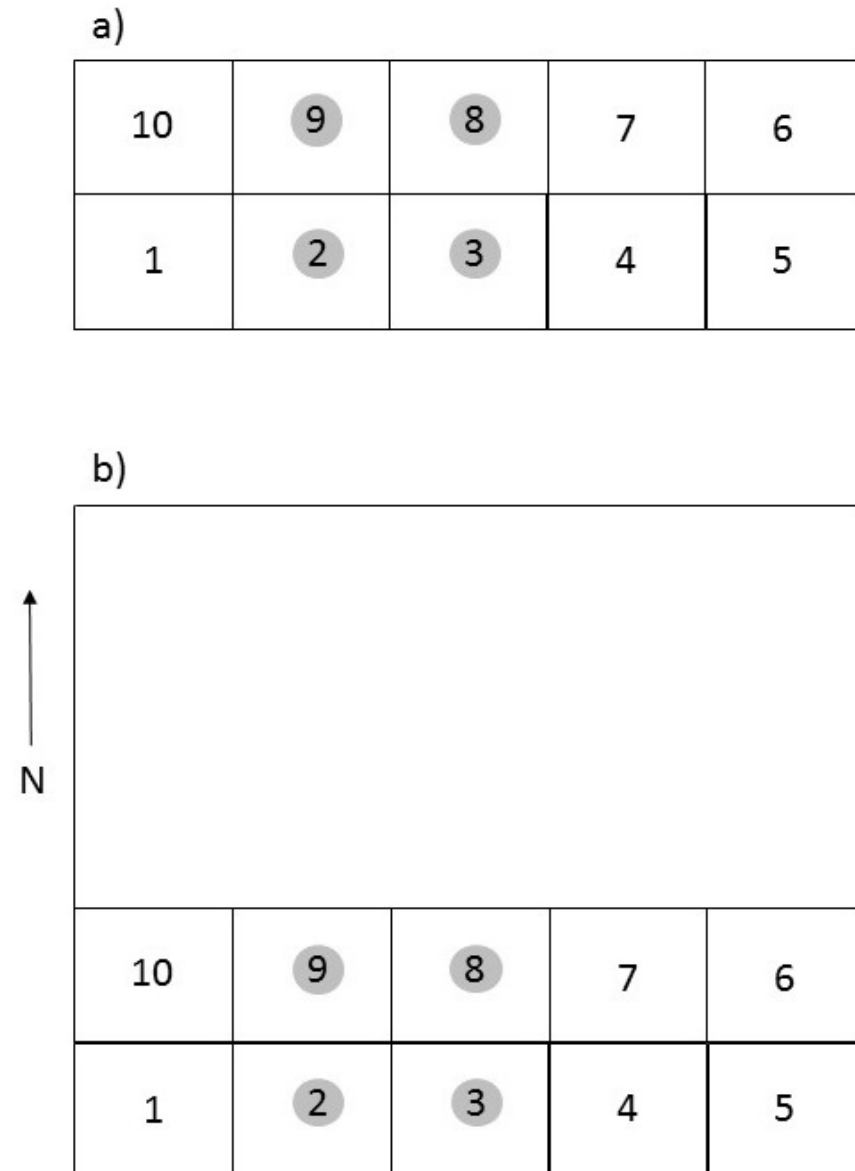


Figure 3. Arrangement of the 0.1 ha plots sampled for the Klamath Network's vegetation monitoring protocol. a) The 20 × 50 m Matrix plot design, and b) the 20 x 50 High-Elevation plot nested within a larger 50 x 50 m Whitebark Pine monitoring plot. Each numbered module is 10 × 10 m. Modules with grey circles are predetermined and permanent where ocular cover estimates are taken.

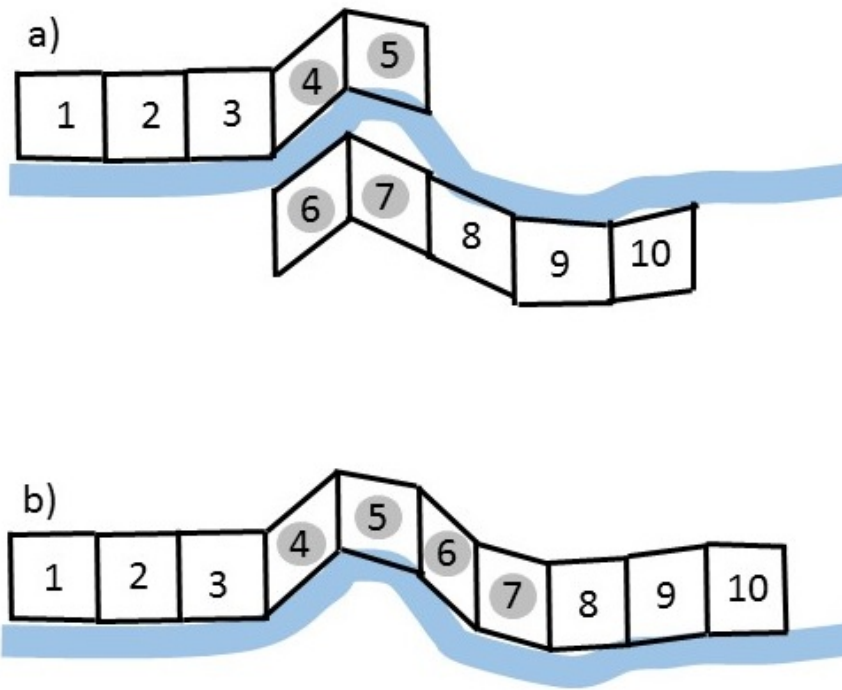


Figure 4. Arrangement of the 0.1 ha plots in the Riparian stratum sampled for the Klamath Network’s vegetation monitoring protocol. Riparian plots were either arranged as a) 2–10 × 50 m modules, covering both sides of the stream, or b) 10 × 100 m modules, only on one side of the stream bank. Each numbered module is 10 × 10 m edge to edge. Some modules are not squares but rather parallelograms; these are not exactly 100 m², but slightly less. Modules with grey circles are predetermined and permanent where ocular cover estimates are taken.

Multiple floras were used for species identification: The California Flora *Jepson Manuals 1 and 2* (Hickman et al. 1993; Baldwin et al. 2012), *Flora of the Pacific Northwest* (Hitchcock and Cronquist 1973); *Flora of North America* (V 24 and 25: 1993); and *Field Guide to Sedges of the Pacific Northwest* (Wilson et al. 2008). To correct differences in the taxonomic conventions of these various floristic references, we matched all identified species to the US Department of Agriculture, Natural Resources Conservation Service PLANTS database (USDA, NRCS 2020). When an identified species did not have a direct match in PLANTS, we carefully evaluated synonymy to match the field name to the accepted PLANTS name. Plants encountered that could not be identified to species level, were excluded from our analysis. This occurred infrequently and only with plants that were rare in a plot.

Data Analyses

Vegetation

We summarized the cover of all major plant growth forms in each stratum in each park, and categorized them out into functional types. We also enumerated the flora of each park and stratum. To help explain the variability of vegetation encompassed in each stratum in each park, we identified

the dominant individual species at each site with highest mean cover value and used its functional type to quantify the range of functional types present in each park stratum.

Non-Native Species

Non-native species were queried from our dataset using the USDA PLANTS (USDA, NRCS 2020). designation of introduced in the lower 48 states (L48 I). We generated rank abundance curves (Magurran 2004) both including and excluding non-native species.

Vegetation/Environment Relationships

To relate variation in species composition and abundance to biophysical gradients, we performed unconstrained gradient analysis using nonmetric multidimensional scaling (NMS) using the vegetation analysis package “vegan” (Oksanen et al. 2019) in R (R Development Core Team 2018). We used square root transformed absolute cover data for all recorded species (rare species were retained) in all 241 plots, and Bray-Curtis (Bray and Curtis 1957) distances to calculate a goodness of fit (stress value) on the reduction of data into two-dimensional ordination space. We correlated the NMS ordination results to environmental variables using the function “envfit” from the vegan package, with the strength of the correlations shown as arrow length when plotted in ordination space.

Gamma Diversity (Total Park and Sample Frame Species Richness).

The total diversity of a landscape or geographic area is gamma diversity (Whittaker 1972). To calculate gamma diversity, we prepared species accumulation curves of observed and estimated species richness values (presence/absence in our 0.1 ha sites) as a function of the number of plots sampled in each park stratum (Chao2, following Gotelli and Colwell 2010) using Primer E (Clarke and Gorley 2015). We did these calculations for all park/sample frame combinations, using 999 permutations.

Beta Diversity (Park and Sample Frame Similarity)

Whittaker (1972) defines beta diversity as the extent of differentiation of communities along habitat gradients. We calculated Bray-Curtis similarities to represent beta diversity across strata in all parks, and within strata at each park. We used square root transformed cover data for all recorded species in 4 10 x 10 m modules from each site to calculate Bray-Curtis similarity values (Anderson et al. 2011) using Primer E v7 (Clarke and Gorley 2015). We then prepared Plexus Diagrams (McIntosh 1978) for each park/stratum combination to visually represent among park Bray-Curtis similarity.

Alpha Diversity (Species Richness within Plots)

Following Whittaker (1972), an important measure of alpha-diversity is the number of species in a standard size sample area. To represent alpha diversity, we calculated the mean number of species in each park and stratum. The species richness average is based on presence/absence data in the 0.1 ha plots.

Diversity and Evenness: A secondary aspect of alpha diversity relates to species dominance vs. evenness (Whittaker 1972): are the species within a site evenly distributed? Does one species dominate in cover or number of individuals, or all are species present in equal abundance? To represent this aspect of alpha diversity, we calculated the Shannon-Wiener Index (H), and Pielou's

evenness (J) using the package “vegan” (Oksanen et al. 2019) in R (R Development Core Team 2018)) in each park and stratum based on either composition or cover. We then converted Shannon-Wiener Index to Hill’s $N1$ ($\exp^H$) (Hill 1973). Shannon entropy can be somewhat difficult to interpret, and the conversion to Hill’s $N1$ allows for comparison of true diversity, referred to as effective number of species. For instance, a site with Shannon entropy of 3.2 has about 24 effective species where as a site with 2.5 Shannon entropy has about 12 effective species, with higher values being more diverse. Pielou’s evenness varies theoretically from 0 to 1, with 0 indicating complete dominance by one species and 1 indicating all species have the same cover value.

Results

Vegetation Description

Total Species

Table 1 shows the total numbers of species (gamma diversity), by park, sampling frame. There were 891 total species found in all 241 plots. There were marginally more Riparian species than Matrix species (654 vs. 556). In contrast, within each park, there were many more Riparian species than Matrix species, and species in both of these strata were much more numerous than in the High-Elevation stratum. Surprisingly, the total number of species in the Riparian stratum was lowest at Redwood. Whiskeytown had 491 species, far more total species than the other parks. Oregon Caves, with only 10 total plots, all in the Matrix stratum, had the fewest species of any park.

Plant Cover, Growth Habit, and Plant Functional Type

Figure 5 summarizes cover of Plant Growth Habit by park and stratum. Cover of all Growth Habits tended to decrease from west (Redwood) to east (Lava Beds) and decrease from lower to higher elevations. Redwood had the highest total plant cover in the Riparian and Matrix strata, with Whiskeytown Riparian only slightly less, roughly twice that of Crater Lake and Lassen (Figure 5). Lava Beds had by far the lowest Matrix cover. High-Elevation strata had substantially lower cover compared to the other strata within the same park. The High-Elevation cover at Whiskeytown was much higher than at Crater Lake and Lassen.

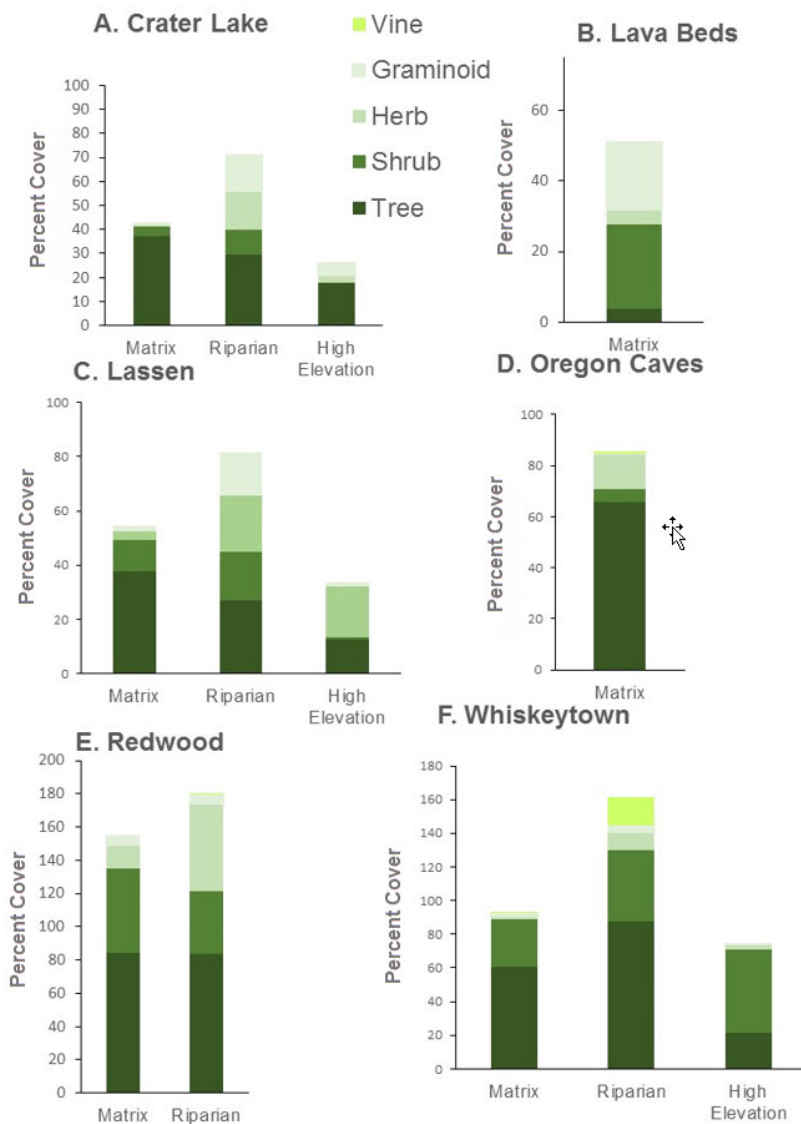


Figure 5. Total of average site cover (%) at each park for trees, shrubs, herbs, graminoids, and vines in each sampling frame as measured during sampling for the Klamath Network’s vegetation monitoring protocol from 2011–2013. Vines were present at the Crater Lake and Redwood Riparian sample frames and Whiskeytown Matrix, but are not shown here as the cover values are very small. See Appendix I for means and SE for this figure.

Across the parks, Plant Functional Type (Table 2) diversity was highest in Whiskeytown and Crater Lake, the highest elevation range occurs at Whiskeytown, and the second highest at Crater Lake (Figure 6A). Among the three strata, Riparian was most diverse across parks in terms of Plant Functional Type, followed by the Matrix and High-Elevation stratum. There were, however, exceptions to these general patterns among parks.

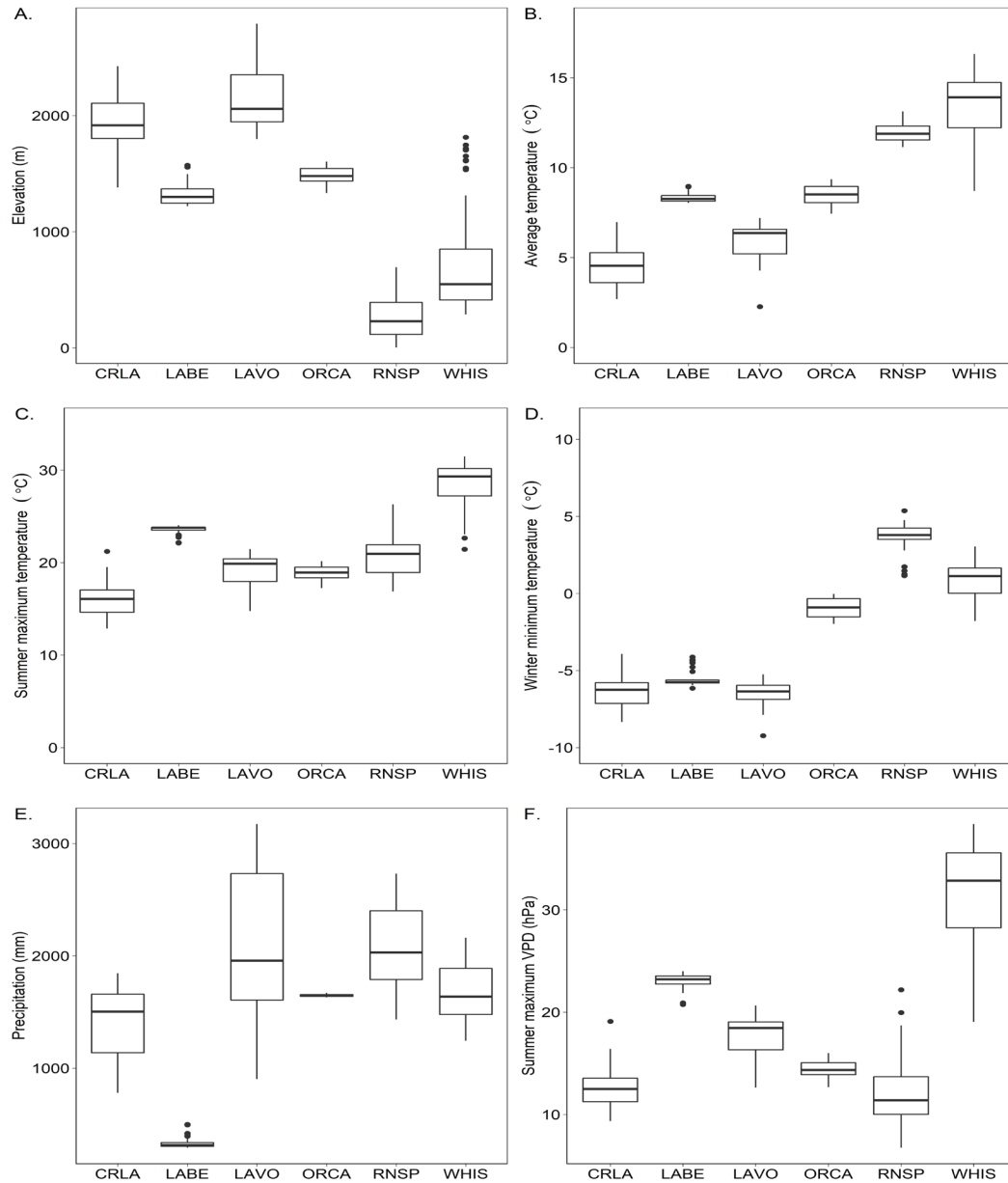


Figure 6. Boxplots of A. Elevation, B. Mean temperature (Tmean), C. Summer maximum temperature, D. Winter minimum temperature, E. Precipitation, and F. Summer Vapor Pressure Deficit (hPa), for vegetation monitoring sampling locations in each of the six national park units in the Klamath Network. The horizontal lines show the median values, while the upper and lower ends of the boxes show the upper and lower quartiles. CRLA-Crater Lake, LAVE-Lava Beds, LAVO Lassen, ORCA-Oregon Caves, RNSP-Redwood, WHIS-Whiskeytown.

Crater Lake. The Matrix stratum was relatively homogeneous, with Plant Functional Type dominated by conifers. Conifer dominants were mountain hemlock (*Tsuga mertensiana*) and California red fir (*Abies magnifica*). The predominant deciduous shrub, which dominated one plot, and was common in most others in the Matrix, was grouse whortleberry (*Vaccinium scoparium*). Riparian plots were also conifer-dominated (mainly subalpine fir (*Abies lasiocarpa*)). In addition, graminoids were

common in Riparian plots, especially bluejoint (*Calamagrostis canadensis*). High-Elevation sites had twice the number of Plant Functional Type dominants as did high elevation plots at Lassen and Whiskeytown. High elevations in Crater Lake, though conifer- (mountain hemlock) dominated, were unique among the Network parks in having a high frequency of graminoids, predominantly smooth woodrush (*Luzula glabrata*) and Brewer's sedge (*Carex breweri*), which dominate large areas of pumice substrata.

Lava Beds. The singular Matrix stratum at Lava Beds was anomalous because of its shrub and annual species dominance of both Plant Growth Habit and Plant Functional Type. Lava Beds had six Plant Functional Types, the highest value we found for a singular stratum. The dominant shrub by far was big sagebrush (*Artemisia tridentata*). Evergreen shrubs as a whole were the predominant Plant Functional Type. Non-native, annual cheatgrass (*Bromus tectorum*) made up almost half of the cover and was found in all 30 plots. Other Plant Functional Types included a semi-arborescent conifer, western juniper (*Juniperus occidentalis*), and a perennial graminoid, Sandberg bluegrass (*Poa secunda*).

Lassen. Similar to Crater Lake, this park's vegetation is dominated by conifers, but by different species [white fir (*Abies concolor*) and California red fir (*Abies magnifica*), in the Matrix and Riparian Strata, respectively]. It also differs from Crater Lake in that it lacks graminoid dominance in the High-Elevation stratum. This resulted in lower Plant Functional Type diversity (only 2 types compared to 4 at Crater Lake). The herb, bluntlobed lupine (*Lupinus obtusilobus*), was most the most dominant species in the High-Elevation stratum in this park.

Oregon Caves. Evergreen Conifers were very strongly dominant in terms of Plant Functional Type (only 1). In fact, conifers, particularly white fir (*Abies concolor*), strongly dominated all 10 plots. Shrubs and Graminoids were almost completely absent.

Redwood. Total plant cover in the Redwood Matrix stratum was far greater than in other parks. However, diversity of Plant Functional Type in the Matrix was only moderate. All dominant shrubs in all strata were evergreen, and the most dominant was California huckleberry (*Vaccinium ovatum*), but massive coast redwood trees (*Sequoia sempervirens*) were nearly as dominant among Plant Functional Type. In the Riparian stratum, four Plant Functional Types were found, like the Riparian stratum at Whiskeytown and Crater Lake. Also, like Whiskeytown, broadleaved deciduous, red alder (*Alnus rubra*) and other species were more frequent Plant Functional Type dominants in Riparian plots. Perennial herbs were particularly common in the Riparian stratum. The dominant was western swordfern (*Polystichum munitum*). Ferns were uncommon in other parks.

Whiskeytown. In contrast to the other parks in the Network, conifers were only dominant in the High-Elevation stratum. Matrix cover of Plant Growth Habit and Plant Functional Type was much greater than at Crater Lake and Lassen, but lower than at Lava Beds and Redwood. Broad-leaved trees dominated: canyon live oak (*Quercus chrysolepis*), an evergreen, and California black oak (*Quercus kelloggii*), a deciduous tree. Also, in the Matrix stratum, the evergreen chaparral shrub, sticky white leaf manzanita (*Arctostaphylos viscida*), was a dominant. Graminoid or herb-dominated plots were lacking. The Riparian stratum was highest in cover of Plant Growth Habit, and diverse in terms of

Plant Functional Type. Broadleaved deciduous trees (white alder (*Alnus rhombifolia*)), were more frequent than conifers in this park's Riparian stratum, where broadleaved evergreen trees (canyon live oak) also exceeded conifers in Growth Habit cover and Plant Functional Type diversity. Unlike any other park/stratum combination, vines (specifically, California wild grape (*Vitis californica*)) were an important Plant Functional Type in Whiskeytown's Riparian stratum. The High-Elevation stratum had only two Plant Functional Type dominants. Of these, the Evergreen Shrub Functional Type was most common, with the ground cover pinemat manzanita (*Arctostaphylos nevadensis*), and the semi-arborescent form of tanoak (*Notholithocarpus densiflorus* var. *echinoides*) sharing dominance.

Non-Native Species

Table 3 presents the percentages of non-native plants out of all plants observed in each park. We observed 74 non-native species in the Matrix sample frame and 61 in the Riparian. We did not detect any non-native species in the Oregon Caves Matrix sites, or in any of the High-Elevation strata. Sites at Lava Beds, Redwood, and Whiskeytown had the highest proportion of non-native species. Non-native species tended to be present with sparse cover. Rank abundance curves from the Riparian and Matrix sample frames show a very quick decline; only a few sites had high non-native species cover values (Figure 7). Only 4 Riparian sites had non-native relative cover values of 10% or greater, three from Whiskeytown and one from Redwood, all four had the same species: Armenian blackberry (*Rubus armeniacus*). Using the same cut-off of 10% cover, we had 9 plots in the Matrix sample frame. Seven of those were at Lava Beds, and all had cheatgrass (*Bromus tectorum*), and one site also had redstem filaree (*Erodium cicutarium*). The other two Matrix sites occurred at Redwood, both had individual non-native species cover over 10%, both had more than one non-native species.

Table 3. Mean percent of non-native species for each park and strata (Matrix, Riparian, and High-Elevation) sampled in 2011–2013 by the Klamath Network using its vegetation monitoring protocol.

Park	Matrix	Riparian	High-Elevation
Crater Lake	1	1	0
Lava Beds	12	–	–
Lassen	1	1	0
Oregon Caves	0	–	–
Redwood	10	10	–
Whiskeytown	13	12	0

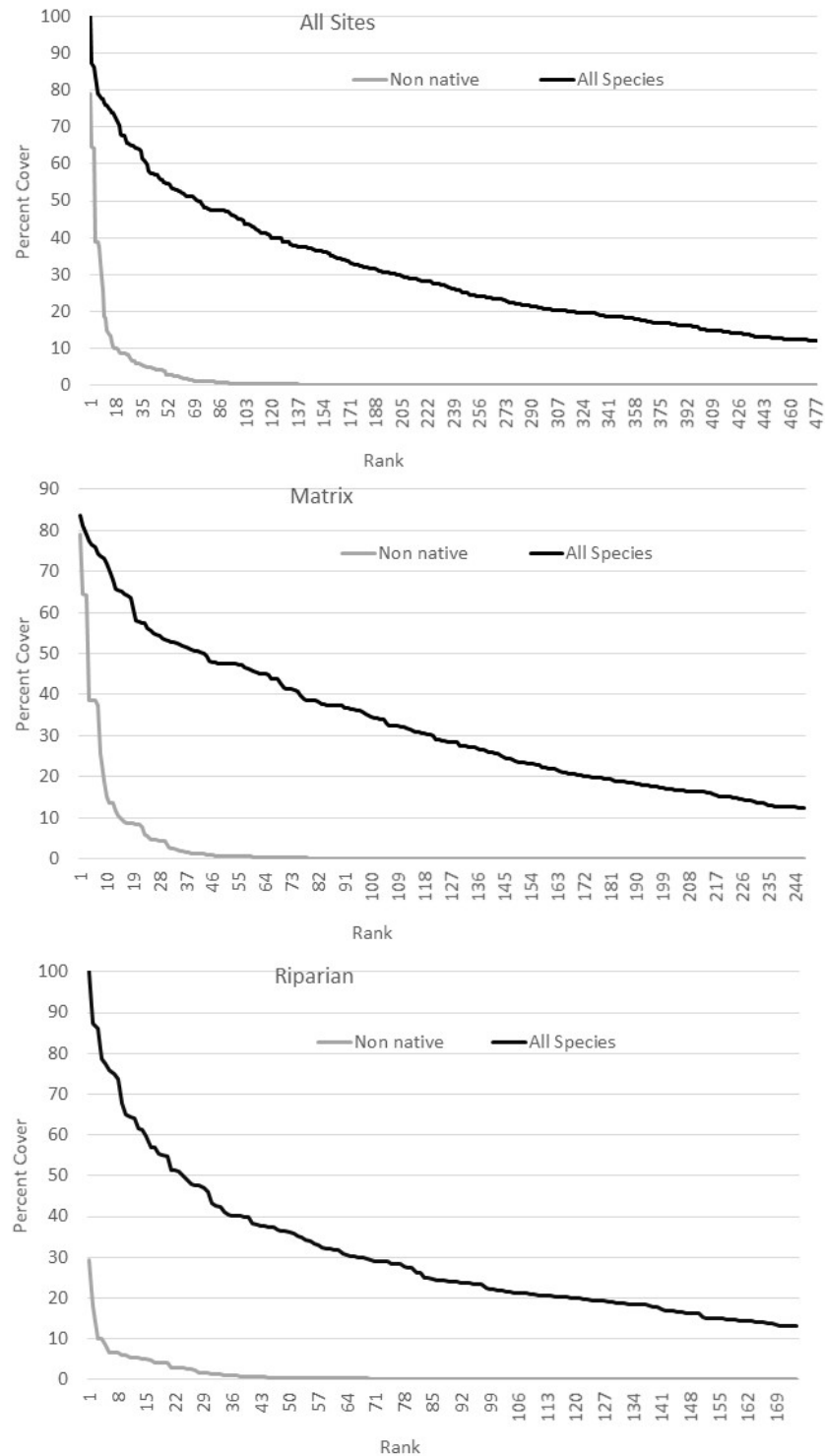


Figure 7. Rank abundance curves for all species and non-native species in all sites, Matrix, and Riparian Strata sampled from 2011–2013 by the Klamath Network using its vegetation monitoring protocol.

Biophysical Parameters

The average elevations of the 241 permanent plots in each park are shown in Figure 6A. Crater Lake and Lassen had the highest plot elevations, Redwood and Whiskeytown had the lowest. The range in elevations among plots was large, except at Lava Beds and Oregon Caves. As expected, temperature patterns (Figures 6B–D) were inversely related to elevations, with one park, Lava Beds, departing from the linear trend due to high maximum and minimum temperatures of the Matrix stratum. There was substantial variation in modeled annual precipitation within and among parks (Figure 6E). Lava Beds' plots had far less, ca. 200 mm, than the other parks (all >1500 mm). The highest modeled precipitation amounts occurred at Redwood and Lassen (2000 mm). Some plot locations at Lassen exceeded 3,000 mm in modeled annual precipitation. Vapor pressure deficit (Figure 6F) closely resembles summer maximum temperatures (Figure 6C), but with the exception that Redwood has the lowest overall mean vapor pressure deficit.

Vegetation/Environment Relationships

The unconstrained ordination of species cover data from all 241 plots that we conducted had a stress value of 0.14 (Figure 8). This is considered to be acceptable reduction to two-dimensional space (Clarke 1993). The goodness of fit of this ordination is displayed as a Shepard diagram in Figure 8.

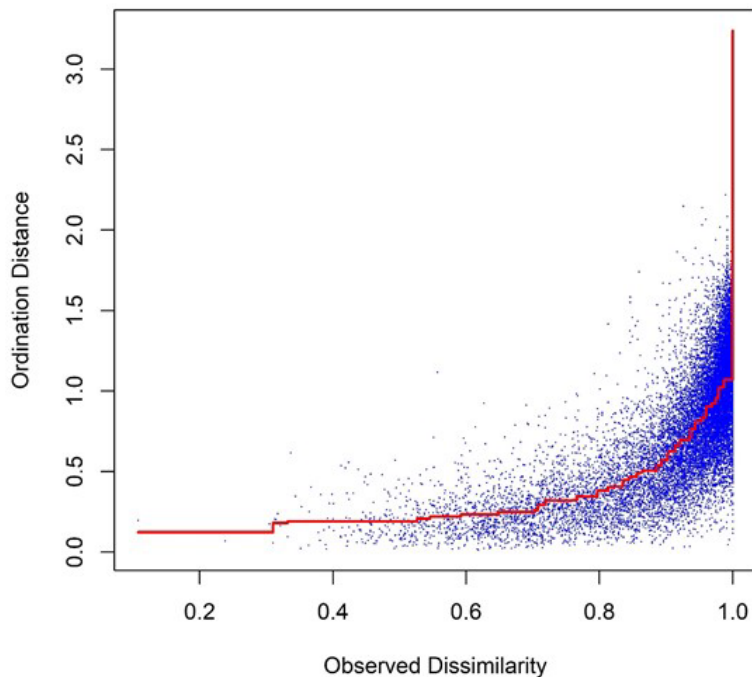


Figure 8. Shepard diagram showing the dissimilarities of the Bray-Curtis distances in vegetation cover among plots versus the ordination distances derived from Non-metric Multidimensional Scaling Ordination.

Ordination of the data visually illustrates the relationships among plots in two-dimensional space based on sites and species (abundances) relations (Figure 9). The correlations between biophysical variables and species composition and abundance in each plot are proportional to the length of the

vectors shown in the ordination plot. Thus, the ordination illustrates the correlation between species composition and biophysical gradients. The most influential environmental variables were elevation and temperature, which were inversely related to each other, and secondly vapor pressure deficit and precipitation, which were also inversely related (Figure 9).

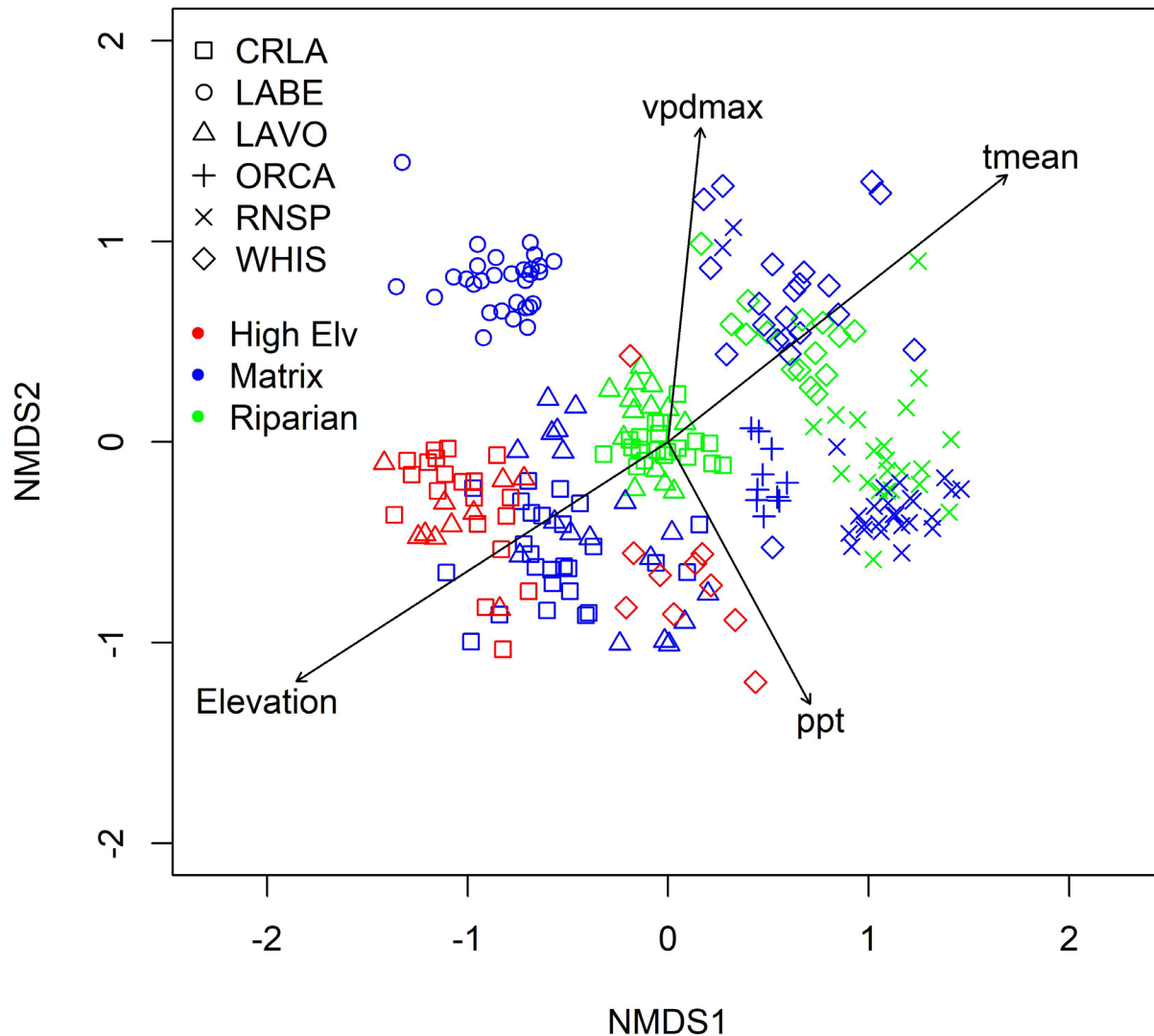


Figure 9. Unconstrained Gradient Analyses of 2011–2013 plot data (N = 241) from the Klamath Network vegetation monitoring protocol using Non-metric Multidimensional Scaling Ordination. Biophysical variables: elevation = site elevation, vpdmax = summer maximum vapor pressure deficit, tmean = mean temperature, ppt = precipitation. CRLA = Crater Lake, LAVE = Lava Beds, LAVO = Lassen Volcanic, ORCA = Oregon caves, RNSP = Redwood National and State Parks, WHIS = Whiskeytown.

Groupings of plots occur for both parks and strata. Two parks had plots that were strongly clustered in ordination space: Lava Beds and Oregon Caves. These parks only had Matrix plots (30 and 10, respectively). Plots at Lava Beds clustered in the ordination space at low precipitation and mid-elevations, while those from Oregon Caves clustered near the mid-point of the precipitation and

elevation gradients. Plots at Redwood, with three exceptions, grouped fairly tightly in the lower elevations/higher precipitation space. Two of the exceptions at Redwood were Matrix plots from the relatively warm interior part of the park (Bald Hills), while the other was a riparian plot (lower Redwood Creek). Plots from Crater Lake and Lassen were similar to one another regardless of stratum and were clustered along the elevation vector.

Riparian and Matrix plots tended to group together within a park, except at Whiskeytown. Points from Whiskeytown had a noticeable lack of cohesion that reflected substantial variation in conditions across this park (Figure 9).

Gamma Diversity

The observed versus estimated species accumulation curves for each park stratum are shown in Figures 10A–C. Species accumulation curves that are asymptotic and where observed and estimated number of species are similar, exemplify sampling that captures species richness well.

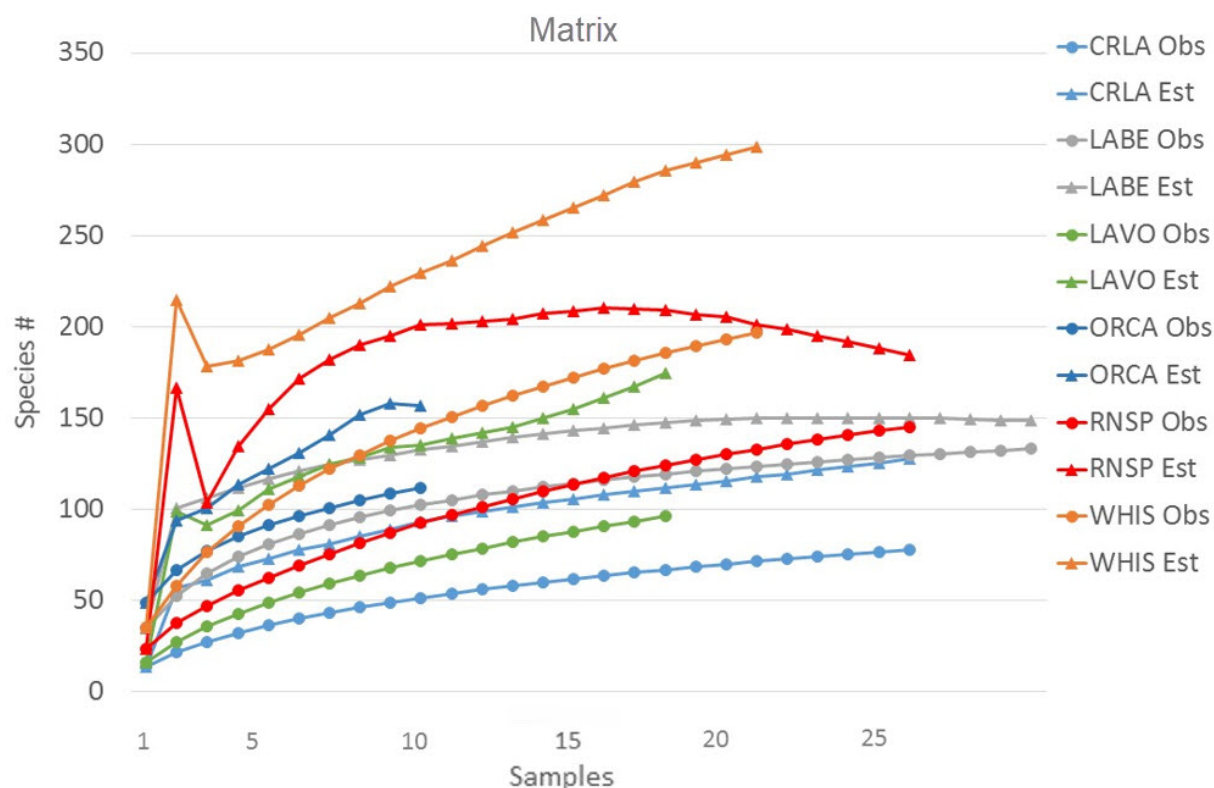


Figure 10A. Estimated (Est) and observed (Obs) species accumulation curves for the Matrix stratum from the Klamath Network vegetation monitoring plots. CRLA = Crater Lake, LAVE = Lava Beds, LAVO = Lassen Volcanic, ORCA = Oregon Caves, RNSP = Redwood National and State Parks, WHIS = Whiskeytown.

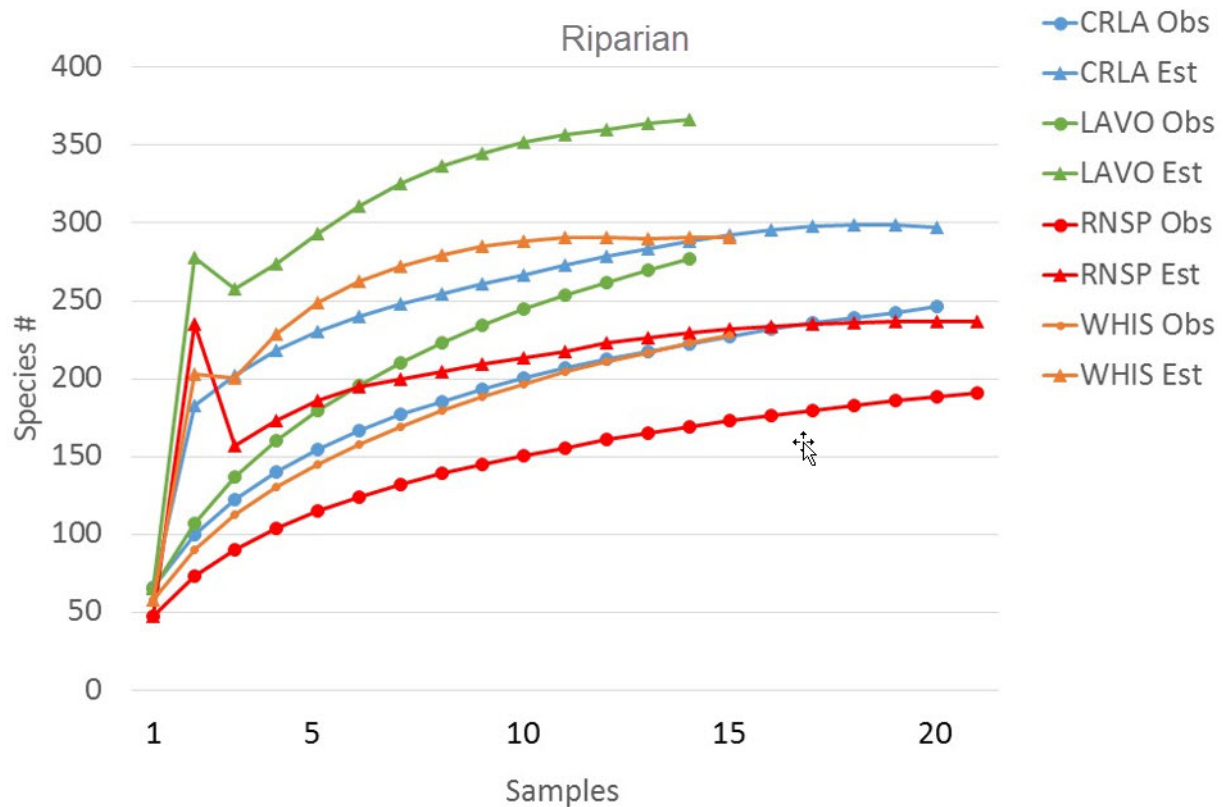


Figure 10B. Estimated (Est) and observed (Obs) species accumulation curves for the Riparian stratum from the Klamath Network vegetation monitoring plots. CRLA = Crater Lake, LAVE = Lava Beds, LAVO = Lassen Volcanic, ORCA = Oregon Caves, RNSP = Redwood National and State Parks, WHIS = Whiskeytown.

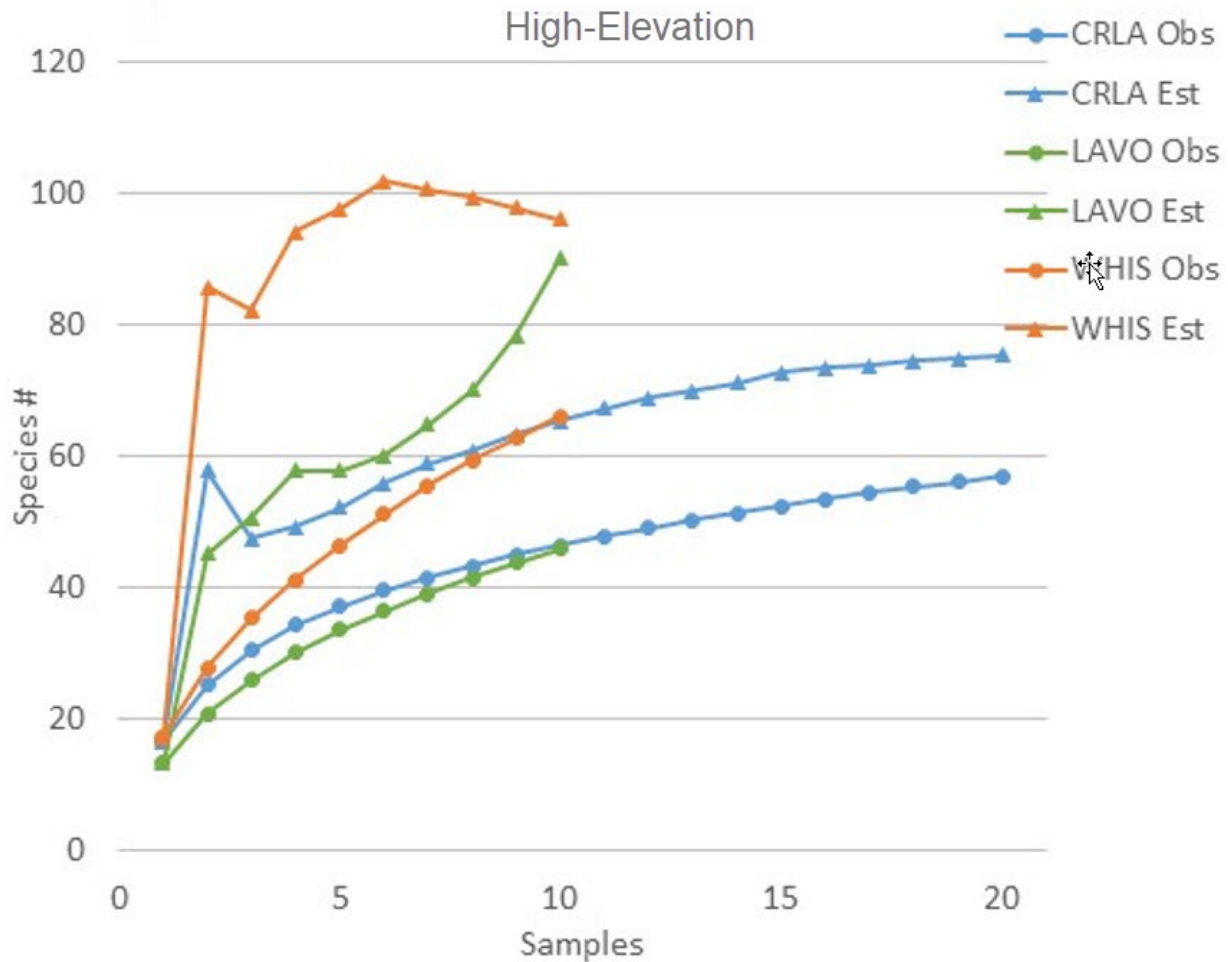


Figure 10C. Estimated (Est) and observed (Obs) species accumulation curves for the High-Elevation stratum from the Klamath Network vegetation monitoring plots. CRLA = Crater Lake, LAVE = Lava Beds, LAVO = Lassen Volcanic, ORCA = Oregon Caves, RNSP = Redwood National and State Parks, WHIS = Whiskeytown.

Gamma diversity was best sampled in a subset of park/strata combinations where sample sizes were largest, specifically at Lava Beds Matrix sites ($n = 30$ plots), where about 95% (observed/estimated) of the species diversity was captured. Also, Redwood ($n = 26$ plots) and Oregon Caves ($n = 10$) have estimated values that are declining towards the observed value. Conversely, in the Matrix at Lassen and Whiskeytown (large parks with only 18 and 21 Matrix plots, respectively), our sampling has likely missed a number of species.

Species diversity was far higher in the Riparian stratum; the sampling captured about 80 percent of the estimated number of riparian species in Crater Lake, and Redwood, where the plot count was highest (21 and 20). There was slightly greater observed versus estimated discrepancy in the Riparian stratum at Lassen and Whiskeytown, where there were only 14 and 15 plots, respectively.

There were only 10 High-Elevation plots at Lassen and Whiskeytown, and only slightly more than half as many species were observed as estimated. Conversely, the 20 High-Elevation plots at Crater Lake captured about 75% of the estimated species richness.

Beta diversity

Figures 11A–C shows the pairwise similarity among strata across parks. These figures depict a numerical representation of species composition and abundance, similar to the relationships shown in the ordination (Figure 8). The highest overall similarity values in each stratum were between Crater Lake and Lassen, in particular the High-Elevation stratum (23.7%), this similarity value is not much lower than the similarity of the riparian frame at Lassen (25.5%). Despite geographic separation, Matrix sites from Lassen and Oregon Caves also had relatively high similarity (12.3%), greater than the similarity between the geographically proximate Redwood and Oregon Caves (8%). As evident with the ordination analysis, we found that Lava Beds had little similarity with other parks, and the lowest pair-wise similarity out of all combinations was between the Matrix stratum at Lava Beds and Redwood (0.1%).

A. Matrix Bray-Curtis similarities

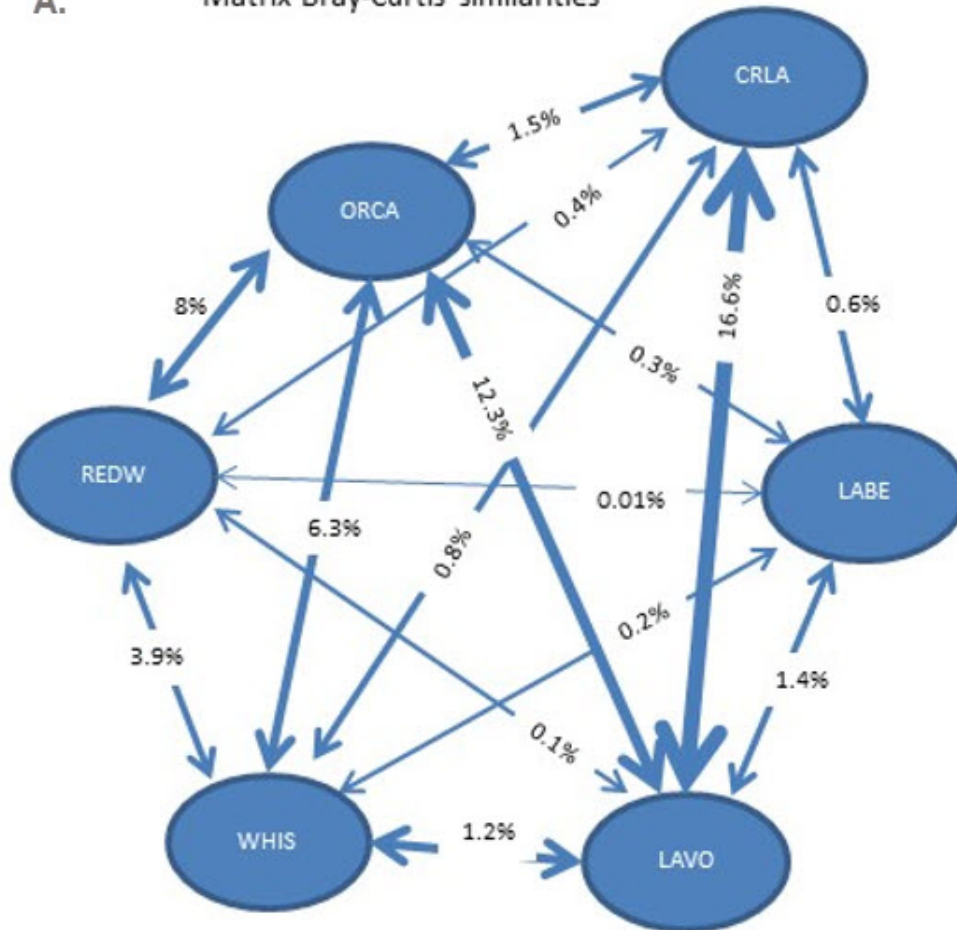


Figure 11A. Plexus diagram showing Bray-Curtis similarities among parks for the Matrix stratum from the Klamath Network vegetation monitoring plots. CRLA = Crater Lake, LAVE = Lava Beds, LAVO = Lassen Volcanic, ORCA = Oregon Caves, RNSP = Redwood National and State Parks, WHIS = Whiskeytown.

B. Riparian Bray-Curtis similarities

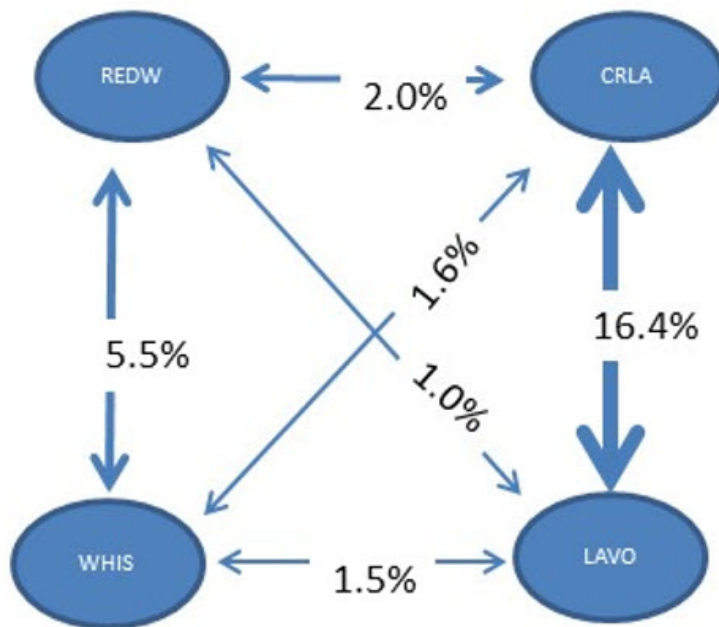


Figure 11B. Plexus diagram showing Bray-Curtis similarities among parks for the Riparian stratum from the Klamath Network vegetation monitoring plots. CRLA = Crater Lake, LAVE = Lava Beds, LAVO = Lassen Volcanic, ORCA = Oregon Caves, RNSP = Redwood National and State Parks, WHIS = Whiskeytown.

c. High elevation Bray-Curtis similarities

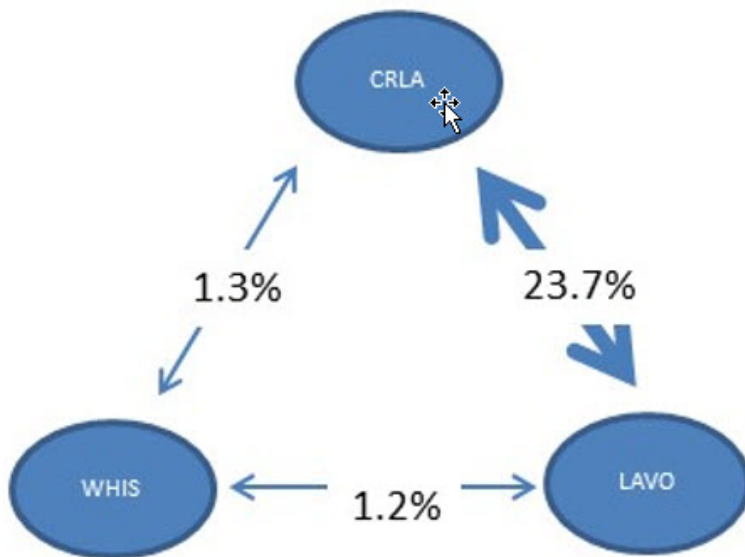


Figure 11C. Plexus diagram showing Bray-Curtis similarities among parks for the High-Elevation stratum from the Klamath Network vegetation monitoring plots. CRLA = Crater Lake, LAVE = Lava Beds, LAVO = Lassen Volcanic, ORCA = Oregon Caves, RNSP = Redwood National and State Parks, WHIS = Whiskeytown.

Within individual parks, the average pairwise Bray-Curtis Similarities (range 0–100%) among strata varied from as low as 1.5 % to only 25.4% (Table 4). Similarity among paired strata was highest for the Matrix/Riparian comparison within Redwood and lowest in the Riparian/High-Elevation comparison at Whiskeytown. There was generally much greater similarity between Matrix vs. Riparian strata than for Riparian vs. High-Elevation strata.

Table 4. Within park stratum Bray Curtis similarities (%) calculated from the Klamath Network’s 2011–2013 vegetation monitoring data.

Park	Matrix/Riparian	Matrix/High-Elevation	Riparian/High Elevation
Crater Lake	13.9	19.7	9.7
Lassen	12.9	4.2	5.9
Redwood	25.4	N/A	N/A
Whiskeytown	17.3	3.8	1.5

Average similarity within a park stratum was low (25.5–49.5%, Table 5). Lassen had the two lowest mean values: 25.5% in the Riparian stratum, and 26.2% in the Matrix stratum. In six sample frames

(4 Matrix), there was no overlap in species composition for at least one plot/plot comparison (i.e., Similarity = 0), no species in common between strata). Moreover, similarity was near zero at Lava Beds. However, in all cases the maximum pairwise overlap was sizeable: 62–89%, except in the Riparian stratum at Lassen (48.2%).

Table 5. Bray-Curtis Similarity (%) means, maxima, and minima from plot by plot comparisons for each stratum within each park from the Klamath Network 2011–2013 vegetation monitoring data.

Park	Stratum	Mean	Maximum	Minimum
Crater Lake	Matrix	32.1	85.9	0.0
	Riparian	32.8	62.6	8.1
	High-Elevation	29.7	74.2	0.0
Lava Beds	Matrix	37.5	79.5	1.7
Lassen	Matrix	26.2	89.5	0.0
	Riparian	25.5	48.2	8.5
	High-Elevation	42.6	73.5	4.9
Oregon Caves	Matrix	49.5	70.4	24.5
Redwood	Matrix	44.1	88.7	0.0
	Riparian	35.8	71.2	0.0
Whiskeytown	Matrix	30.3	68.5	0.0
	Riparian	37.2	66.9	12.0
	High-Elevation	27.1	73.5	0.9

Alpha Diversity

Species richness (i.e., alpha diversity) was lowest at Crater Lake and Lassen (30–32 species/plot) (Table 6). Richness was highest at Oregon Caves (49 species/plot). Lava Beds, Redwood and Whiskeytown had very similar species richness (34–39 species/plot).

The average number of species per 0.1 ha plot in the Riparian stratum (58 species/plot) was consistently high among all parks, and dramatically higher than it was in the Matrix (27 species/plot) and especially higher than the High-Elevation stratum (16.7 species/plot).

Hill's N1 Diversity and Evenness

Across strata, riparian Hill's N1 Diversity was highest (Table 6). Among parks, the highest N1 diversity value was not where the average number of species per plot was highest (Oregon Caves), but rather at Redwood, which also had the greatest species evenness. We observed a large range in Hill's N1 diversity (1.0–24.2). Overall Hill's N1 diversity was lowest at Crater Lake Matrix sites while Oregon Caves had the lowest Pielou's evenness. Mean evenness was intermediate and very similar among strata (0.4–0.6) (Table 6), but we observed substantial variation at the plot level, with a range of 0.0–0.89.

Table 6. Number of species (standard error), Hill's N1, and Pielou's evenness metrics for each park in each stratum from the Klamath Network 2011–2013 vegetation monitoring data. The species richness average is based on presence/absence data in the 0.1 ha plots. Hills N1 and Pielou's evenness are based on cover data from 4–100m² modules at each site.

Stratum	Matrix			Riparian			High-Elevation			All		
Park	# Species	Hill's N1	Pielou Evenness	# Species	Hill's N1	Pielou Evenness	# Species	Hill's N1	Pielou Evenness	# Species	Hill's N1	Pielou Evenness
Crater Lake	13(1.2)	2.6(0.3)	0.36(0.04)	66(2.2)	10.1(0.9)	0.55(0.02)	17(1.4)	4.2(0.7)	0.47(0.05)	30(3.1)	5.4(0.5)	0.45(0.02)
Lava Beds	35(1.6)	5.9(0.5)	0.50(0.03)	–	–	–	–	–	–	35(1.6)	5.9(0.5)	0.49(0.03)
Lassen	16(1.7)	3.3(0.3)	0.46(0.04)	65(3.9)	11.5(1.6)	0.58(0.02)	14(1.6)	3.2(0.5)	0.46(0.05)	32(4.0)	6.0(0.8)	0.50(0.02)
Oregon Caves	49(1.9)	5.7(0.8)	0.44(0.03)	–	–	–	–	–	–	49(1.9)	5.7(0.8)	0.44(0.03)
Redwood	24(1.8)	5.3(0.2)	0.56(0.01)	47(3.6)	9.0(0.7)	0.58(0.02)	–	–	–	34(2.5)	6.9(0.4)	0.57(0.01)
Whiskeytown	36(3.6)	4.9(0.4)	0.47(0.02)	57(4.2)	10.7(0.6)	0.62(0.01)	17(3.3)	3.4(0.4)	0.47(0.01)	39(3.1)	6.4(0.5)	0.52(0.02)
ALL	27(1.4)	4.6(0.2)	0.47(0.01)	58(2.0)	10.2(0.5)	0.58(0.01)	16(0.9)	3.8(0.4)	0.46(0.02)	34(1.4)	6.1(0.3)	0.50(0.01)

Discussion

Vegetation Description

Plant Cover: As an overview of vegetation, we present summaries of Growth Habit and Plant Functional Types (Appendices C–H). These data illustrate how dominant vegetation Functional Groups vary tremendously at all levels of comparison. Detailed analyses of structural and functional vegetation characteristics will be undertaken in future analysis, linking them to biophysical gradients.

Park Floras: While not part of the formal analyses in the vegetation monitoring protocol, a species list, and a simple tally of the number of species found in each park and park stratum, and their cover, can provide very useful data for illustrating vegetation change. Other measures of diversity at the park and stratum level focus on compositional similarity comparisons, or average numbers of species per stratum and plot.

Given the renowned diversity in the Klamath-Siskiyou ecoregion (Whittaker 1960; DellaSala et al. 1999; Sarr et al. 2007; Burge et al. 2016; Baldwin et al. 2017), it is of interest to compare the park floristic diversity between this region with the park diversity in the Cascades-Modoc sub region. Oregon Caves, in the area of the Klamath-Siskiyou, considered by Whittaker (1960) to have forests of unparalleled diversity, did have substantially greater alpha diversity in the Matrix stratum (49 species/plot). However, our highest alpha diversity value at Oregon Caves is not complimented by high beta diversity, possibly due to the small sample size, and the presence of only one dominant Plant Functional Type (Conifer). Also of note, we did not sample serpentine soils at Oregon Caves, or other parks. Serpentine soils and associated endemic species are partially responsible for the high diversity in the Klamath-Siskiyou sub region

Within parks, Crater Lake and Lassen had higher diversity in the Riparian stratum. Lassen had especially high estimated Riparian species diversity ~375 species vs. ~300 at Whiskeytown and Crater Lake. While we did not sample Riparian areas at Oregon Caves, they could have higher diversity than the other parks, as the riparian areas were noted as especially diverse by the Oregon Caves vegetation inventory and mapping project (Odion et al. 2013). Whiskeytown had far greater estimated overall species richness in the Matrix (~300 species) than other parks. In comparison, Lassen and Redwood each had a projected Matrix Richness of ~175 species, Oregon Caves and Lava Beds ~150, and Crater Lake had ~125.

Biophysical Parameters

Because much of the information and insight about temporal change in vegetation communities can be explained by multivariate analyses of vegetation in relation to environment, it is essential that environmental gradients are well-characterized.

Our dataset contains a number of biophysical environmental gradients that can be related to the vegetation of each park: elevation, temperature, precipitation, and vapor pressure deficit, (Figure 6). The gradients were similar between Crater Lake and Lassen, otherwise they varied considerably among the parks. Across the whole Network, there are distinct gradients in elevation and modeled climate. The Network-wide gradient ranges from low elevations with wet, warm, maritime influences

(Redwood) to the high-elevations where cold temperatures and snow are prominent features shaping vegetation composition (Crater Lake and Lassen), and back down to arid desert. Thus, across the Network, vapor pressure deficit varies widely. The gradient reflects both elevation and the maritime to Mediterranean air masses across the Network that were described by Mitchell (1976) as a summer climate boundary running northeast through the Klamath region, and a winter boundary, running from west to east, at approximately 40 degrees north.

Non-Native Species

Non-native species play little role in community diversity. Within the Klamath Network parks, they occur mostly along roads and trails, and are monitored in a separate protocol (Odion et al. 2010). However, one species, cheatgrass (*Bromus tectorum*), is widespread at Lava Beds, and of great concern (see Anticipated Vegetation Changes, below).

Vegetation Environment Relationships

Figure 8 shows clear linkages between biophysical variables and the composition and abundance of species across the Klamath Network. The gradient structure of vegetation, and the individual response of species along elevation gradients, was described in classic studies by Robert Whittaker from the western Klamath region. (Whittaker 1960). Whittaker (1960) found moisture as the second most important gradient along which species aligned. A similar, more recent study was done in Lassen (Parker 1991), where elevation largely differentiated forest types, and topographic position, related to moisture, was the second axis of variation. The linkages between the biophysical variables, gradients, and species composition provide a strong basis for predicting vegetation change, especially when considered in concert with expected effects of climate change.

Anticipated Vegetation Changes: National parks are considered to be particularly susceptible to the effects of climate change on biodiversity (Gonzalez et al. 2018). Klamath Network parks may be even more susceptible to loss of biodiversity because of narrow species' range limits and high numbers of relatively rare species. Species already at the edge of their ecological/environmental niche are expected to be vulnerable to local extirpation (Brown 1984). Eventually, parks may experience novel mixes of species due to species' migrations. Unfortunately, the current rate of climate change may be too fast for most species to adapt or migrate to favorable habitats (Nogués-Bravo et al. 2018; Loarie et al. 2009), although the complex topography and steep elevation gradients that characterize the Klamath region may supply climate refugia at a greater frequency than many other areas (Morelli et al. 2016). However, the direction and rate of changes in species' ranges due to climate change will vary with each species' physiology, life histories, dispersal capacity, responses to disturbances, ecological plasticity and other factors (Pitelka et al. 1997), making predictions about changes in species composition especially difficult.

Climate change can also exert strong effects on vegetation where it alters disturbance regimes (Dale et al. 2001; Johnstone et al. 2016; Parks et al. 2018). The degree to which these factors influence species' composition along elevation and moisture gradients is uncertain, but may be profound. Increases in large fires and fire severity are ongoing, and to be expected to continue in many areas of western North America (Schoennagel et al. 2017; Miller et al. 2012, but see Parks et al. 2016). Large, severe fires have the potential to rearrange vegetation patterns in the Klamath Network parks. For

example, the 2018 Carr Fire in Whiskeytown was driven by very extreme weather. It burned most of the park with unusually high amounts of crown fire, killing substantial areas and very large patches of forests. Early successional vegetation will develop, including shrub growth in burned conifer forest or if severe fire patch size is too large to promote conifer establishment. Conifer establishment after fire is a particular concern in lower elevation dry forests (Davis et al. 2019). If fires recur too frequently shrub and young tree vegetation may persist and mature forests may be significantly reduced (Odion et al. 2010). Also, after severe fire there is increased potential for debris flows that can greatly alter riparian areas.

At Lava Beds, fire frequency may be increased due to cheatgrass (*Bromus tectorum*) invasion, and this change will presumably have an interactive, positive relationship with climate, both in terms of the effects of a longer fire season, lower foliar moisture, and weather-driven fire spread and intensity. Cheatgrass is the most widespread species at Lava Beds, and is second in overall dominance. It has a self-reinforcing relationship with fire and human ignitions in Great Basin ecosystems (Billings 1994), both of which are increasing. Shrub species throughout Lava Beds are very sensitive to fire and may suffer increased mortality with higher fire frequency and intensity. The Jack Fire, which burned the northern portion of Lava Beds in 2008, caused very high mortality of shrubs, and a conversion to considerably more cheatgrass (DiPaolo et al. 2015).

Conversely, fire *suppression* over many decades has had and continues to have a profound influence on vegetation that will interact with climate. Fire suppression in forests favors shade tolerant trees, like Douglas (*Pseudotsuga menziesii*) and white fir (*Abies concolor*) in drier pine forests (e.g., lodgepole (*Pinus contorta*), ponderosa (*Pinus ponderosa*), and Jeffrey pine (*Pinus jeffreyi*) forests). This has recently been documented from plot and vegetation mapping studies at Crater Lake, where ponderosa and lodgepole forests have decreased (Forrestel et al. 2017; DiPaolo et al. 2018). In aspen stands and shrub vegetation like chaparral, fire suppression promotes encroachment of conifers, as has been observed at Lassen (Adamus et al. 2013; Lauvaux et al. 2016). Despite climate effects that are fostering more fire, fire exclusion may continue to be effective in many areas of the Klamath Network, leading to continued, gradual changes in vegetation along elevation and moisture gradients.

A highly significant concern relating to disturbance and vegetation change occurs in the High-Elevation stratum at Crater Lake and Lassen, where the non-native fungal species, white pine blister rust (*Cronartium rubicola*), is infecting whitebark pine (*Pinus albicaulis*), a keystone species. Loss of whitebark pines, could have cascading effects, such as loss of biodiversity (Tomback and Kendell 2001) and increased dominance of mountain hemlock (*Tsuga mertensiana*) (Jules et al. 2016). Blister rust currently infects about 50 percent of whitebark pines in Crater Lake and Lassen (Jules et al. 2017).

Gamma Diversity

Our comparisons of the gamma diversity of the strata at each park is illustrated by the species accumulation curves. The curves that have not plateaued (Figures 9A–C), represent park by strata instances where plot numbers could be increased to better capture species composition: 1. The High-Elevation stratum in Lassen and Whiskeytown (only 10 plots each, and steeply rising species accumulation curves). 2. The Matrix (highly variable stratum) at Lassen and Whiskeytown, with 18

and 21 plots, respectively. 3. The Riparian stratum at Lassen and Whiskeytown, with only 14 and 15 plots, respectively. 4. The High-Elevation stratum in Lassen and Whiskeytown (only 10 plots each, and steeply rising species accumulation curves). Conversely, the curves at Crater Lake, Redwood and especially Lava Beds (Matrix only); and, despite only having 10 plots, the curve of Oregon Caves has nearly plateaued.

Notwithstanding these limitations, it is clear that, at the park level, Whiskeytown has the highest species diversity, a finding mostly supported by Plant Functional Type diversity, which was tied for highest overall with Crater Lake (10 types) (Table 2). Whiskeytown park has a very large elevation gradient and a great deal of heterogeneity and species turnover within elevation zones (Appendix A, see beta diversity). Redwood has as many Plant Functional Types in the Matrix, and Riparian Strata combined as Whiskeytown, but Redwood lacks a High-Elevation stratum. Lava Beds has a higher number of Plant Functional Types in the Matrix stratum than Whiskeytown, but between these types there is little species turnover.

Whiskeytown even has the highest estimated number of species in the High-Elevation stratum, despite the much greater size of the High-Elevation stratum at Crater Lake and Lassen, and the greater number of Plant Functional Types in this stratum at Crater Lake (Table 2). Crater Lake, however, has a very low number of estimated species in the High-Elevation stratum (~75), and also the lowest estimated number of species in the Matrix, a surprising result given the large area of this park.

Beta Diversity

Bray-Curtis similarities between plots in different strata within each park were generally low (Tables 4–5). This may be indicative of high beta diversity driven by variability in local gradients (i.e., within individual park's strata). The main exception is the Matrix/Riparian strata in Redwood. Riparian to Matrix microclimate differences are generally low in this park, and the same conifers may dominate both strata (Appendix G). The next highest intra-park similarity between individual park strata occurs between the Matrix and High-Elevations at Crater Lake.

However, the inter-park similarities in strata composition are not all particularly low in the case of high elevations at Crater Lake and Lassen. These parks share the same strong tree dominance by mountain hemlock (*Tsuga mertensiana*), and vary mainly in graminoid (Crater Lake), and herb (Lassen) dominance (Appendices C and E, Table 2).

Alpha Diversity

We found 1.5 to 6 times more species in the riparian stratum than in the Matrix and High-Elevation strata in each park (Table 6). This was most notable at Crater Lake (66 species/plot in Riparian and vs. 13 species/plot in matrix). High riparian species richness is often created through fluvial disturbances that result in a high diversity of microsites (Gregory et al. 1991) and vegetation patches (Planty-Tabacchi et al. 1996). Interestingly, across the Network, riparian plots had higher richness as a function of increasing elevation. McCain and Grytnes (2010) note that increasing richness with elevation is unusual in studies that span elevation gradients. Roland and Schmidt (2015) describe a positive rare species richness/elevational pattern they called a 'reverse' relationship, which they

observed in Alaska and hypothesize that it is driven by elevational community shifts following glacial retreat. A similar phenomenon could be occurring with our riparian sites.

Conversely, richness decreased with elevation at matrix sites, which is a more typical pattern. In addition, plots in the high elevation stratum had far lower diversity than those in the other strata (Table 6), which is also supported in terms of a smaller number of Plant Functional Types, except at Crater Lake (Table 2). This is presumably due to environmental stress due to cold climate extremes and short growing seasons (Tsuyuzaki and Titus 1996). Crater Lake Plant Functional Type diversity may be higher due to the presence of unusual pumice substrata.

In the Matrix stratum at Oregon Caves, there was only 1 Plant Functional Type (Conifer), the lowest of any Matrix stratum. White fir (*Abies concolor*), was strongly dominant, and the combined cover of this species with Douglas fir (*Pseudotsuga menziesii*), and noble fir (*Abies procera*) was 58% (the total cover of all species was 85%) (Appendix D). These three trees are all shade tolerant conifers that increase with the lack of fire. Fire has been effectively suppressed in Oregon Caves (Agee 1991, Odion et al. 2013), except for a very small amount of prescribed burning. It is unclear why species diversity has remained high in the absence of contagious disturbances in this park, and with the dominance so concentrated in three species. However, non-fire disturbances are readily evident in some of the area where plots were located. For example, mortality of large trees, and subsequent tree fall creating of gaps that can influence plant understory heterogeneity (Fahey and Puettmann 2007), and could be maintaining diversity even with a lack of other disturbances at Oregon Caves.

Diversity and Evenness

Our Riparian Hill's N1 values ranged from 4–24 with park averages from 9–11.5, but elsewhere diversity was lower (Table 6). Surprisingly, some sites were had very low Hill's N1, particularly Crater Lake in the Matrix (1). These sites had very low species richness and one species dominating the overstory cover, indicating low evenness.

Our mean evenness measures ranged from 0.44 to 0.57 among the parks and strata (Table 6). This intermediate degree of evenness can be visually illustrated by relatively flat rank abundance curves (Figure 7) and also lists of the most common species in each park and their dominance (Appendices C–H). In general, 2–3 species are relatively strong dominants (high cover) at each site, commonplace in ecological studies in temperate regions. Notably, despite high plot level richness at Oregon Caves, mean evenness there was nearly the lowest due to the especially strong dominance of white fir (*Abies concolor*), and Douglas fir (*Pseudotsuga menziesii*).

High species richness and community heterogeneity may promote stability (Barbour et al. 1999), so a shift to lower values of diversity (Hill's N1) or a higher value of Pielou's evenness can identify possible site or park level reduction in stability.

Species Richness Comparisons with Other Studies: The number of scholarly publications related to community diversity has increased in recent years (Anderson et al. 2011), as ecologists continue to grapple with the underlying causes of community diversity. Alpha diversity at the 0.1 ha scale provides fundamental information on the basic nature and structure of ecological communities

(Whittaker 1960). As such, our richness and diversity data are of interest to the wider scientific community.

A comprehensive comparison of alpha diversity patterns between our studies and those presented in the literature is beyond the scope of this report, but there are noteworthy comparisons at the 0.1 ha scale.

Matrix Forests: The mean alpha diversity of our Redwood matrix sites (24/plot) is similar to the findings of Westman and Whittaker (1975) from Mendocino County, with 17 species on redwood (*Sequoia sempervirens*) flats, and 23.4 on sloped sites. Whittaker (1960) also found a mean of 15 species in a coastal redwood forest near Mill Creek, at the northern end of Redwood. At Oregon Caves, we found an average of 49 species/0.1 ha in our ten plots, whereas Whittaker (1960) reports mean alpha diversity values from the central Siskiyou Mountains near Oregon Caves of 33 and 34 species/0.1 ha. For the Mediterranean-like climate at Whiskeytown we found comparable species richness values from two studies. Cowling et al (1996), report 56 species/0.1 ha for oak woodlands and forests, and Keeley and Fotheringham (2003) found an average alpha diversity of 39 species/0.1 ha, 3 years after fire, and 19 species/0.1 ha in unburned forests. This later study further illustrates the importance of site history when comparing richness values.

Matrix Chaparral: There is a large body of literature comparing species diversity among Mediterranean shrublands throughout the world. Cowling et al (1996), report diversity from 31 species/0.1 ha in chaparral (*Ceanothus* and *Adenostoma* communities). Diversity in these shrublands has been found to be strongly influenced by disturbance. An example from southern California, Keeley and Fotheringham (2003), found an average of 53 species/0.1 ha 2 years after fire in chaparral, and 35 species/0.1 ha 4 years after fire. Though there could be differences in fire history and environmental drivers between northern California and southern California chaparral, our findings from unburned sites at Whiskeytown are within the range of these studies, but, again, these comparisons emphasize the importance of site history when making species richness comparisons. We now have the opportunity to determine the effects of fire over time at Whiskeytown because of the 2018 Carr Fire.

Riparian: Comparisons of alpha diversity in riparian vegetation, suggest that the Klamath parks, with an average of 59 species/0.1 ha (N=70), may be similar to other areas in the western US. For example, some sites in the Colorado Rockies had alpha diversity of 51 species/0.1 ha (Baker 1990), while alpha diversity in Teton National Park was 90 species/0.1 ha (Marks 2000).

High-Elevation: The richness of mountain hemlock forests in SW Washington (45 species in 500 m² plots) (Brockway 1998) was over twice as high as in stands containing mountain hemlock (*Tsuga mertensiana*) at Crater Lake and Lassen (14–17 species/0.1 ha), respectively. The lower richness values we observed could be explained by the relatively new volcanic soils found at Crater Lake and Lassen, as ground surface instability at Mount Saint Helens was observed to limit species composition and cover (Tsuyuzaki and Titus 1996).

Future Sampling and Analyses

In this section we discuss considerations for future analyses to quantify change, and make several recommendations for how to improve analysis and sampling.

Future Analysis Considerations

Based on the baseline data presented in this report, we offer considerations for future analyses that address the Klamath Network vegetation monitoring protocol's second objective of quantifying temporal and spatial changes in vegetation communities.

Quantifying Changes in Relative Abundance of Species

To track changes in the relative abundance of species, univariate analyses can be done along elevation and modeled climate gradients to determine whether species are shifting in their positions and/or abundance along these gradients. Species' response curves along environmental gradients are often (but not always) unimodal (Whittaker 1960). The shape of these curves and their positions along environmental gradients will shift over time as species adjust to changing environments. This study provides a baseline for evaluating change at the six parks.

Quantifying Changes in Beta Diversity (Species Identity and Relative Abundance) and Relate Compositional Turnover to Environmental Gradients

The unconstrained gradient analysis that we presented partially captured the baseline composition and abundance of species along gradients in elevation and climate (i.e., at the start of this monitoring effort, Figure 8). As we re-sample plots over time, we will re-ordinate the data, thus allowing us to identify trends in vegetation change by charting the movement of species and plots in ordination space. Any changes to beta diversity between or within strata at a park over time would indicate profound changes in the organization of vegetation assemblages (Wilson and Shmida 1984; Socolar et al. 2016). Hillebrand et al. (2017) note that beta diversity is particularly important for monitoring changes in biodiversity.

Quantifying Changes in Alpha and Gamma Diversity (Species Richness and Evenness)

Changes in alpha and gamma diversity will shed light on what univariate analyses will be most instructive. Species evenness will indicate which park strata are most sensitive to change, and others that may be more stable (Barbour et al. 1999). However, changes in species richness do not necessarily indicate profound ecological changes, and should be reviewed in the context of other biodiversity metrics, diversity (Hill's N1), and beta diversity (van der Plas et al. 2016; Hillebrand et al. 2017) and the abundance of non-native species.

Suggestions for Future Sampling and Analysis Efforts

We also make several recommendations to improve future sampling and analysis.

- Some park/strata combinations could benefit from additional plots. This would serve two objectives from Odion et al. (2011): Objective #1 to describe vegetation composition diversity, and Objective #3 to sample high elevation and riparian areas with greater intensity. Increasing sample size at Whiskeytown Matrix and Riparian sites would allow us to better describe the compositional diversity in these strata. These are both very diverse, as shown by difference in

observed to estimated species richness, and by species accumulation curves that are still climbing rather than showing an asymptote. We mention earlier in this report the Lassen Matrix and Riparian show the same pattern as Whiskeytown, but in 2016 at Lassen we added sites going from 18 matrix and 14 riparian to 23 matrix and 19 riparian. The high elevation sites at Whiskeytown and Lassen, each only have 10 plots. These species accumulation curves are rising, and not near an asymptote. Increasing sample sizes here would allow us to better meet Objectives #1 and #3, described in Odion et al. (2011).

- Odion et al (2011) did include the expansion area in the original matrix sample frame at Oregon Caves, but due to uncertainty of the land acquisition by the National Park Service, we did not establish plots in the expansion area in 2013. If we intend to make assessments in the expansion of the park, we will need to establish plots within.
- After three rounds of sampling, undertake analyses to identify how best to improve statistical power, and how it can be affected by the addition of plots, increasing plot return intervals, or other potential modifications of the protocol.
- Consider adding post-burn measures of fire severity as parks experience fires. This recommendation comes in the aftermath of the 2018 Carr Fire at Whiskeytown. We believe, quantifying plot level burn severity will allow better correlation between fire severity and post burn vegetation successional trajectories. Park staff will be consulted as to their interest in collecting these types of data.

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Appendix A. Dominant Vegetation Types of the Klamath Region and East Cascade/Great Basin

1.1. Introduction

This list of vegetation types is intended to provide a coarse overview of the dominant terrestrial vegetation types and their arrangement across the Klamath region. Nearly all these vegetation types vary substantially from place to place and through time, and contain many unique (micro) habitats that for brevity are not included here.

1.2. Coastal Environments

A. Coastal Strand and Dune (Redwood)

Along the coastal dunes and the foggiest and most windswept bluffs, highly distinct plant communities occur. On the coastal strand and foredunes, coastal sand verbena (*Abronia latifolia*), silver burr ragweed (*Ambrosia chamissonis*), and European sea rocket (*Cakile maritima*) are common. Dune habitats have American dunegrass (*Leymus mollis* ssp. *mollis*), and the non-native European beachgrass (*Ammophila arenaria*), with woody plants, such as willow (*Salix* spp.) and coyote brush (*Bacharis pilularis*) becoming more important with greater distance from the sea.

B. Coastal Prairie (Redwood)

On moist coastal terraces and windswept hilltops in the redwood zone, productive perennial grasslands occur. These prairies are dominated by California oatgrass (*Danthonia californica*), red fescue (*Festuca rubra*), Idaho fescue (*Festuca idahoensis*), and Pacific hairgrass (*Deschampsia caespitosa* ssp. *holciformis*). These coastal prairies are under threat from invasive plant species, tree encroachment, and agriculture.

C. Coastal Forest (Redwood)

A maritime coniferous forest of shore pine (*Pinus contorta* var. *contorta*) and Sitka spruce (*Picea sitchensis*) occurs in a thin coastal strip between the foredunes and the redwood forests. Strong winds and salt spray from the ocean limit branch growth in the seaward direction and produce spectacular “flagged” trees and shrubs along the bluffs and headlands.

1.3. Low Elevation Environments (Klamath)

A. Redwood Forest (Redwood)

These massive forests, dominated by the coastal redwood (*Sequoia sempervirens*), contain the tallest trees and highest biomass concentrations in the world. The forests are restricted to the fog-affected coastal strip, just inland from areas of salt spray, where redwoods reach their greatest size in alluvial habitats. Associated tree species include Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), western redcedar (*Thuja plicata*), Port-Orford cedar (*Chamaecyparis lawsoniana*), tanoak (*Lithocarpus densiflorus*), red alder (*Alnus rubra*), and bigleaf maple (*Acer macrophyllum*). Common shrubs include salmonberry (*Rubus spectabilis*), salal (*Gaultheria shallon*), and evergreen huckleberry (*Vaccinium ovatum*). Sword fern (*Polystichum munitum*) is an important groundcover.

B. Mixed Evergreen Forest (Redwood, Oregon Caves, and Whiskeytown)

These forests often occur just inland or at higher elevations than the summer fog belt, and have much warmer summers, but experience mild, wet weather most of the year. These mixed conifer/broadleaved evergreen forests are believed to be the remnants of forest types that cloaked large areas of the west in the Tertiary (Whittaker 1960, 1961). Douglas fir (*Pseudotsuga menziesii*) is the dominant conifer and usually comprises most of the biomass in these forests. Other minor conifers include knobcone pine (*Pinus attenuata*), grand fir (*Abies grandis*), Port-Orford cedar (*Chamaecyparis lawsoniana*) and yew (*Taxus brevifolia*). Associated hardwood species, many of which are evergreen, give these forests their distinctive character. They include tanoak, canyon oak (*Quercus chrysolepis*), madrone (*Arbutus menziesii*), bay (*Umbellularia californica*), and chinquapin (*Chrysolepis chrysophylla*). Common shrubs include hazelnut (*Corylus cornuta*), Oregon grape (*Berberis nervosa*), oceanspray (*Holodiscus discolor*), salal, and poison oak (*Toxicodendron diversilobum*).

C. Oak/Pine Woodlands (Redwood and Whiskeytown)

Oak vegetation often intermixes with and can be difficult to separate from chaparral, grasslands, and mixed conifer forest along the drier edges of the interior valleys. Severe summer drought lowers stand densities in these woodlands, which are dominated by Oregon oak and California black oak. Ponderosa pine (*Pinus ponderosa*) is often scattered among the oaks. At the edge of the Sacramento Valley, gray pine (*Pinus sabiniana*), blue oak (*Quercus douglasii*), valley oak (*Quercus lobata*), and buckeye (*Aesculus californica*) become important. Most of the species mentioned for chaparral above can be found in these stands. More typically, the ground layer is composed of annual grasses and forbs. As with chaparral, fire is believed to be an especially important factor structuring these vegetation types.

D. Chaparral (Whiskeytown)

This distinctive physiognomic type, which includes a variety of associations dominated by sclerophyllous shrubs, occurs as a seral type in many forest types in the region and appears as a more permanent drought and fire-adapted type at lower elevations abutting the Rogue and Sacramento valleys. Trees often occur as scattered individuals in the communities, including ponderosa pine (*Pinus ponderosa*), white fir, or oaks. Common species in Klamath chaparral are various species of manzanita (*Arctostaphylos* spp.), wedgeleaf ceanothus (*Ceanothus cuneatus*), deerbrush (*Ceanothus integerrimus*), chamise (*Adenostoma fasciculatum*), silk-tassel (*Garrya fremontii*), birchleaf mountain mahogany (*Cercocarpus betuloides*), and Klamath plum (*Prunus subcordata*). Many native and exotic grasses and forbs occur in these communities, yielding a very species-rich flora.

1.4. Mid Elevation Environments

A. Mixed Conifer Forests (Oregon Caves, Whiskeytown, Crater Lake, and Lassen)

These forests typically occur at middle elevations in the Klamath-Siskiyou subregion and comprise the most diverse conifer forests in North America. They are generally dominated by fir, but pine-dominated forests occur as well. Due to variation in climate and geology they are quite distinct in structure and composition across the subregion. Typical tree species include Douglas fir

(*Pseudotsuga menziesii*), white fir (*Abies concolor*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*), yew (*Taxus brevifolia*), and ponderosa pine (*Pinus ponderosa*). Less widespread but locally abundant species include Jeffrey pine (*Pinus jeffreyi*), grand fir, Port-Orford cedar (*Chamaecyparis lawsoniana*), and knobcone pine (*Pinus attenuata*). Shasta red fir (*Abies magnifica* var. *shastensis*) becomes common at highest elevations of these forests. Forest understories vary greatly across the region, due to climate differences. Common hardwoods and shrub species include Pacific dogwood (*Cornus nuttallii*), canyon oak, California black oak (*Quercus kelloggii*), and bigleaf maple. Typical understory shrubs and subshrubs include the endemic Sadler's oak (*Quercus sadleriana*), greenleaf manzanita (*Arctostaphylos patula*), prince's pine (*Chimaphila umbellata*), and mahala mat (*Ceanothus prostratus*).

In the Cascades, these forests are essentially similar, but contain fewer endemic species and a greater complement of northern species, as well as Rocky Mountain species, such as Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*), especially near Crater Lake.

B. Montane Chaparral (Whiskeytown, Crater Lake, and Lassen)

Montane chaparral occurs at higher elevations than the main realm of this vegetation (1,000–3,000 m) and is dominated by a different set of shrubs. It is less common in the Cascades. This community may be relatively persistent where edaphic factors limit tree growth. More commonly, it regenerates following stand-replacing fire in conifer forests. In these cases, its persistence will depend on the frequency and severity of subsequent fires. Montane chaparral has thus been described as having a self-reinforcing relationship with fire (Show and Kotok, 1924). Greenleaf manzanita (*Arctostaphylos patula*) and several ceanothus species, huckleberry oak (*Quercus vaccinifolia*), and chinquapin (*Castanopsis sempervirens*) are common evergreen shrubs in montane chaparral. There is often a deciduous shrub component (e.g. *Ceanothus integerrimus*).

1.5. Upper Montane, Subalpine, and Alpine Environments

A. Subalpine Forests (Crater Lake, and Lassen)

Subalpine forests dominated by whitebark pine (*Pinus albicaulis*), Shasta red fir (*Abies magnifica* var. *shastensis*), western white pine (*Pinus monticola*), and mountain hemlock (*Tsuga mertensiana*) occur at High-Elevation throughout the region. In the Cascades, Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and lodgepole pine (*Pinus contorta* ssp. *latifolia*) are also abundant. Shrubs include huckleberry oak (*Quercus vaccinifolia*), greenleaf manzanita, and pinemat manzanita (*Arctostaphylos nevadensis*) on dry slopes, and Sitka alder (*Alnus viridis* ssp. *sitchensis*), black swamp currant (*Ribes lacustre*), and red-osier dogwood (*Cornus sericea*) in wetter areas.

B. Montane and Subalpine Meadows (Crater Lake, and Lassen)

Sedge and forb meadows are common at middle to High-Elevations across the region and harbor many species-rich plant associations. In many cases they are associated with wetlands or areas with shallow water tables. Moisture loving forbs such as false hellebore (*Veratrum californicum*), speedwell (*Veronica* spp.), American bistort (*Polygonum bistortoides*), cow parsnip (*Heracleum lanatum*), and lillies (*Lillium* spp.) are common, usually mixed with graminoids such as tufted hairgrass (*Deschampsia caespitosa*), meadow barley (*Horeum brachyantherum*) and species-rich

assemblages of sedges (*Carex* spp.) and rushes (*Juncus* spp.). Drier meadows dominated by yarrow (*Achillea millefolium*), Arnica (*Arnica* spp.), Fescue (*Festuca* spp.), and California oatgrass. Historical overgrazing was ubiquitous in these community types and many protected meadows are still degraded due to gully erosion or a high abundance of invasive plant species.

C. Alpine Vegetation (Crater Lake, and Lassen)

This varied vegetation type is relatively rare in the Klamath Region overall, but is well represented on Lassen Peak, and secondarily on Mount Scott and rim areas of Crater Lake National Park. The alpine flora comprises circumboreal alpine genera (*Cassiope*, *Phyllodoce*, *Kalmia*), as well as taxa derived from the more xeric low elevation floras (e.g., *Eriogonum*, *Penstemon*) (Major and Taylor 1977). Alpine flora is internally heterogeneous with considerable floristic variation from rocky, exposed slopes to concave, sheltered areas with late lying snows. Despite their small area, alpine areas are zones of high endemism (Major and Taylor 1977) where rare, endemic, or disjunct species are found, including *Draba aureola* and *Smelowskia ovalis* var. *congesta* on Lassen Peak and *Botrychium pumicola* on the Crater Lake rim.

1.6. East Cascade/Great Basin Environments

A. Ponderosa Pine (Lava Beds and Lassen)

A cooler, drier variant of this type, usually dominated by ponderosa (*Pinus ponderosa*) or Jeffrey pine (*Pinus jeffreyi*), is widespread along the eastern slopes of the Cascades. Although oaks may be mixed with the pines, especially near the heads of west flowing river valleys, these types typically have understories similar to the adjacent steppe. Common shrub species include big sagebrush (*Artemisia tridentata*) or bitterbrush (*Purshia tridentata*), chokecherry (*Prunus virginiana*), or wedgeleaf ceanothus (*Ceanothus cuneatus*). In frost-prone depressions, lodgepole pine (*Pinus contorta*) may be locally dominant.

B. Juniper Savanna/Woodland (Lava Beds)

Along the eastern edges of the Cascades and on the Modoc Plateau, western juniper (*Juniperis occidentalis*) occurs in open stands, with occasional individuals of Jeffrey (*Pinus jeffreyi*) or ponderosa pine (*Pinus ponderosa*). The understory typically includes big sagebrush, bitterbrush, rabbitbrush (*Chrysothamnus nauseosus*), and desert currant (*Ribes cereum*). Perennial bunchgrasses are usually present, including Idaho fescue (*Festuca idahoensis*), bottlebrush squirreltail (*Elymus elymoides*), and needlegrass (*Stipa* spp.).

C. Sagebrush Steppe (Lava Beds)

This community occurs over large expanses of the Modoc Plateau in various forms. The most abundant species is big sagebrush, with bitterbrush or rabbitbrush present. Low sagebrush (*Artemisia arbuscula*) is also locally dominant on areas with shallow soils. Where groundwater comes close to the surface, such as at toeslopes or riparian areas, stands of aspen (*Populus tremuloides*) occur. With the shrubs are various mixtures of native bunchgrasses, including Idaho fescue, needlegrasses, bottlebrush squirrel tail, bluebunch wheatgrass (*Pseudoroegneria spicata*), and Sandberg's bluegrass (*Poa secunda*). Although widespread, these communities are regionally threatened by invasive species, such as cheatgrass (*Bromus tectorum*) and medusahead (*Taeniatherum caput-madusae*).

D. Rosaceous Shrubland (Lava Beds)

These unique winter-deciduous shrublands occur along escarpments and droughty slopes of the eastern Cascades, and in scattered locations in the eastern Klamath-Siskiyou subregion. They are dominated by tall shrubs, usually including antelope bitterbrush (*Purshia tridentata*), and on somewhat wetter sites, also including birchleaf mountain mahogany (*Cercocarpus betuloides*), Saskatoon serviceberry (*Amelanchier alnifolia*), bitter cherry (*Prunus emarginata*), chokecherry (*Prunus virginiana*), and rose (*Rosa* spp.). They have similar herbaceous species to the surrounding sagebrush steppe.

1.7. Hydrologically-Influenced Environments

The seasonal to permanent influence of water and its many physical and chemical effects creates a broad suite of floristic communities that parallel the variety in upland vegetation in the Klamath region. Across this complex region, hydrologically-influenced environments occur in most landscape settings and span a gradient from permanently flooded marshes and estuaries to seasonally flooded riparian forests and intermittently flooded gullies and vernal pools. Below we describe several major types of hydrologically influenced vegetation along a hydrologic continuum from permanently to intermittently flooded environments.

A. True Wetlands

True wetlands include sites with semipermanent or permanently wet soils and associated hydric soils and vegetation. These wetlands take a number of forms. Note that true wetlands are not found at Lava Beds and at Oregon Caves only within the new expansion area.

Freshwater marshes – occur throughout the region from the deflation plain wetlands in the lee of coastal dunes to the subalpine environments of the Lassen uplands. The most common species in these environments include obligate wetland species including cattail (*Typha latifolia*), bulrush (*Scirpus* spp.), and any of a large number of sedge (*Carex*) species. Most dominant species are large (0.5–2.0 m in height), clonal graminoids with physiological adaptations to flooding.

Fens and seeps – are usually true wetlands situated at areas of consistent groundwater discharge. Owing to the mineral-laden groundwater flowing through them, these wetlands often harbor highly distinctive or rare species, such as the California pitcher plant (*Darlingtonia californica*) and the globally rare Howell's alkali grass (*Puccinellia howellii*).

B. Riparian Forests and Shrublands (Redwood, Oregon Caves, Whiskeytown, Crater Lake, Lassen)

Riparian communities range from cottonwood gallery forests at low elevations to subalpine meadows and willow carrs at the highest elevations. They show strong shifts in species composition across climate and geologic gradients and many species occur in only part of the region. They have been less studied than upland communities. Common and widespread riparian tree species are typically deciduous hardwoods, including black cottonwood (*Populus trichocarpa*), red alder (*Alnus rubra*), white alder (*A. rhombifolia*), bigleaf maple, Pacific willow (*Salix lucida* ssp. *lasiandra*), Pacific dogwood (*Cornus nutallii*), and Oregon ash (*Fraxinus latifolia*). Important conifers such as Port-Orford cedar (*Chamaecyparis lawsoniana*), coast redwood (*Sequoia sempervirens*), yew (*Taxus*

brevifolia), and Douglas fir (*Pseudotsuga menziesii*) can also be important parts of these forests. At the edge of the Sacramento Valley, a number of southern species occur, including Fremont's cottonwood (*Populus fremontii*), boxelder (*Acer negundo*), and valley oak. At the colder, higher Great Basin steppe margin, aspen, thinleaf alder (*Alnus incana* ssp. *tenuifolia*), and water birch (*Betula occidentalis*) appear, and many of the other species are absent. With increasing elevation, shrub and graminoid-dominated riparian communities are common, and trees become less important.

C. Seasonal Wetlands Crater Lake, Lassen, and Oregon Caves

A number of communities occur in seasonally flooded areas that subsequently dry out during the summer drought. The most common types include vernal pools, ephemeral streams, seasonal snowmelt ponds, and snowmelt beds. Vernal pools often have distinctive annual species such as meadow foam (*Limnanthus* spp.), or perennial graminoids such as spiked rush (*Eleocharis* spp.). Ephemeral streams often have species that can tolerate both flooding and seasonal flooding and drought (e.g., Oregon ash). Snowmelt ponds and swales often provide unique habitats for northern alpine species with high moisture requirements, such as bog-laurel (*Kalmia polifolia* ssp. *microphylla*) and Labrador tea (*Ledum glandulosum*).

1.8 Literature Cited

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- Whittaker, R. H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecological Monographs 30:279–338.
- Whittaker, R. H. 1961. Vegetation history of the Pacific coast states and the central significance of the Klamath region. Madroño 16:5–23.

Appendix B. Park Vegetation Mapping Products

Detailed vegetation descriptions and maps or classified images are also available for Crater Lake (DiPaolo et al. 2018): <https://irma.nps.gov/DataStore/DownloadFile/602432>)

Lava Beds (DiPaolo et al. 2015): <https://irma.nps.gov/DataStore/DownloadFile/533910>)

Oregon Caves (Odion et al. 2013): <https://irma.nps.gov/DataStore/DownloadFile/586607>)

Redwood (Stumpf et al. 2017): <https://irma.nps.gov/DataStore/DownloadFile/578548>)

Whiskeytown (Fox et al. 2006): <https://irma.nps.gov/DataStore/DownloadFile/422978>)

Detailed vegetation descriptions and maps or classified images will soon be available for Lassen: <https://irma.nps.gov/DataStore/Reference/Profile/2177185>

Appendix C. Crater Lake National Park Dominant Species

Table C-1. The 15 most common species at Crater Lake National Park and the average cover in which they occurred in each stratum (Matrix, Riparian, and High-Elevation) during the 2013 sampling of the permanent plots in Klamath Network's vegetation monitoring protocol. The Plant Functional Type we assigned for each species is shown in the far right column.

Stratum (Total # of plots)	Species	Average Cover	Number of plots	Plant Functional Type
Matrix (26)	<i>Tsuga mertensiana</i>	16.25	23	Tree (Conifer)
	<i>Abies magnifica</i>	11.56	23	Tree (Conifer)
	<i>Pinus contorta</i> var. <i>murrayana</i>	4.84	21	Tree (Conifer)
	<i>Vaccinium scoparium</i>	2.02	8	Shrub (Deciduous)
	<i>Abies lasiocarpa</i>	1.71	3	Tree (Conifer)
	<i>Arctostaphylos nevadensis</i>	1.66	10	Shrub (Evergreen)
	<i>Pinus ponderosa</i>	1.57	1	Tree (Conifer)
	<i>Luzula glabrata</i> var. <i>hitchcockii</i>	0.77	8	Graminoid
	<i>Pinus monticola</i>	0.75	16	Tree (Conifer)
	<i>Ceanothus velutinus</i>	0.42	1	Shrub (Evergreen)
	<i>Carex inops</i> ssp. <i>inops</i>	0.42	22	Graminoid
	<i>Pseudotsuga menziesii</i>	0.31	2	Tree (Conifer)
	<i>Pinus albicaulis</i>	0.13	3	Tree (Conifer)
	<i>Lupinus andersonii</i>	0.08	11	Herb (Perennial)
	<i>Arctostaphylos patula</i>	0.07	3	Shrub (Evergreen)
Riparian (20)	<i>Abies lasiocarpa</i>	9.93	19	Tree (Conifer)
	<i>Tsuga mertensiana</i>	9.46	18	Tree (Conifer)
	<i>Picea engelmannii</i>	4.95	4	Tree (Conifer)
	<i>Calamagrostis canadensis</i>	4.05	20	Graminoid
	<i>Carex inops</i> ssp. <i>inops</i>	3.71	16	Graminoid
	<i>Lupinus polyphyllus</i>	3.19	13	Herb (Perennial)
	<i>Pinus contorta</i> var. <i>murrayana</i>	3.03	16	Tree (Conifer)
	<i>Alnus incana</i>	2.72	3	Shrub (Deciduous)
	<i>Senecio triangularis</i>	2.21	20	Herb (Perennial)
	<i>Vaccinium membranaceum</i>	2.17	14	Shrub (Deciduous)
	<i>Scirpus microcarpus</i>	1.63	4	Graminoid
	<i>Salix sitchensis</i>	1.61	6	Shrub (Deciduous)
	<i>Agrostis idahoensis</i>	1.29	10	Graminoid
	<i>Rubus lasiococcus</i>	1.28	11	Shrub (Deciduous)
	<i>Abies grandis</i>	1.01	5	Tree (Conifer)
	<i>Tsuga mertensiana</i>	14.97	15	Tree (Conifer)

Stratum (Total # of plots)	Species	Average Cover	Number of plots	Plant Functional Type
High-Elevation (20)	<i>Luzula glabrata</i> var. <i>hitchcockii</i>	3.75	12	Graminoid
	<i>Pinus contorta</i> var. <i>murrayana</i>	1.33	9	Tree (Conifer)
	<i>Polygonum davisiae</i>	1.16	16	Herb (Perennial)
	<i>Pinus albicaulis</i>	1.16	18	Tree (Conifer)
	<i>Carex breweri</i>	0.91	10	Graminoid
	<i>Phlox diffusa</i>	0.47	4	Shrub (Evergreen)
	<i>Abies magnifica</i>	0.38	3	Tree (Conifer)
	<i>Lupinus andersonii</i>	0.33	8	Herb (Perennial)
	<i>Elymus elymoides</i>	0.28	14	Graminoid
	<i>Achnatherum occidentale</i>	0.23	15	Graminoid
	<i>Ericameria greenei</i>	0.21	13	Shrub (Deciduous)
	<i>Lupinus lepidus</i>	0.12	13	Herb (Perennial)
	<i>Juncus parryi</i>	0.12	10	Graminoid
	<i>Luzula piperi</i>	0.10	1	Graminoid

Appendix D. Lava Beds Dominant Species

Table D-1. The 15 most common species at Lava Beds National Monument and the average cover in which they occurred in each stratum (Matrix, Riparian, and High-Elevation) during the 2011 sampling of the permanent plots in Klamath Network's vegetation monitoring protocol. The Plant Functional Type we assigned for each species is shown in the far right column.

Stratum (Total # of plots)	Species	Average Cover	Number of Plots	Plant Functional Type
Matrix (30)	<i>Artemisia tridentata</i>	14.39	28	Shrub (Evergreen)
	<i>Bromus tectorum</i>	12.69	30	Graminoid (Annual)
	<i>Purshia tridentata</i>	3.78	22	Shrub (Evergreen)
	<i>Cercocarpus ledifolius</i>	2.75	11	Shrub (Evergreen)
	<i>Poa secunda</i>	2.73	28	Graminoid
	<i>Pseudoroegneria spicata</i>	2.02	27	Graminoid
	<i>Ericameria nauseosa</i>	1.95	27	Shrub (Evergreen)
	<i>Ribes cereum</i>	1.12	17	Shrub (Deciduous)
	<i>Ribes velutinum</i>	1.00	19	Shrub (Deciduous)
	<i>Juniperus occidentalis</i>	0.97	10	Tree (Conifer)
	<i>Achnatherum thurberianum</i>	0.74	26	Graminoid
	<i>Chrysothamnus viscidiflorus</i>	0.71	17	Shrub (Evergreen)
	<i>Festuca idahoensis</i>	0.67	7	Graminoid
	<i>Crepis acuminata</i>	0.48	21	Herb (Perennial)
	<i>Agastache parvifolia</i>	0.45	6	Herb (Perennial)
Riparian (14)	<i>Abies magnifica</i>	9.68	12	Tree (Conifer)
	<i>Alnus incana</i>	8.61	9	Shrub (Deciduous)
	<i>Pinus contorta</i> var. <i>murrayana</i>	8.11	11	Tree (Conifer)
	<i>Salix lucida</i> ssp. <i>lasianдра</i>	4.11	2	Shrub (Deciduous)
	<i>Calamagrostis canadensis</i>	3.05	10	Graminoid
	<i>Tsuga mertensiana</i>	2.94	6	Tree (Conifer)
	<i>Abies concolor</i>	2.71	8	Tree (Conifer)
	<i>Trifolium longipes</i>	2.34	8	Herb (Perennial)
	<i>Carex nervina</i>	1.76	13	Graminoid
	<i>Carex angustata</i>	1.68	3	Graminoid
	<i>Salix lemmonii</i>	1.67	3	Shrub (Deciduous)
	<i>Salix boothii</i>	1.65	5	Shrub (Deciduous)
	<i>Pinus monticola</i>	1.64	7	Tree (Conifer)
	<i>Elymus glaucus</i>	1.60	10	Graminoid
	<i>Carex lenticularis</i>	1.54	4	Graminoid
	<i>Lupinus obtusilobus</i>	17.33	9	Forb/herb (Perennial)

Stratum (Total # of plots)	Species	Average Cover	Number of Plots	Plant Functional Type
High-Elevation (10)	<i>Tsuga mertensiana</i>	10.02	9	Tree (Conifer)
	<i>Pinus albicaulis</i>	2.25	9	Tree (Conifer)
	<i>Carex breweri</i>	0.99	5	Graminoid
	<i>Polygonum davisiae</i>	0.56	8	Forb/herb (Perennial)
	<i>Lupinus polyphyllus</i>	0.55	1	Forb/herb (Perennial)
	<i>Pinus monticola</i>	0.35	1	Tree (Conifer)
	<i>Phyllodoce breweri</i>	0.27	3	Shrub (Evergreen)
	<i>Achnatherum occidentale</i>	0.26	3	Graminoid
	<i>Holodiscus discolor</i>	0.20	2	Shrub (Deciduous)
	<i>Eriogonum marifolium</i>	0.16	9	Forb/herb (Perennial)
	<i>Carex rossii</i>	0.15	5	Graminoid
	<i>Carex stramineiformis</i>	0.11	3	Graminoid
	<i>Juncus parryi</i>	0.08	5	Graminoid
	<i>Sambucus racemosa</i>	0.07	1	Shrub (Deciduous)

Appendix E. Lassen Volcanic National Monument Dominant Species

Table E-1. The 15 most common species at Lassen Volcanic National Monument and the average cover in which they occurred in each stratum (Matrix, Riparian, and High-Elevation) during the 2012 sampling of the permanent plots in Klamath Network's vegetation monitoring protocol. The Plant Functional Type we assigned for each species is shown in the far right column.

Stratum (Total # of plots)	Species	Average Cover	Number of Plots	Plant Functional Type
Matrix (18)	<i>Abies concolor</i>	17.27	12	Tree (Conifer)
	<i>Arctostaphylos nevadensis</i>	9.92	10	Shrub (Evergreen)
	<i>Abies magnifica</i>	9.70	15	Tree (Conifer)
	<i>Pinus contorta</i> var. <i>murrayana</i>	4.37	7	Tree (Conifer)
	<i>Pinus jeffreyi</i>	2.91	8	Tree (Conifer)
	<i>Pinus monticola</i>	1.83	12	Tree (Conifer)
	<i>Chimaphila umbellata</i>	1.19	3	Herb (Perennial)
	<i>Pinus washoensis</i>	1.05	1	Tree (Conifer)
	<i>Achnatherum occidentale</i>	0.99	14	Graminoid
	<i>Monardella odoratissima</i> ssp. <i>pallida</i>	0.98	7	Herb (Perennial)
	<i>Chrysolepis sempervirens</i>	0.87	8	Shrub (Evergreen)
	<i>Tsuga mertensiana</i>	0.84	2	Tree (Conifer)
	<i>Lupinus obtusilobus</i>	0.57	1	Herb (Perennial)
	<i>Elymus elymoides</i>	0.40	10	Graminoid
	<i>Penstemon heterodoxus</i> var. <i>shastensis</i>	0.20	4	Herb (Perennial)
Riparian (14)	<i>Abies magnifica</i>	9.68	12	Tree (Conifer)
	<i>Alnus incana</i>	8.61	9	Shrub (Deciduous)
	<i>Pinus contorta</i> var. <i>murrayana</i>	8.11	11	Tree (Conifer)
	<i>Salix lucida</i> ssp. <i>lasiandra</i>	4.11	2	Shrub (Deciduous)
	<i>Calamagrostis canadensis</i>	3.05	10	Graminoid
	<i>Tsuga mertensiana</i>	2.94	6	Tree (Conifer)
	<i>Abies concolor</i>	2.71	8	Tree (Conifer)
	<i>Trifolium longipes</i>	2.34	8	Herb (Perennial)
	<i>Carex nervina</i>	1.76	13	Graminoid
	<i>Carex angustata</i>	1.68	3	Graminoid
	<i>Salix lemmonii</i>	1.67	3	Shrub (Deciduous)
	<i>Salix boothii</i>	1.65	5	Shrub (Deciduous)
	<i>Pinus monticola</i>	1.64	7	Tree (Conifer)
	<i>Carex lenticularis</i>	1.54	4	Graminoid
	<i>Lupinus obtusilobus</i>	17.33	9	Forb/herb (Perennial)

Stratum (Total # of plots)	Species	Average Cover	Number of Plots	Plant Functional Type
High-Elevation (10)	<i>Tsuga mertensiana</i>	10.02	9	Tree (Conifer)
	<i>Pinus albicaulis</i>	2.25	9	Tree (Conifer)
	<i>Carex breweri</i>	0.99	5	Graminoid
	<i>Polygonum davisiae</i>	0.56	8	Forb/herb (Perennial)
	<i>Lupinus polyphyllus</i>	0.55	1	Forb/herb (Perennial)
	<i>Pinus monticola</i>	0.35	1	Tree (Conifer)
	<i>Phyllodoce breweri</i>	0.27	3	Shrub (Evergreen)
	<i>Achnatherum occidentale</i>	0.26	3	Graminoid
	<i>Holodiscus discolor</i>	0.20	2	Shrub (Deciduous)
	<i>Eriogonum marifolium</i>	0.16	9	Forb/herb (Perennial)
	<i>Carex rossii</i>	0.15	5	Graminoid
	<i>Carex stramineiformis</i>	0.11	3	Graminoid
	<i>Juncus parryi</i>	0.08	5	Graminoid
	<i>Sambucus racemosa</i>	0.07	1	Shrub (Deciduous)

Appendix F. Oregon Caves National Monument and Preserve Dominant Species

Table F-1. The 15 most common species at Oregon Caves National Monument and Preserve, and the average cover in which they occurred in each stratum (Matrix only) during the 2013 sampling of the permanent plots in Klamath Network's vegetation monitoring protocol. The Plant Functional Type we assigned for each species is shown in the far right column.

Stratum (Total # of plots)	Species	Average Cover	Number of Plots	Plant Functional Type
Matrix (10)	<i>Abies concolor</i>	34.61	10	Tree (Conifer)
	<i>Pseudotsuga menziesii</i>	16.77	8	Tree (Conifer)
	<i>Abies procera</i>	7.16	3	Tree (Conifer)
	<i>Acer macrophyllum</i>	3.12	4	Tree (Broadleaved, Deciduous)
	<i>Achlys triphylla</i>	2.82	10	Herb (Perennial)
	<i>Lathyrus polyphyllus</i>	2.54	7	Herb (Perennial)
	<i>Pinus monticola</i>	1.65	1	Tree (Conifer)
	<i>Mahonia nervosa</i>	1.36	8	Shrub (Evergreen)
	<i>Actaea rubra</i>	1.29	7	Herb (Perennial)
	<i>Chamaecyparis lawsoniana</i>	1.25	1	Tree (Conifer)
	<i>Campanula scouleri</i>	0.97	8	Herb (Perennial)
	<i>Phlox adsurgens</i>	0.96	9	Herb (Perennial)
	<i>Corylus cornuta</i>	0.88	9	Shrub (Deciduous)
	<i>Whipplea modesta</i>	0.81	4	Shrub (Evergreen)
	<i>Quercus chrysolepis</i>	0.77	4	Tree (Broadleaved, Evergreen)

Appendix G. Redwood National and State Parks Dominant Species

Table G-1. The 15 most common species at Redwood National and State Parks, and the average cover in which they occurred in each stratum (Matrix, Riparian) during the 2011 sampling of the permanent plots in Klamath Network's vegetation monitoring protocol. The Plant Functional Type we assigned for each species is shown in the far right column.

Stratum (Total # of plots)	Species	Average Cover	Number of Plots	Plant Functional Type
Matrix (26)	<i>Vaccinium ovatum</i>	31.34	24	Shrub (Evergreen)
	<i>Sequoia sempervirens</i>	28.10	24	Tree (Conifer)
	<i>Pseudotsuga menziesii</i>	20.15	16	Tree (Conifer)
	<i>Notholithocarpus densiflorus</i> var. <i>densiflorus</i>	18.50	18	Tree (Broadleaved, Evergreen)
	<i>Tsuga heterophylla</i>	13.89	16	Tree (Conifer)
	<i>Rhododendron macrophyllum</i>	12.01	17	Shrub (Evergreen)
	<i>Polystichum munitum</i>	9.29	23	Herb (Perennial)
	<i>Gaultheria shallon</i>	5.54	24	Shrub (Evergreen)
	<i>Anthoxanthum odoratum</i>	2.93	2	Graminoid
	<i>Arrhenatherum elatius</i>	1.50	2	Graminoid
	<i>Picea sitchensis</i>	1.37	3	Tree (Conifer)
	<i>Alnus rubra</i>	1.28	8	Tree (Broadleaved, Deciduous)
	<i>Blechnum spicant</i>	0.99	16	Herb (Perennial)
	<i>Oxalis oregana</i>	0.94	12	Herb (Perennial)
	<i>Vaccinium parvifolium</i>	0.87	20	Shrub (Deciduous)
Riparian (21)	<i>Alnus rubra</i>	35.09	17	Tree (Broadleaved, Deciduous)
	<i>Polystichum munitum</i>	26.06	20	Herb (Perennial)
	<i>Sequoia sempervirens</i>	20.55	18	Tree (Conifer)
	<i>Tsuga heterophylla</i>	9.99	12	Tree (Conifer)
	<i>Rubus spectabilis</i>	8.84	20	Shrub (Deciduous)
	<i>Oxalis oregana</i>	7.33	19	Herb (Perennial)
	<i>Notholithocarpus densiflorus</i> var. <i>densiflorus</i>	6.85	12	Tree (Broadleaved, Evergreen)
	<i>Vaccinium ovatum</i>	5.80	15	Shrub (Evergreen)
	<i>Blechnum spicant</i>	4.74	16	Herb (Perennial)
	<i>Rubus ursinus</i>	3.92	12	Shrub (Evergreen)
	<i>Tolmiea menziesii</i>	3.60	19	Herb (Perennial)
	<i>Gaultheria shallon</i>	3.60	13	Shrub (Evergreen)

Stratum (Total # of plots)	Species	Average Cover	Number of Plots	Plant Functional Type
	<i>Pseudotsuga menziesii</i>	3.08	12	Tree (Conifer)
	<i>Acer circinatum</i>	2.97	9	Shrub (Deciduous)
	<i>Picea sitchensis</i>	2.94	6	Tree (Conifer)

Appendix H. Whiskeytown National Recreation Area Dominant Species

Table H-1. The 15 most common species at Whiskeytown National Recreation Area and the average cover in which they occurred in each stratum (Matrix, Riparian, and High-Elevation) during the 2012 sampling of the permanent plots in Klamath Network's vegetation monitoring protocol. The Plant Functional Type we assigned for each species is shown in the far right column.

Stratum (Total # of plots)	Species	Average Cover	Number of Plots	Plant Functional Type
Matrix (21)	<i>Quercus chrysolepis</i>	22.59	20	Tree (Broadleaved, Evergreen)
	<i>Quercus kelloggii</i>	15.38	18	Tree (Broadleaved, Deciduous)
	<i>Arctostaphylos viscida</i>	7.34	14	Shrub (Evergreen)
	<i>Pinus ponderosa</i>	6.85	16	Tree (Conifer)
	<i>Notholithocarpus densiflorus</i> var. <i>densiflorus</i>	4.38	7	Tree (Broadleaved, Evergreen)
	<i>Pseudotsuga menziesii</i>	4.21	14	Tree (Conifer)
	<i>Ceanothus lemmonii</i>	3.89	10	Shrub (Evergreen)
	<i>Heteromeles arbutifolia</i>	3.48	15	Shrub (Evergreen)
	<i>Toxicodendron diversilobum</i>	2.68	20	Shrub (Deciduous)
	<i>Adenostoma fasciculatum</i>	2.36	3	Shrub (Evergreen)
	<i>Abies concolor</i>	2.20	1	Tree (Conifer)
	<i>Acer macrophyllum</i>	2.18	4	Tree (Broadleaved, Deciduous)
	<i>Quercus wislizeni</i>	1.84	4	Tree (Broadleaved, Evergreen)
	<i>Styrax redivivus</i>	1.68	8	Shrub (Deciduous)
	<i>Corylus cornuta</i>	1.31	1	Shrub (Deciduous)
Riparian (15)	<i>Quercus chrysolepis</i>	25.52	15	Tree (Broadleaved, Evergreen)
	<i>Alnus rhombifolia</i>	20.35	15	Tree (Broadleaved, Deciduous)
	<i>Vitis californica</i>	14.43	14	Vine (Deciduous)
	<i>Cornus sessilis</i>	11.33	8	Shrub (Deciduous)
	<i>Acer macrophyllum</i>	10.09	12	Tree (Broadleaved, Deciduous)
	<i>Pseudotsuga menziesii</i>	9.85	13	Tree (Conifer)
	<i>Notholithocarpus densiflorus</i> var. <i>densiflorus</i>	5.02	7	Tree (Broadleaved, Evergreen)
	<i>Rubus ursinus</i>	4.31	13	Shrub (Evergreen)

Stratum (Total # of plots)	Species	Average Cover	Number of Plots	Plant Functional Type
	<i>Quercus garryana</i> var. <i>garryana</i>	3.57	5	Tree (Broadleaved, Deciduous)
	<i>Rubus armeniacus</i>	3.54	7	Shrub (Evergreen)
	<i>Pinus ponderosa</i>	3.35	11	Tree (Conifer)
	<i>Robinia pseudoacacia</i>	3.25	2	Tree (Broadleaf, Deciduous)
	<i>Rhododendron occidentale</i>	3.08	5	Shrub (Deciduous)
	<i>Pteridium aquilinum</i> var. <i>pubescens</i>	2.91	13	Herb (Perennial)
	<i>Calocedrus decurrens</i>	2.56	10	Tree (Conifer)
High-Elevation (10)	<i>Notholithocarpus densiflorus</i> var. <i>echinoides</i>	16.68	9	Tree (Broadleaved, Evergreen)
	<i>Arctostaphylos nevadensis</i>	13.10	7	Shrub (Evergreen)
	<i>Quercus vaccinifolia</i>	8.93	3	Shrub (Evergreen)
	<i>Abies magnifica</i>	8.39	6	Tree (Conifer)
	<i>Pinus ponderosa</i>	6.92	4	Tree (Conifer)
	<i>Chrysolepis sempervirens</i>	5.89	7	Shrub (Evergreen)
	<i>Abies concolor</i>	4.84	7	Tree (Conifer)
	<i>Arctostaphylos patula</i>	2.84	7	Shrub (Evergreen)
	<i>Lotus crassifolius</i>	1.09	6	Herb (Perennial)
	<i>Pteridium aquilinum</i> var. <i>pubescens</i>	1.00	2	Herb (Perennial)
	<i>Pinus lambertiana</i>	0.98	6	Tree (Conifer)
	<i>Acer glabrum</i>	0.93	2	Shrub (Deciduous)
	<i>Symphoricarpos mollis</i>	0.69	4	Shrub (Deciduous)
	<i>Amelanchier utahensis</i>	0.35	2	Shrub (Deciduous)
	<i>Apocynum androsaemifolium</i>	0.29	6	Herb (Perennial)

Appendix I. Means and Standard Deviations for Plant Growth Habit for Each Park and Stratum

Table I-1. Means and standard deviations for Plant Growth Habit for each park and stratum.

Park	Plant Growth Habit	Matrix	Riparian	High-Elevation
CRLA	Tree	37.1 (4.2)	29.6 (4.2)	17.8 (4.3)
	Shrub	4.2 (2.1)	10.4 (3.1)	0.2 (0.2)
	Herb	0.4 (0.1)	15.9 (2.6)	2.7 (0.8)
	Graminoid	1.3 (0.8)	15.2 (3.0)	5.7 (2.3)
	Vine	–	0.01 (0.01)	–
LABE	Tree	3.7 (1.2)	–	–
	Shrub	24.1 (2.9)	–	–
	Herb	3.9 (0.5)	–	–
	Graminoid	19.5 (4.3)	–	–
	Vine	–	–	–
LAVO	Tree	37.9 (4.9)	26.8 (3.4)	12.7 (3.3)
	Shrub	11.3 (5.1)	17.9 (7.9)	0.6 (0.4)
	Herb	3.4 (1.7)	20.7 (6.2)	18.9 (6.8)
	Graminoid	1.8 (1.0)	16.3 (3.9)	1.7 (2.4)
	Vine	–	–	–
ORCA	Tree	65.6 (6.6)	–	–
	Shrub	5.2 (1.5)	–	–
	Herb	13.8 (3.1)	–	–
	Graminoid	0.3 (0.05)	–	–
	Vine	0.5 (0.3)	–	–
RNSP	Tree	84 (5.5)	79.7 (6.1)	–
	Shrub	50.9 (6.4)	36.1 (5.1)	–
	Herb	14.1 (2.9)	49.5 (5.9)	–
	Graminoid	5.6 (3.6)	6.1 (2.1)	–
	Vine	–	0.6 (0.3)	–
WHIS	Tree	60.5 (7.2)	87.6 (9.2)	21.1 (6.2)
	Shrub	28.2 (6.8)	42.3 (6.6)	49.8 (9.9)
	Herb	1.9 (0.4)	10.4 (2.2)	3 (1.3)
	Graminoid	2 (0.7)	4.6 (1.8)	0.2 (0.07)
	Vine	0.8 (0.5)	16.4 (4.7)	–

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NPS 963/175124, March 2021

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