National Park Service
U.S. Department of the Interior

Science Report NPS/SR—2025/291
https://doi.org/10.36967/2311589

Vegetation Community Monitoring

Forest Structure in Klamath Network Parks

Trent Berrian measuring the diameter at breast height of a redwood tree on a vegetation monitoring plot in Redwood National and State Parks.

NPS / NATASHA PAGEL-APRIL

Vegetation community monitoring: Forest structure in Klamath Network parks

Science Report NPS/SR—2025/291

Sean B. Smith[1], Lauren N. Youngblood[1], Micah Wright[2], Phillip van Mantgem[2]

[1] National Park Service
Klamath Inventory and Monitoring Network
1250 Siskiyou Blvd
Ashland, Oregon 97520

[2] U.S. Geological Survey
Western Ecological Research Center
1655 Heindon Road
Arcata, California 95521

Please cite this publication as:

Smith, S. B., L. N. Youngblood, M. Wright, and P. van Mantgem. 2025. Vegetation community monitoring: Forest structure in Klamath Network parks. Science Report NPS/SR—2025/291. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/2311589

NPS 963/197123, May 2025

Contents

Figures

Page

Abstract

The Klamath Network, comprising six national park units in northern California and southern Oregon, initiated a vegetation monitoring protocol in 2011 to discern ecologically significant vegetation trends in these parks. The premise of the protocol is that multivariate analyses of species composition data are the most robust means for early detection of vegetation change over time. Here, we present these community metrics based on our sampling efforts from 2011 to 2019. Observations from the first sampling event (2011–2013) were used to establish baseline conditions for the vegetation communities. Observations from subsequent sampling in 2014–2019 were used to identify potential temporal variation in forest structure across habitat types and parks.

Park landscapes were categorized into three strata: matrix (low- to mid-elevation upland habitats), riparian (within 10 m of a perennial stream), and high-elevation (above a predefined elevation, park-specific). At the onset of the network's vegetation monitoring protocol, 241 permanent plots were established at random locations across the three strata. We present summary statistics from three repeated samplings (2011–2019) of each plot, describing variation in forest structure across broad habitat types and parks. Observable differences in forest structure aligned with expected productivity gradients across the parks. Measures of forest structure (vegetation cover, stem density, basal area, tree heights, height to live crown, shrub cover, and surface fuels) were generally higher in mesic sites, compared to sites located in more arid, continental climates. Differences across sampling frames also followed this general pattern of productivity. Matrix and riparian sampling frames had similar ranges of values in most cases, while high elevation sites had relatively lower stem density, basal area, shrub cover, fuels, and recruitment. Notably, we observed a relative lack of change in forest structure over time. This is not surprising given the relatively short (six-year) timespan of observations in each park. The fourth set of Klamath Network surveys (2021–2023) is likely to show substantial changes in vegetation cover and forest structure, particularly for parks that have recently experienced major fires.

Continued long-term vegetation monitoring is crucial for understanding ecosystem responses to a rapidly changing world. This report on vegetation composition is the second in a series; upcoming reports will analyze structure and function, aiming to detect spatiotemporal trends.

Acknowledgments

We thank the many field crews who collected the field data. Adrian Das and Jon Keeley 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.

Introduction

The mission of the National Park Service is to conserve "… unimpaired the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations" (https://www.nps.gov/orgs/1955/our-mission-and-role.htm). To accomplish this goal, science-based management decisions must be based on reliable information. The National Park Service instituted the Inventory and Monitoring Program to help gather this information (https://www.nps.gov/im/index.htm). The program is divided among 32 separate networks that collect and analyze data on specific taxa, communities, and environments that are key components of local ecosystems. The program conducts inventories to capture the range of biota and conditions across the parks, while its long-term monitoring efforts aim to describe and understand where and how changes in natural resources are occurring.

Climates, ecosystems, and their dependent biota are constantly changing over time. However, we are now in an era of anthropogenically driven rapid changes in climate, which may have profound effects on natural resources across national parks (Gonzalez et al. 2018). Conservation problems associated with disrupted historical fire regimes, invasive species, air pollution, and habitat loss are also continuing in national parks (Beissinger et al. 2017). Indeed, these stressors may interact to cause major, long-lasting shifts in the biota and ecosystem functioning. Considering these trends, the data collected by the Inventory and Monitoring Program are becoming ever more important.

The inventory and monitoring data collected on forested ecosystems may be especially crucial. In western North America coniferous forests are vulnerable to increasing incidence of drought and fire (Allen et al. 2015; Williams et al. 2013). The effects of moisture stress have been linked to both chronic and acute increases in forest mortality (Allen and Breshears 1998; van Mantgem et al. 2009). Fire size, frequency, and severity are increasing across much of this region that supports coniferous forests (Parks and Abatzoglou 2020; Dennison et al. 2014; Westerling 2006). Nearly all conifers are obligate seeders (i.e., they do not resprout following disturbance), so that coniferous forest recovery following severe fire is dependent on recruitment from seeds. It is difficult for wind-dispersed conifer seeds to reach the interior of large, high-severity burned areas (Coop et al. 2020). Tree seedlings lack well-developed roots and are sensitive to moisture stress (Augustine and Reinhardt 2019), so that drying trends are limiting opportunities for seedlings to establish following disturbance (Davis et al. 2019). The result of these disturbances is the conversion of forests to nonforested ecosystems, which may persist for decades or centuries (Coop et al. 2020; Falk et al. 2022). These conversions are associated with losses in essential ecosystem services such as wildlife habitat, water quality, and carbon sequestration.

The Klamath Network

The Klamath Inventory and Monitoring Network consists of six parks: Crater Lake National Park (CRLA), Lava Beds National Monument (LABE), Lassen Volcanic National Park (LAVO), Oregon Caves National Monument and Preserve (ORCA), Redwood National and State Parks (REDW in this report; also RNSP), and Whiskeytown National Recreation Area (WHIS). The parks span large ranges in climates, soil types, vegetation, and elevations (Sarr et al. 2007; Smith et al. 2021).

The Klamath region is a well-known biodiversity hotspot and center of endemism (Whittaker 1960; Whittaker 1961). The vegetation of the Klamath Network parks reflects this diversity, ranging from dense coastal redwood forests at REDW to shrublands and sagebrush communities at LABE. For a comprehensive treatment of vegetation at the Klamath Network parks see Smith et al. (2021). Vegetation change is one of the “vital signs” that help determine overall ecosystem health. Forested ecosystems are an important component of all the Klamath Network parks, and for REDW, conserving the forested ecosystem was a primary purpose for establishing the park.

Objective

The goal of this work is to describe forest composition and structure across the Klamath Network parks. The parks in the network were visited three times each from 2011 to 2019. We consider differences across broad habitat types and over time. Specifically, we address the following question:

How do common measures of forest structure (basal area, stem density, tree height, and height to live crown) vary over the Klamath Network parks? We consider differences among riparian, matrix, and high-elevation forest types and important tree genera. We also describe differences in surface fuels, vegetation cover, shrub height, and surface substrate types.

Methods

Study area

Klamath Network (https://www.nps.gov/im/klmn/index.htm) parks are distributed throughout Southern Oregon and Northern California (Figure 1). The network covers a diverse range of ecosystems in an area noted for complex topography and high biodiversity (Skinner et al. 2006), ranging from coastal redwoods to sagebrush scrub. Potential sampling locations were divided into three broad vegetation types, termed "sample frames": matrix (low- to mid-elevation upland habitats), riparian (within 10 m of a perennial stream), and high-elevation (above a predefined elevation, park-specific). Riparian and high elevation sample frames were used to identify sensitive riparian and high elevation vegetation, whereas the matrix sample frame included all other available vegetation types and thus could be quite diverse within the network. Within each park, plot locations were generated by sample frame using Generalized Random Tessellation Stratified design (GRTS, Stevens and Olsen 2003). Sites were excluded if they were difficult to access (i.e., not 100–1000 m from a road or trail) or were on a steep slope (>30°). Some parks had fewer than three sample frames when a particular vegetation type (i.e., high elevation) was not found within the park. Plot locations with unsafe working conditions such as steep terrain, dangerous wildlife, or illegal marijuana cultivation were not sampled. See Odion et al. (2011) and Smith et al. (2021) for a full discussion of the network's long-term monitoring motivation and sample design. All descriptive statistics and visualizations were done in R (R Core Team 2024).

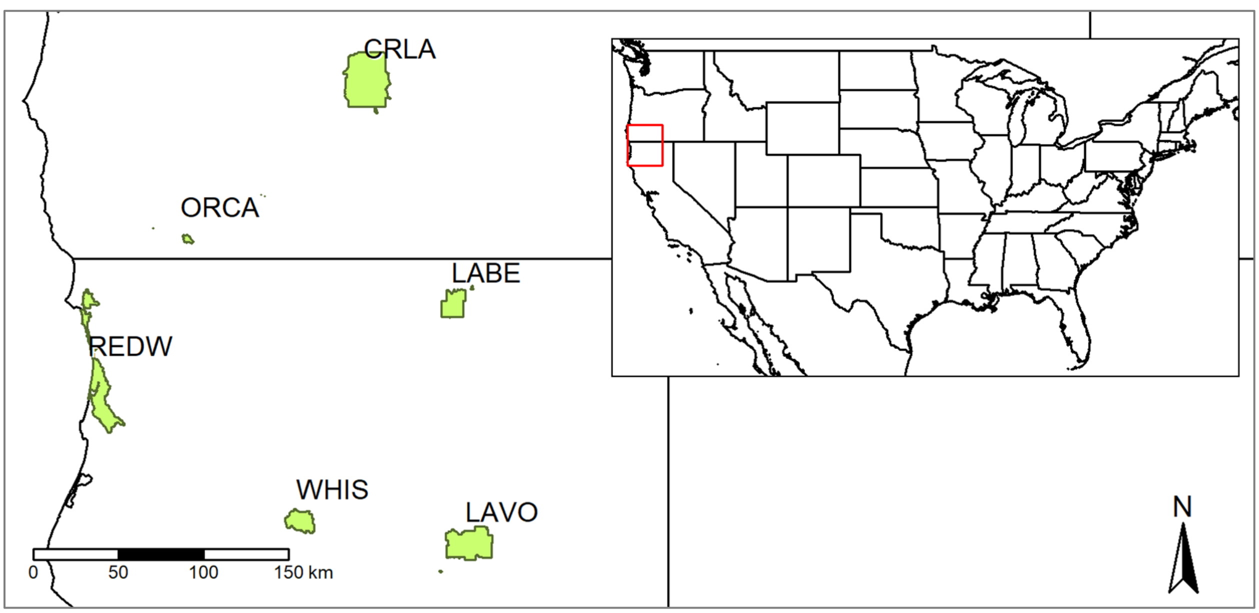

Figure 1. Parks of the Klamath Network in southern Oregon and northern California. The Klamath area is shown in the red box in the inset. Klamath Network parks include: CRLA = Crater Lake National Park, LABE = Lava Beds National Monument, LAVO = Lassen Volcanic National Park, ORCA = Oregon Caves National Monument and Preserve, REDW = Redwood National and State Parks, and WHIS = Whiskeytown National Recreation Area.

NPS

Field sampling

Plots were 0.1 ha in size. Each plot consisted of 10 square modules 100 m^2 in area, usually arranged in a 2 × 5 format (Figure 2), though a different format was used for riparian areas (Smith et al. 2021).

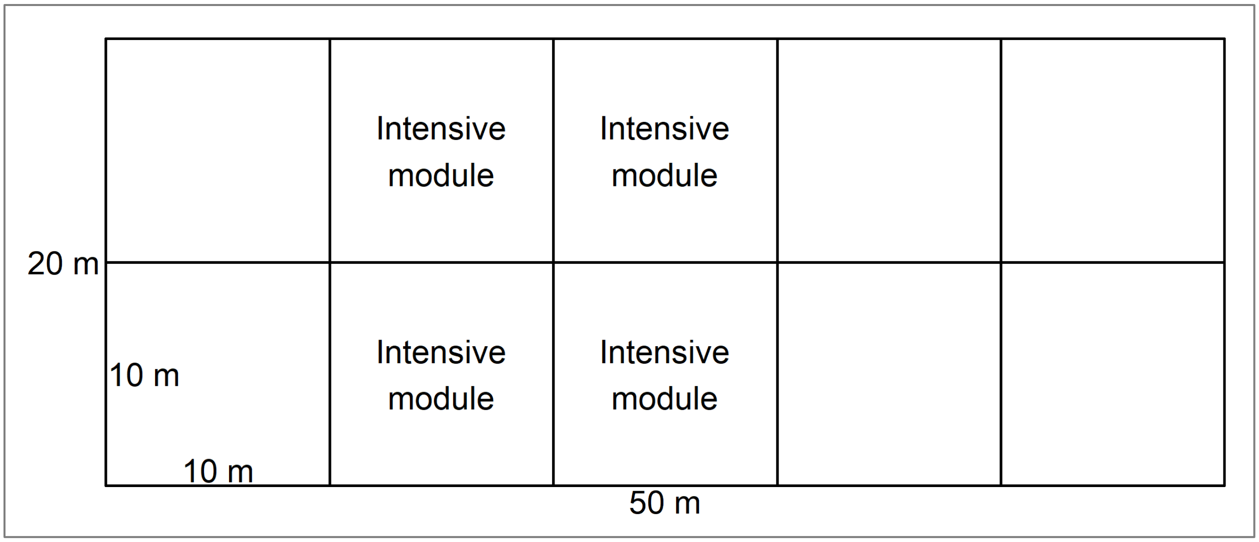

Figure 2. Typical plot layout for sampling matrix and high-elevation vegetation types in the Klamath Network monitoring program. Riparian areas used a similar sampling scheme, but with subplots following stream courses. Each module is 10 × 10 m (individual module area = 100 m^2). There are four intensive modules (total intensive module area = 400 m^2).
NPS

The plots were sampled on a rotating three-year basis. This meant that each park was visited and all plots in that park were sampled in a single year, then resampled every three years (Figure 3). With the exception of a small number of plots that were first sampled later in the series, each plot was sampled a total of three times by 2019. The details for the measurements taken within each plot are given in the sections below.

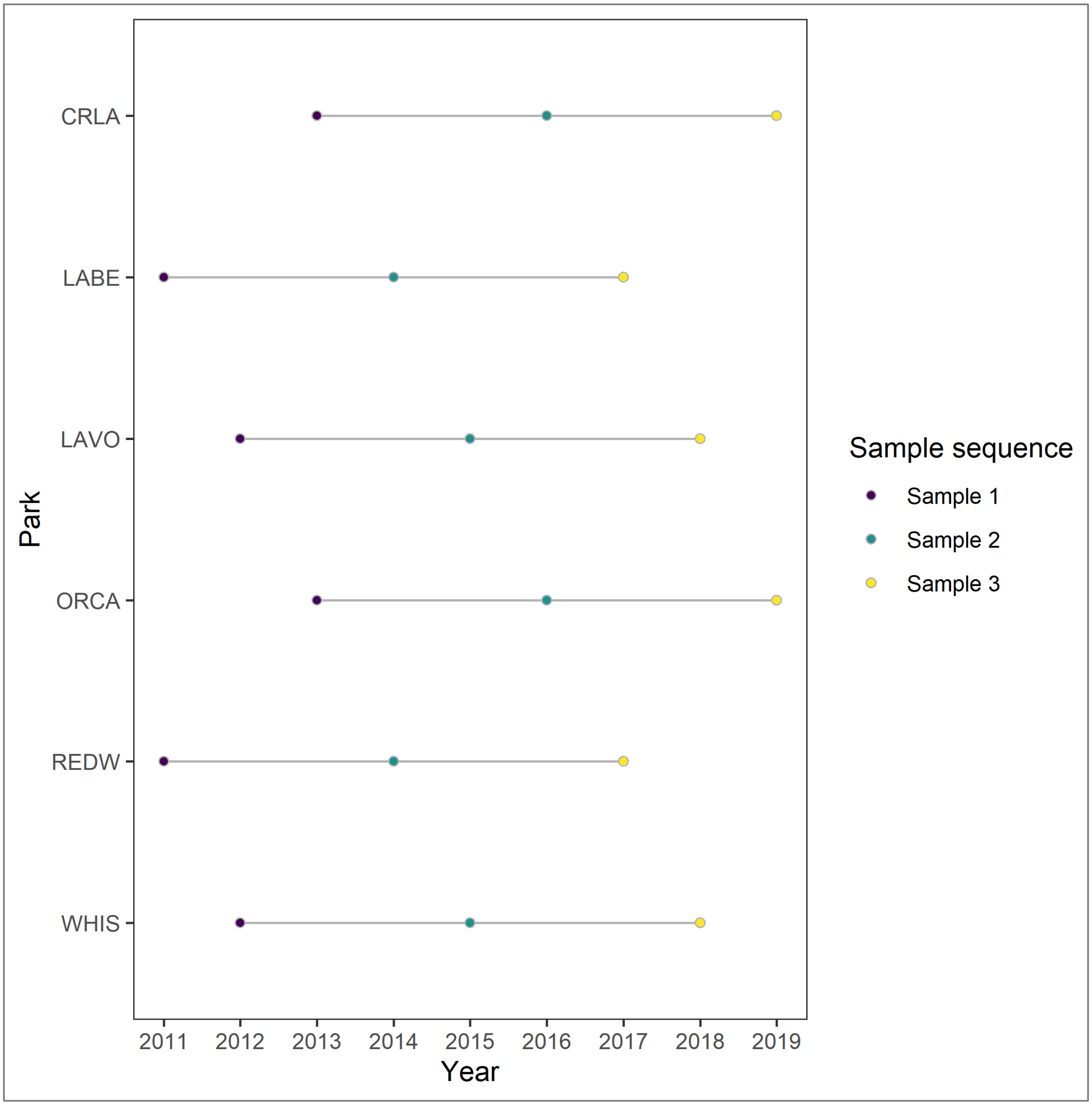

Figure 3. Vegetation sampling years for each park in the Klamath Network. Note that sampling first began in different years for different parks. Each sample sequence spans three years (data collection for sample sequence 1 = 2011–2013, sample sequence 2 = 2014–2016, sample sequence 3 = 2017–2019). CRLA = Crater Lake National Park, LABE = Lava Beds National Monument, LAVO = Lassen Volcanic National Park, ORCA = Oregon Caves National Monument and Preserve, REDW = Redwood National and State Parks, and WHIS = Whiskeytown National Recreation Area.
NPS

Vegetation Cover

Field crews performed visual estimates of percentage cover by species for four vegetation height strata (<0.75 m, 0.75–2.5 m, 2.6–5 m, and >5 m) in four 100 m^2 intensive sampling modules (Figure

2). The height strata to which vegetation belonged was determined by the height of the individual plant. We summarized vegetation cover by sample frame and sample event in each park to get an overall estimate of vegetation cover for each sample year.

Overstory Trees

Field crews tagged all trees with stem diameter at breast height (dbh) ≥ 15 cm, and recorded species, dbh, canopy position (dominant, co-dominant, intermediate, suppressed, or open grown), crown condition (including if the tree was live or dead), tree height, and crown base height.

In some cases dbh measurements were either missing or obviously spurious, which, after inspecting the data, we defined as outside the 1% and 99.5% growth quantiles for each species. These criteria resulted in 176 instances of growth observations that were corrected in the following ways: if there were two or more remaining dbh values for the tree, we used linear interpolation to estimate the missing or spurious dbh values; if there were fewer than two remaining observations, we assumed no growth and assigned the same diameter to all years (these were primarily dead trees). We visually inspected the data, and confirmed that this approach appeared to account for the large differences in individual tree measurements. While this approach assumes there is a constant error rate in the dbh measurements, it does not assume absolute upper or lower growth limits, which ideally allows for large variation in tree growth. Our approach retains some negative growth values (19% of growth measurements), which might represent bark loss, physical damage to the stem, or measurement error. We assumed that measurement error was equally likely to be positive or negative, so removing any negative growth values would bias our growth measurements in a positive direction. Therefore, we retained all negative growth values. Trees with corrected diameters were only used in estimates of basal area and stand density, not for growth analyses.

We calculated basal area (the summed cross-sectional area of the tree stems per unit area) and stem density (count of trees per unit area) of live overstory trees at the plot level. We then calculated the mean and standard error for each sample event by park and sample frame for all genera combined, as well as for select major genera: *Abies*, *Pinus*, *Pseudotsuga*, and *Sequoia*. We also calculated the mean and standard error for both tree height and height to live crown, using the same tree genus groupings as the stand structure metrics above.

Recruitment

Field crews recorded recruitment by species and size class in each of the four intensive modules. The sample area varied depending on tree size. All live tree seedlings (stems <2.54 cm dbh) were counted in a 100 m^2 subplot within the 400 m^2 intensive module, while pole size trees (stem ≥2.54 and <15 cm dbh) were counted throughout the entire module (see Fig. 2 for module layout description). We calculated means and standard errors for seedlings and poles for each park and sample frame, both for all species and the major genera described above.

Fuels

Crews sampled fuels for four size classes (one-, 10-, 100-, and 1,000-hour) along 50 m transects based on methods presented in Brown (1974). We calculated woody fuel loads in Mg/ha for each size class using coefficients for conifers in the Sierra Nevada (van Wagdendonk et al. 1996). We weighted the coefficients by the annual proportion of basal area of each species in each plot, including dead trees. We assigned the "All species" value for species that were not listed in van Wagdendonk et al. (1996). We calculated 1,000-hour fuel loads by decay class, but then used the total 1,000-hour loads for this analysis. Duff and litter were reported as depth values (cm). We calculated means and standard errors for each sample event in each park, grouped by sample frame and fuel size class.

Shrubs

Crews divided each of the four intensive modules into four quadrants and estimated the average height of all shrubs in the quadrant. We averaged the quadrant-level values for each plot and calculated the park/sample frame summary statistics (mean and standard error) from the plot level averages from each sample event.

Substrate

In each intensive module, field crews estimated the percentage cover for six classes of substrate: rock, bare soil, bryophytes, fine woody debris and litter, coarse woody debris, and water. We summarized these values by substrate class to the plot level, and the plot level summary values were used to calculate the sample frame summary statistics.

Data Availability

Data are publicly available and can be accessed on the National Park Service DataStore - Klamath Vegetation Monitoring Data Package (https://irma.nps.gov/DataStore/Reference/Profile/2305651).

Results

Vegetation Cover

Vegetation cover varied considerably across parks, sample frames, and elevation strata (Figure 4; KLMN 2025a). As expected, differences between park and sample frame combinations were influenced by dominant vegetation type and height strata. For instance, LABE matrix plots had the highest average cover in the <0.75 m strata, while more forested parks like WHIS and REDW showed higher cover in taller strata. Riparian plots followed similar trends, though differences in the <0.75 m strata were less pronounced. The small sample size in the high elevation plots made any existing patterns hard to discern.

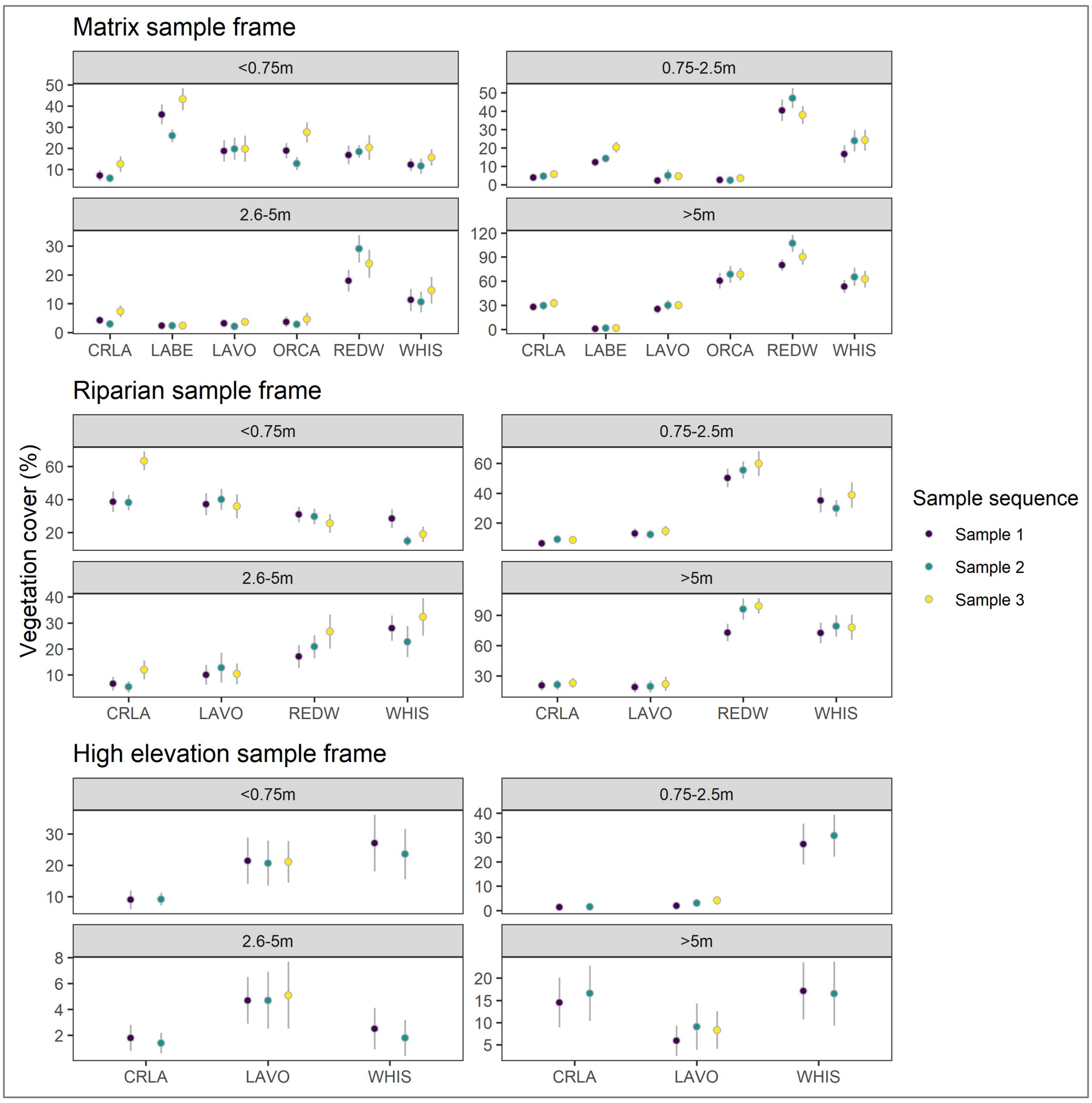

Figure 4. Average percentage vegetation cover (95% CI) by height strata across sample frames and parks. Confidence intervals were calculated as the mean ± 1.96 times the standard error. Observations are shown for all parks and all sample events (data collection for sample sequence 1 = 2011–2013, sample sequence 2 = 2014–2016, sample sequence 3 = 2017–2019). CRLA = Crater Lake National Park, LABE = Lava Beds National Monument, LAVO = Lassen Volcanic National Park, ORCA = Oregon Caves National Monument and Preserve, REDW = Redwood National and State Parks, and WHIS = Whiskeytown National Recreation Area.
NPS

Basal Area

There was little discernible change in average basal area of trees over time (Figure 5; KLMN 2025b). Average basal area for all species tended to scale with expected productivity; it was much higher in REDW than the other parks for the matrix and riparian sample frames. There appeared to be relatively little difference in the average basal area among parks in the high elevation sample frames.

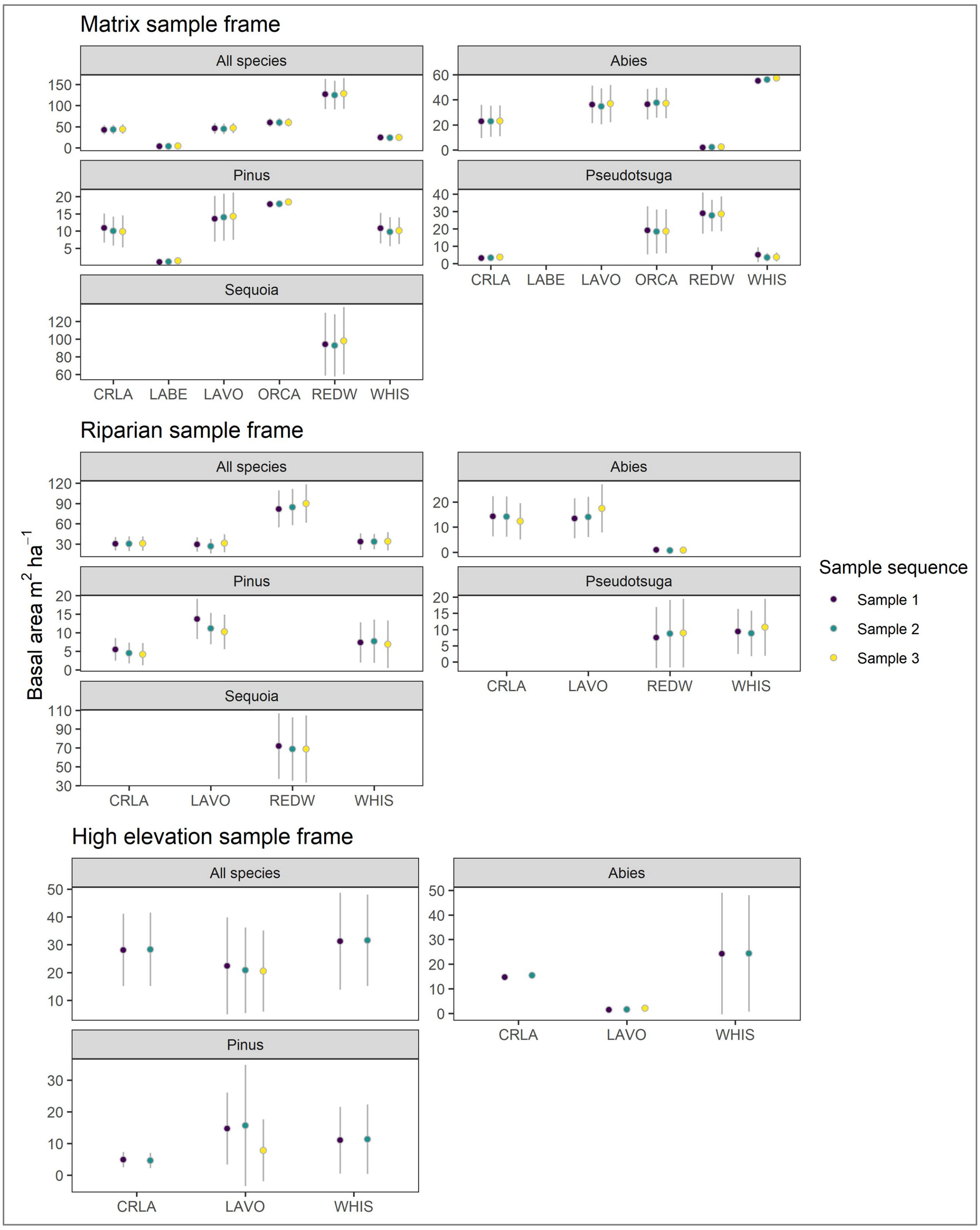

Figure 5. Average live basal area (95% CI) for each sample event by sample frame and park for common tree genera. Confidence intervals were calculated as the mean ± 1.96 times the standard error. Note the differing y-axis scales between panels. Observations are shown for all parks and all sample events (data collection for sample sequence 1 = 2011–2013, sample sequence 2 = 2014–2016, sample sequence 3 = 2017–2019). CRLA = Crater Lake National Park, LABE = Lava Beds National Monument, LAVO = Lassen Volcanic National Park, ORCA = Oregon Caves National Monument and Preserve, REDW = Redwood National and State Parks, and WHIS = Whiskeytown National Recreation Area.
NPS

Stem Density

Average stem density also appeared to be relatively static over time (Figure 6; KLMN 2025c). However, unlike basal area, stem density was similar across most parks, except for LABE. LABE has far fewer trees than the rest of the parks in the Klamath region.

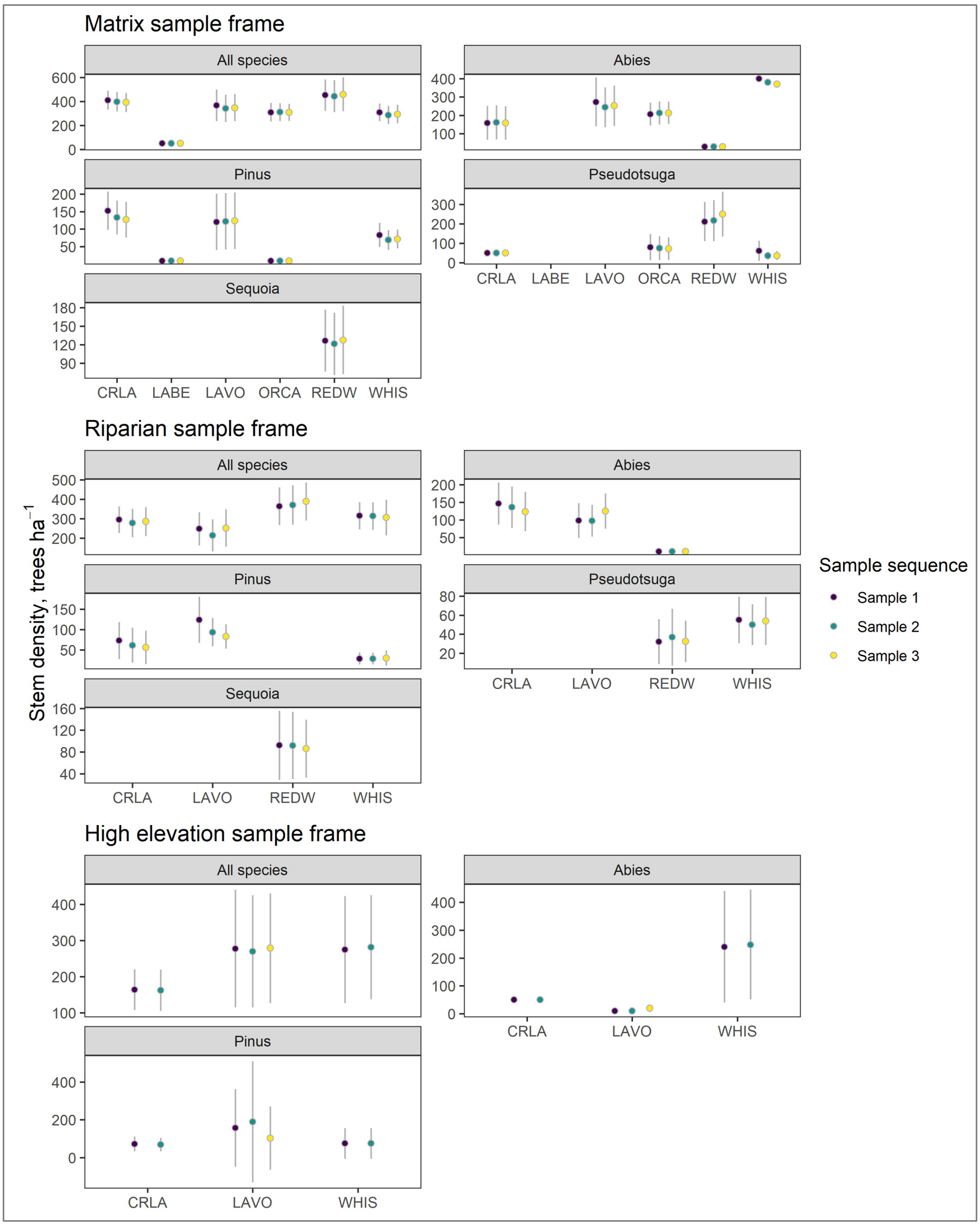

Figure 6. Average stem density (95% CI) for each sample event by sample frame and park for common tree genera. Confidence intervals were calculated as the mean ± 1.96 times the standard error. Observations are shown for all parks and all sample events (data collection for sample sequence 1 = 2011–2013, sample sequence 2 = 2014–2016, sample sequence 3 = 2017–2019). CRLA = Crater Lake National Park, LABE = Lava Beds National Monument, LAVO = Lassen Volcanic National Park, ORCA = Oregon Caves National Monument and Preserve, REDW = Redwood National and State Parks, and WHIS = Whiskeytown National Recreation Area.

NPS

Tree Height

Tree height summary statistics are shown in Figure 7 and are available in KLMN (2025d). In the matrix sample frame, the parks with the highest expected productivity had the tallest trees, which was expected. Though average height for *Abies* in the matrix plots of REDW appears to be dramatically increasing over time, note that these estimates are taken from a very small sample with a total of six trees in four plots.

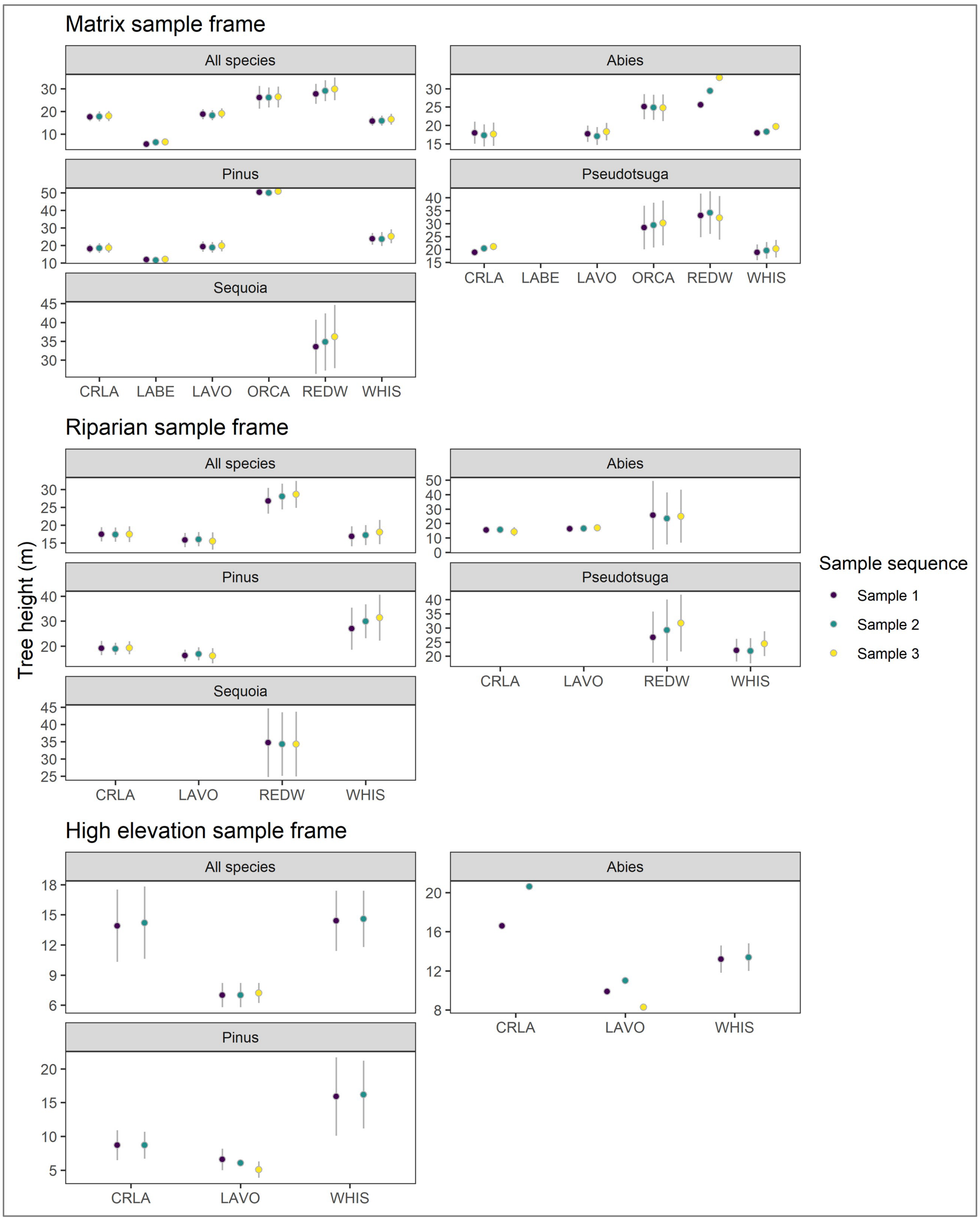

Figure 7. Average tree height (95% CI) for each sample event by sample frame and park for common tree genera. Confidence intervals were calculated as the mean ± 1.96 times the standard error. Observations are shown for all parks and all sample events (data collection for sample sequence 1 = 2011–2013, sample sequence 2 = 2014–2016, sample sequence 3 = 2017–2019). CRLA = Crater Lake National Park, LABE = Lava Beds National Monument, LAVO = Lassen Volcanic National Park, ORCA = Oregon Caves National Monument and Preserve, REDW = Redwood National and State Parks, and WHIS = Whiskeytown National Recreation Area.

NPS

Height to Live Crown

Average height to live tree crown was highly variable (Figure 8; KLMN 2025e), though it followed similar patterns to basal area, where parks with larger trees had larger values for height to live crown.

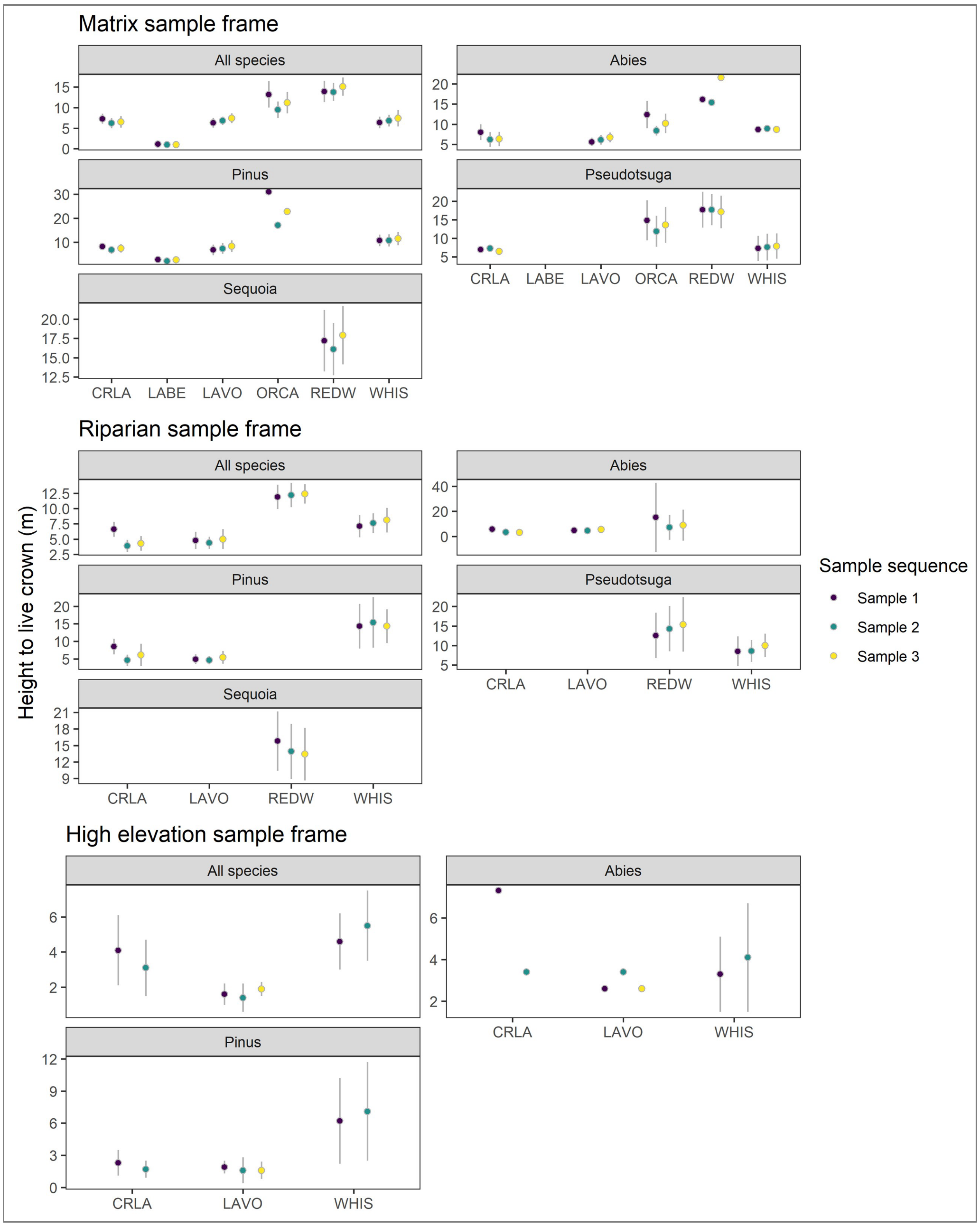

Figure 8. Average height to live tree crown (95% CI) for each sample event by sample frame and park for common genera. Confidence intervals were calculated as the mean ± 1.96 times the standard error. Observations are shown for all parks and all sample events (data collection for sample sequence 1 = 2011–2013, sample sequence 2 = 2014–2016, sample sequence 3 = 2017–2019). CRLA = Crater Lake National Park, LABE = Lava Beds National Monument, LAVO = Lassen Volcanic National Park, ORCA = Oregon Caves National Monument and Preserve, REDW = Redwood National and State Parks, and WHIS = Whiskeytown National Recreation Area.

NPS

Fuel Load and Depth

Fuels summary statistics are shown in Figure 9 and in KLMN (2025f). Average fuel loads were highly variable, especially for the one-hour and forest floor (litter and duff depth) size classes. LABE had far lower fuel loading than the other parks, regardless of size class. REDW had far higher values for 1,000-hour fuels and shared deep duff measurements with ORCA. However, for the other size classes, most parks had relatively similar fuel load values, except for low litter depths in CRLA.

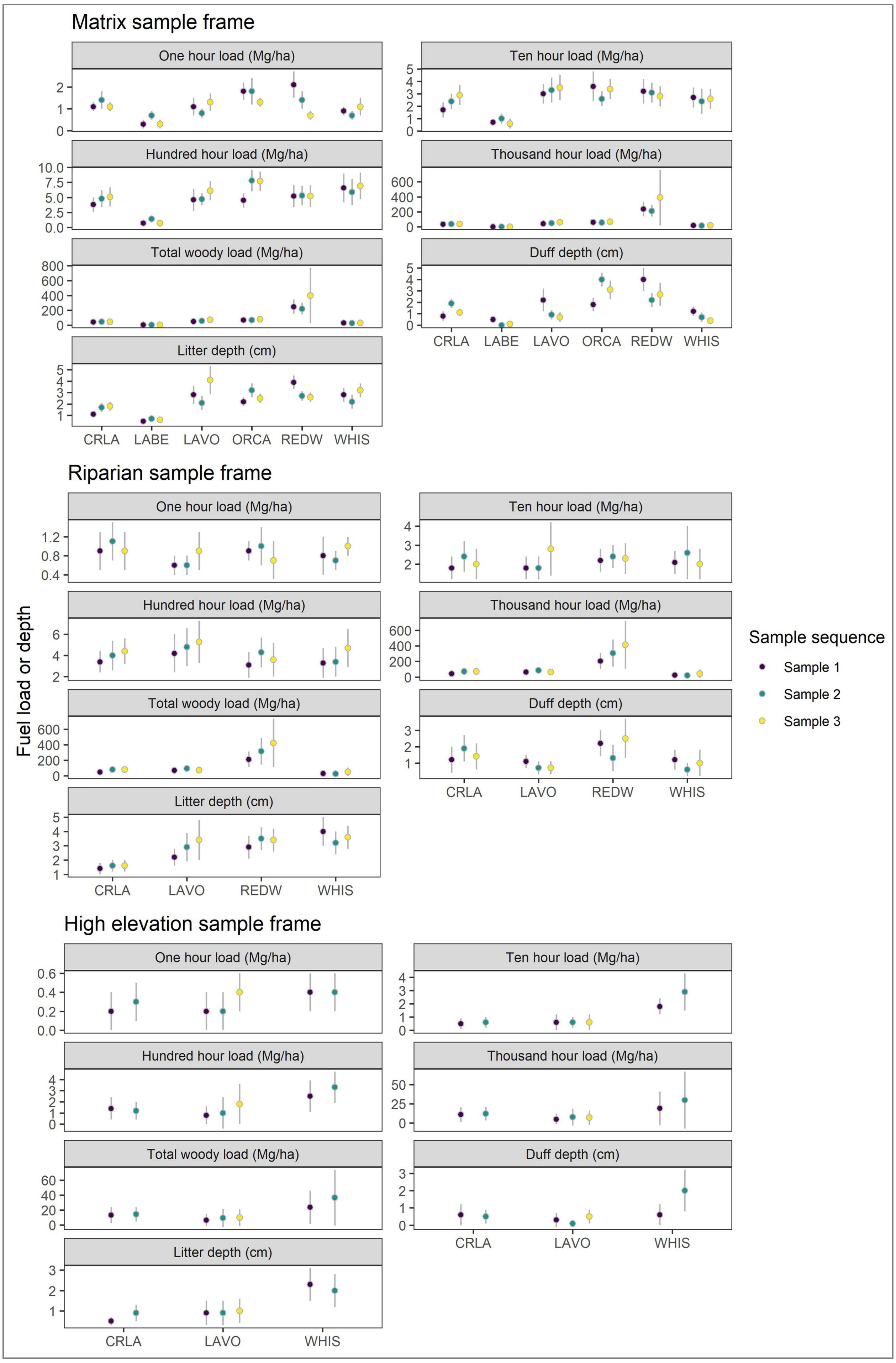

Figure 9. Average fuel load or depth (95% CI) by size class for each sample event by sample frame and park. Confidence intervals were calculated as the mean ± 1.96 times the standard error. Observations are shown for all parks and all sample events (data collection for sample sequence 1 = 2011–2013, sample sequence 2 = 2014–2016, sample sequence 3 = 2017–2019). CRLA = Crater Lake National Park, LABE = Lava Beds National Monument, LAVO = Lassen Volcanic National Park, ORCA = Oregon Caves National Monument and Preserve, REDW = Redwood National and State Parks, and WHIS = Whiskeytown National Recreation Area.

NPS

Shrub Height

Shrub height summary statistics are shown in Figure 10 and in KLMN (2025g). Average shrub heights were highest in REDW for the matrix and riparian sample frames, followed by WHIS. Shrub heights were low in the high elevation sample frame.

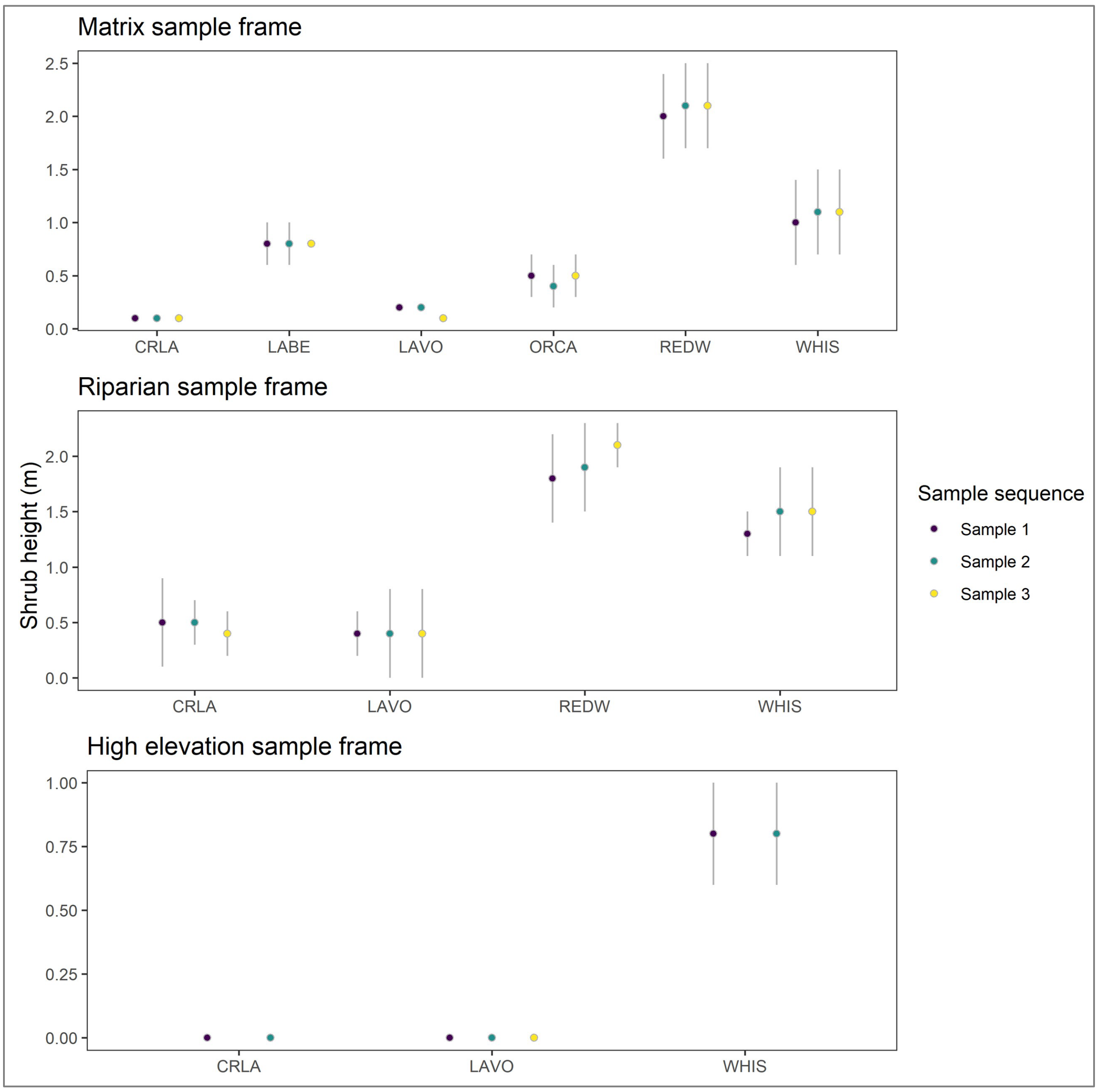

Figure 10. Average shrub height (95% CI) by sample frame for all sample events in each park. Confidence intervals were calculated as the mean ± 1.96 times the standard error. Observations are shown for all parks and all sample events (data collection for sample sequence 1 = 2011–2013, sample sequence 2 = 2014–2016, sample sequence 3 = 2017–2019). CRLA = Crater Lake National Park, LABE = Lava Beds National Monument, LAVO = Lassen Volcanic National Park, ORCA = Oregon Caves National Monument and Preserve, REDW = Redwood National and State Parks, and WHIS = Whiskeytown National Recreation Area.

NPS

Substrate Percentage Cover

Substrate summary statistics are shown in Figure 11 and in KLMN (2025h). In the matrix sample frame, cover estimates for bare soil and rock were highest in LABE, and bryophytes were highest in REDW. Fine and coarse woody material was similar across most parks except for LABE, which had lower values in these cover types. Water was only listed as a cover type in the riparian sample frame. Differences between parks were also less discernible in the riparian sample frame. The most notable differences were in rock (low in CRLA, high in WHIS) and bryophyte cover, which was highest in REDW. CRLA had the highest bare soil cover in the high elevation sample frame, while rock was highest in LAVO and fine wood was highest in WHIS. Differences were hard to distinguish between the other cover types in the high elevation sample frame.

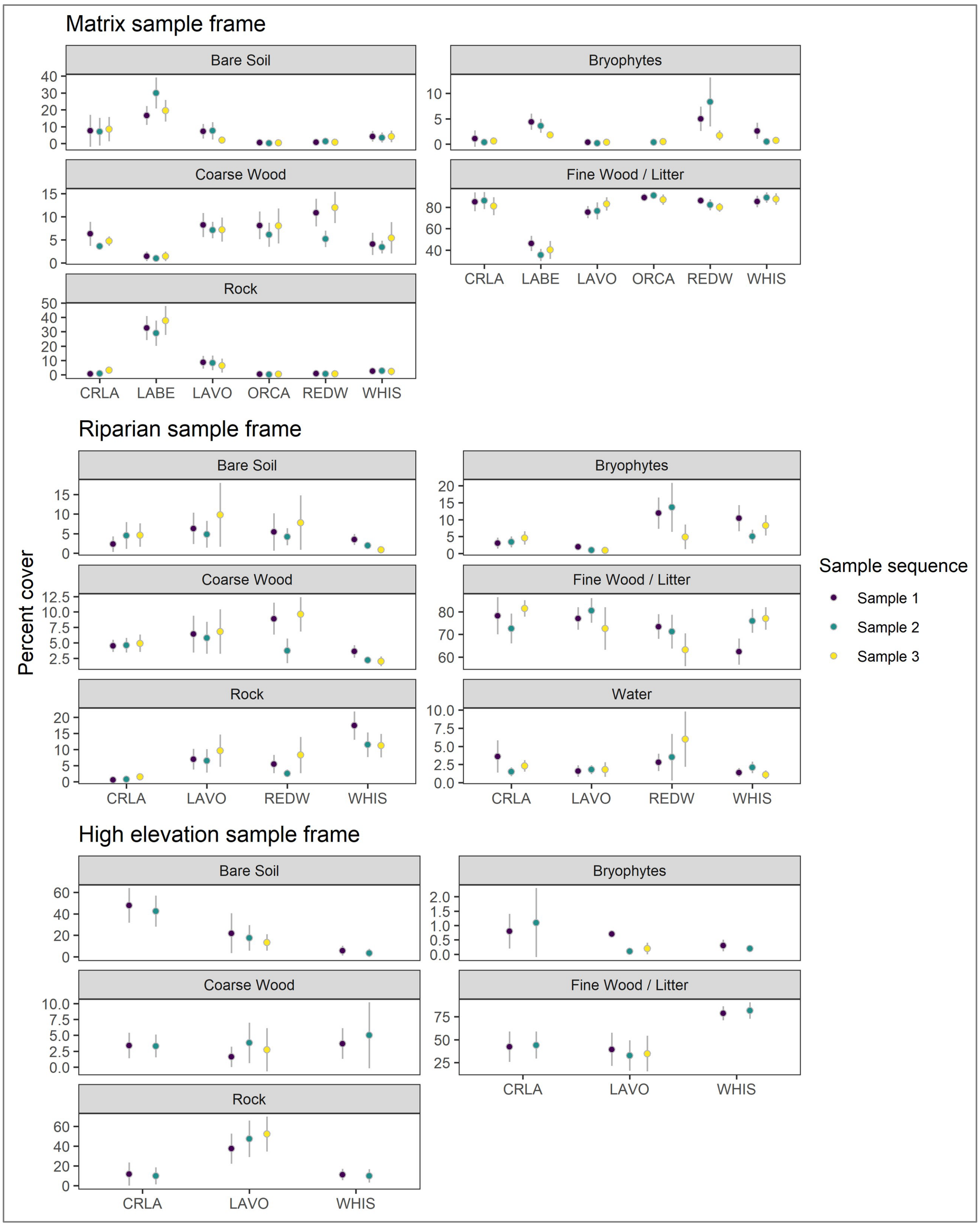

Figure 11. Average percentage cover (95% CI) by sample frame and substrate class for each sample event and park. Confidence intervals were calculated as the mean ± 1.96 times the standard error. Observations are shown for all parks and all sample events (data collection for sample sequence 1 = 2011–2013, sample sequence 2 = 2014–2016, sample sequence 3 = 2017–2019). CRLA = Crater Lake National Park, LABE = Lava Beds National Monument, LAVO = Lassen Volcanic National Park, ORCA = Oregon Caves National Monument and Preserve, REDW = Redwood National and State Parks, and WHIS = Whiskeytown National Recreation Area.

NPS

Recruitment Counts

Recruitment summary statistics are shown in Figures 12 and 13 and in KLMN (2025i). Differences were less distinguishable between parks in general, though REDW tended to have fewer seedlings. REDW did tend to have more *Pseudotsuga* pole size trees in the matrix sample frame, and as expected, it was the only park where *Sequoia* was found. LAVO appeared to have a large number of *Abies* seedlings in the first matrix sample event. However, these did not persist to the second and third sample events and there does not appear to be a corresponding increase in pole size trees, suggesting that growth to the next size class was unlikely.

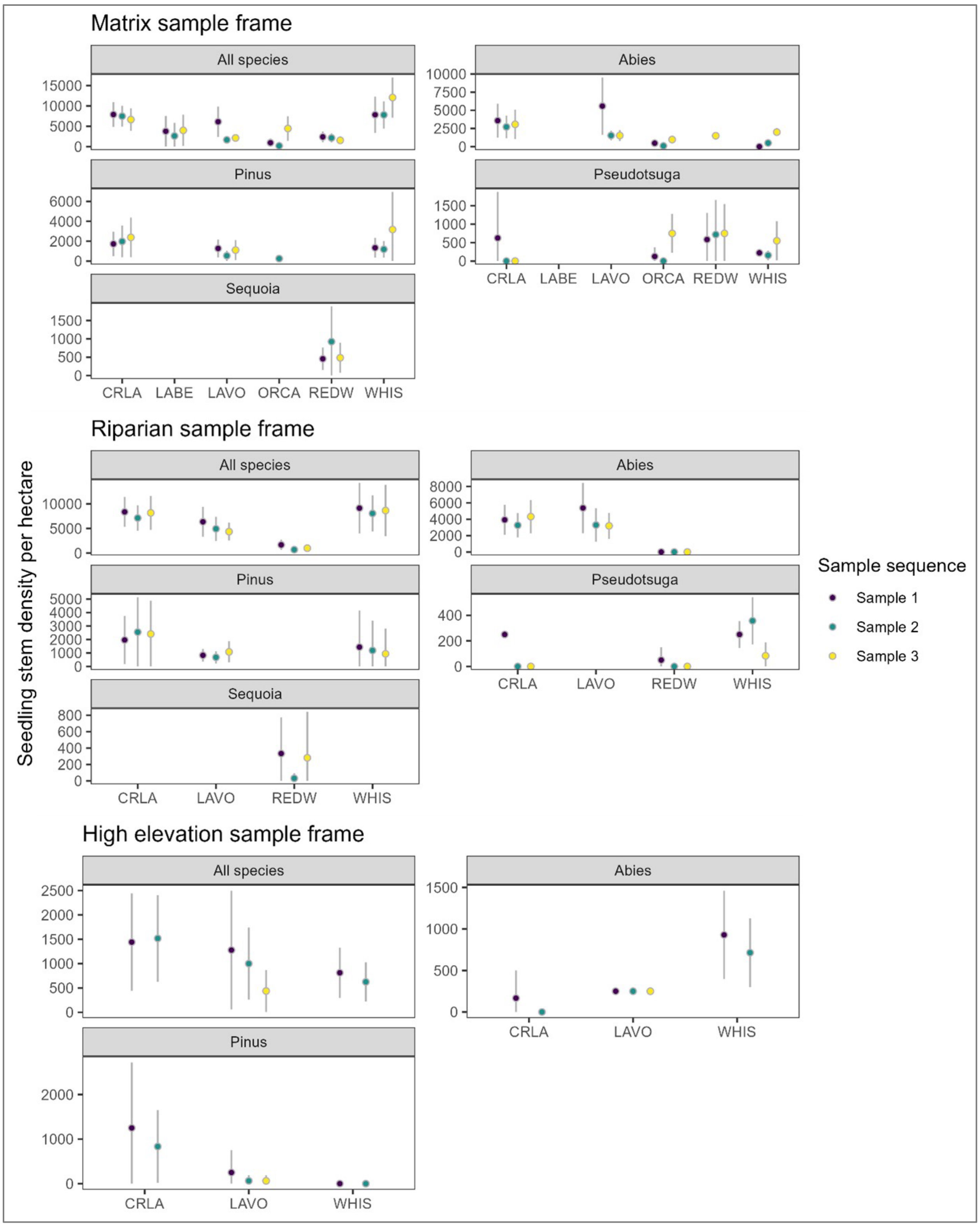

Figure 12. Average seedling count (95% CI) by sample frame and tree genus for each sample event and park. Live tree seedlings were defined as having a dbh of <2.54 cm. Confidence intervals were calculated as the mean ± 1.96 times the standard error. Observations are shown for all parks and all sample events (data collection for sample sequence 1 = 2011–2013, sample sequence 2 = 2014–2016, sample sequence 3 = 2017–2019). CRLA = Crater Lake National Park, LABE = Lava Beds National Monument, LAVO = Lassen Volcanic National Park, ORCA = Oregon Caves National Monument and Preserve, REDW = Redwood National and State Parks, and WHIS = Whiskeytown National Recreation Area.
NPS

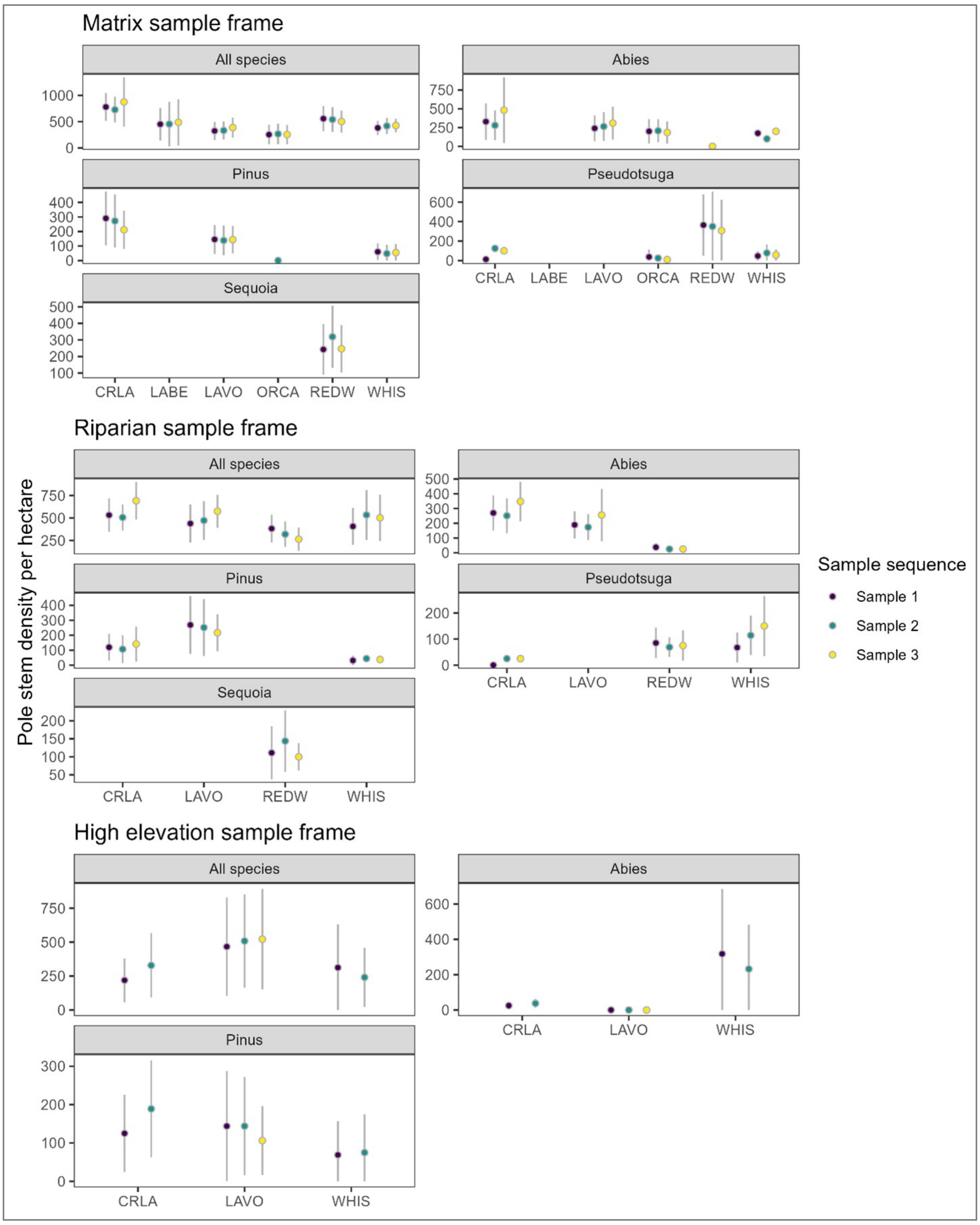

Figure 13. Average count of pole size trees (95% CI) by sample frame and genus for each sample event and park. Pole size trees were defined as having a dbh between 2.54 and 15 cm. Confidence intervals were calculated as the mean ± 1.96 times the standard error. Observations are shown for all parks and all sample events (data collection for sample sequence 1 = 2011–2013, sample sequence 2 = 2014–2016, sample sequence 3 = 2017–2019). CRLA = Crater Lake National Park, LABE = Lava Beds National Monument, LAVO = Lassen Volcanic National Park, ORCA = Oregon Caves National Monument and Preserve, REDW = Redwood National and State Parks, and WHIS = Whiskeytown National Recreation Area.

NPS

Discussion

Differences in forest structure were apparent across the parks, generally following a presumed productivity gradient from the mesic, coastal Redwood National and State Parks (REDW) to the arid, continental climate at Lava Beds National Monument (LABE) (Sarr et al. 2007). Measures of forest structure (vegetation cover, stem density, basal area, tree heights, height to live crown, shrub cover, and surface fuels) were generally higher in mesic sites, with much lower values found at LABE. An exception to this pattern was vegetation cover at the lowest height stratum, which tended to be greater at LABE relative to the other parks. Matrix and riparian sampling frames appeared similar in many measures of forest structure, contrasting with generally lower values at high elevation sites. Values for forest structure were largely similar at high elevation sites across parks that contained this sampling frame (Crater Lake National Park [CRLA], Lassen Volcanic National Park [LAVO], Whiskeytown National Recreation Area [WHIS]). Unusually high values for basal area and fuels were associated with the presence of *Sequoia* at REDW. *Sequoia* resprouts following fire and main stems often survive intense crown fire (Peltier et al. 2023). This allows *Sequoia* to maintain or develop additional live basal area following fires that would be stand replacing for other conifers. *Sequoia* also does not frequently reproduce from seed in the absence of disturbance, so counts of seedlings and pole size trees were low for this species, even though it occurs in highly productive forests. In sum, patterns in forest structure across the parks of the Klamath Network followed expected patterns in productivity, although exceptional species such as *Sequoia* could produce deviations from these expected patterns.

Differences among sampling frames also followed this general pattern of productivity. Matrix and riparian sampling frames had similar ranges of values in most cases, while high elevation sites had relatively lower stem density, basal area, shrub cover, fuels, and recruitment. These differences were also expressed in differences in substrate values, with more bare soil and rock in high elevation sites.

Monitoring to date reveals a relative lack of change in forest structure over time. This is not surprising given the short six-year span of the current observations. Three observations over six years is unlikely to reveal temporal patterns. In contrast, earlier studies of undisturbed old growth forests relied on multiple decades of records to identify trends in tree mortality rates (van Mantgem et al. 2009). While the interval from 2011 to 2019 encompassed a major state-wide drought from 2012 to 2016, the drought was most severe in southern California (Ullrich et al. 2018). The effects of this drought were not readily apparent in the Klamath Network monitoring data. While this period was dry in northern California and southern Oregon, there have not been reports of widespread tree mortality or bark beetle outbreaks like those recorded in the southern Sierra Nevada (Goulden and Bales 2019; Stephenson et al. 2019; Fettig et al. 2019). However, future droughts may be more severe in the Klamath Network. We are unaware of specific thresholds of moisture stress that may trigger forest dieback.

The present results do not reflect the impacts of the recent large fires in the Klamath region, including those fires that had major effects on Klamath Network parks. Data are currently being collected to understand the effects of these large, severe fires. The 2018 Carr Fire burned much of

WHIS, often at high severity (https://www.nps.gov/whis/upload/Carr-Fire-site-bulletin_updateded-July-2020.pdf, accessed 4/4/2024). The 2018 sampling event for the Klamath vegetation at WHIS occurred before the fire and its effects are not captured in the present data. Other studies conducted at WHIS suggest major impacts on forest structure, albeit with higher than expected recruitment, following the Carr Fire (van Mantgem et al. 2024). LABE has recently been burned in two separate fires: the 2020 Caldwell Fire, which burned most of the sagebrush communities in the park, and the 2021 Antelope Fire, which together with the Caldwell Fire burned almost the entire park. These fires potentially caused a significant loss of big sagebrush (*Artemisia tridentata*), with uncertain recovery and potential for conversion to cheatgrass (*Bromus tectorum*) dominated landscapes in the monument. The Dixie Fire in 2021 also burned large areas within LAVO (nearly 70% of the park), currently with uncertain effects. Early characterizations of fire severity patterns at LAVO suggest that areas with a history of prescribed fire tended to burn at low to moderate severity in the Dixie Fire (Calvin Farris, pers. comm.). Regionally, forests in the Klamath Network have experienced high fire activity over recent years and drought in 2022 (NOAA National Centers for Environmental Information 2023), suggesting a potential for rapid change.

The potential for significant changes in forest structure and function in the near term is high. We expect the fourth set of Klamath Network surveys to show substantial changes in vegetation cover and forest structure, particularly for parks that have experienced recent major fires (LABE, LAVO, and WHIS). While some broad-scale estimates of change are possible to acquire from remotely sensed imagery (e.g., burn severity maps, https://www.mtbs.gov), on-the-ground surveys provide fine-scale data that cannot be otherwise obtained. For example, on-the-ground surveys provide the empirical observations necessary to detect fine-scale changes in understory species composition, tree regeneration, and the presence of important focal species—such as rare species or noxious invasive species. Plot-based surveys, such as those used in the Klamath Network vegetation monitoring plots, will be invaluable for understanding ecosystem responses in a rapidly changing world.

Literature Cited

Allen, C. D., and D. D. Breshears. 1998. Drought-induced shift of a forest–woodland ecotone: Rapid landscape response to climate variation. Proceedings of the National Academy of Sciences 95(25): 14839–42.

Allen, C. D., D. D. Breshears, and N. G. McDowell. 2015. On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. Ecosphere 6(8): 1–55.

Augustine, S. P., and K. Reinhardt. 2019. Differences in morphological and physiological plasticity in two species of first-year conifer seedlings exposed to drought result in distinct survivorship patterns. Tree Physiology 39(8): 1446–60.

Beissinger, S. R., D. D. Ackerly, H. D. Doremus, and G. E. Machlis. 2017. Science, conservation, and national parks. University of Chicago Press.

Brown, J. K. 1974. Handbook for inventorying downed woody material. General Technical Report INT-16. US Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Coop, J. D., S. A. Parks, C. S. Stevens-Rumann, S. D. Crausbay, P. E. Higuera, M. D. Hurteau, A. Tepley, et al. 2020. Wildfire-driven forest conversion in western North American landscapes. BioScience 70(8): 659–73.

Davis, K. T., S. Z. Dobrowski, P. E. Higuera, Z. A. Holden, T. T. Veblen, M. T. Rother, S. A. Parks, A. Sala, and M. P. Maneta. 2019. Wildfires and climate change push low-elevation forests across a critical climate threshold for tree regeneration. Proceedings of the National Academy of Sciences 116(13): 6193–98.

Dennison, P. E., S. C. Brewer, J. D. Arnold, and M. A. Moritz. 2014. Large wildfire trends in the western United States, 1984–2011. Geophysical Research Letters 41(8): 2928–33.

Falk, D. A., P. J. van Mantgem, J. E. Keeley, R. M. Gregg, C. H. Guiterman, A. J. Tepley, D. J. N. Young, and L. A. Marshall. 2022. Mechanisms of forest resilience. Forest Ecology and Management 512: 120129.

Fettig, C. J., L. A. Mortenson, B. M. Bulaon, and P. B. Foulk. 2019. Tree mortality following drought in the Central and Southern Sierra Nevada, California, US. Forest Ecology and Management 432: 164–78.

Gonzalez, P., F. Wang, M. Notaro, D. J. Vimont, and J. W. Williams. 2018. Disproportionate magnitude of climate change in United States national parks. Environmental Research Letters 13(10): 104001.

Goulden, M. L., and R. C. Bales. 2019. California forest die-off linked to multi-year deep soil drying in 2012–2015 drought. Nature Geoscience 12(8): 632–37.

National Park Service, Klamath Network (KLMN). 2025a. Average percentage vegetation cover from vegetation monitoring in Klamath Network parks, 2011-2019 [dataset]. National Park Service.

National Park Service, Klamath Network (KLMN). 2025b. Average live and dead basal area from vegetation monitoring in Klamath Network parks, 2011-2019. [dataset]. National Park Service.

National Park Service, Klamath Network (KLMN). 2025c. Average live and dead stem density from vegetation monitoring in Klamath Network parks, 2011-2019 [dataset]. National Park Service.

National Park Service, Klamath Network (KLMN). 2025d. Average live and dead tree height from vegetation monitoring in Klamath Network parks, 2011-2019 [dataset]. National Park Service.

National Park Service, Klamath Network (KLMN). 2025e. Average height to live crown from vegetation monitoring in Klamath Network parks, 2011-2019 [dataset]. National Park Service.

National Park Service, Klamath Network (KLMN). 2025f. Average fuel load and depth from vegetation monitoring in Klamath Network parks, 2011-2019 [dataset]. National Park Service.

National Park Service, Klamath Network (KLMN). 2025g. Average shrub height from vegetation monitoring in Klamath Network parks, 2011-2019 [dataset]. National Park Service.

National Park Service, Klamath Network (KLMN). 2025h. Average substrate percentage cover from vegetation monitoring in Klamath Network parks, 2011-2019 [dataset]. National Park Service.

National Park Service, Klamath Network (KLMN). 2025i. Average recruitment counts from vegetation monitoring in Klamath Network parks, 2011-2019 [dataset]. National Park Service.

NOAA National Centers for Environmental Information. Published online January 2023. Monthly Drought Report for Annual 2022. https://www.ncei.noaa.gov/access/monitoring/monthly-report/drought/202213 (accessed 16 April 2024).

Odion, D. C., D. A. Sarr, S. R. Mohren, and S. B. Smith. 2011. Monitoring vegetation composition, structure and function in the parks of the Klamath Network. Natural Resource Report NPS/KLMN/NRR—2011/401. National Park Service, Fort Collins, Colorado.

Parks, S. A., and J. T. Abatzoglou. 2020. Warmer and drier fire seasons contribute to increases in area burned at high severity in western US Forests from 1985 to 2017. Geophysical Research Letters 47(22): e2020GL089858.

Peltier, D. M. P., M. S. Carbone, M. Enright, M. C. Marshall, A. M. Trowbridge, J. LeMoine, G. Koch, and A. D. Richardson. 2023. Old reserves and ancient buds fuel regrowth of coast redwood after catastrophic fire. Nature Plants 9(12): 1978-1985.

R Core Team. 2024. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Sarr, D. A., D. C. Odion, S. R. Mohren, E. E. Perry, R. L. Hoffman, L. K. Bridy, and A. A. Merton. 2007. Klamath Network vital signs monitoring plan. Natural Resource Report. NPS/KLMN/NRR—2007/016. National Park Service. Fort Collins, Colorado https://irma.nps.gov/DataStore/Reference/Profile/650806

Skinner, C. N., A. H. Taylor, and J. K. Agee. 2006. Klamath Mountains Bioregion. Pages 170–194 *in* N. G. Sugihara, J. W. van Wagtendonk, J. Fites-Kaufmann, K. E. Shaffer, and A. E. Thode, editors. Fire in California's ecosystems. University of California Press, Berkeley, California.

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.

Stephenson, N. L., A. J. Das, N. J. Ampersee, B. M. Bulaon, and J. L. Yee. 2019. Which trees die during drought? The key role of insect host-tree selection. Journal of Ecology 107(5): 2383–2401.

Stevens, D. L., and A. R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. Environmetrics 14(6): 593–610.

Ullrich, P. A., Z. Xu, A. M. Rhoades, M. D. Dettinger, J. F. Mount, A. D. Jones, and P. Vahmani. 2018. California's drought of the future: A midcentury recreation of the exceptional conditions of 2012–2017. Earth's Future 6(11): 1568–87.

van Mantgem, P. J., N. L. Stephenson, J. C. Byrne, L. D. Daniels, J. F. Franklin, P. Z. Fulé, M. E. Harmon, et al. 2009. Widespread increase of tree mortality rates in the western United States. Science 323(5913): 521–24.

van Mantgem, P. J., M. C. Wright, K. Thorne, J. Beckmann, K. Buffington, and E. A. Engber. 2024. Learning from a high-severity fire event: Conditions following the 2018 Carr Fire at Whiskeytown National Recreation Area. U.S. Geological Survey, Denver. Open File Report 2023–1053. https://doi.org/10.3133/ofr20231053.

van Wagdendonk, J. W., J. M. Benedict, and W. M. Sydoriak. 1996. Physical properties of woody fuel particles of Sierra Nevada conifers. International Journal of Wildland Fire 6(3): 117–23.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313(5789): 940-943.

Whittaker, R. H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecological Monographs 30 (3): 279–338.

Whittaker, R. H. 1961. Vegetation history of the Pacific Coast States and the" Central" significance of the Klamath Region. Madroño 16(1): 5–23.

Williams, A. P., C. D. Augustine, A. K. Macalady, D. Griffin, C. A. Woodhouse, D. M. Meko, T. W. Swetnam, et al. 2013. Temperature as a potent driver of regional forest drought stress and tree mortality. Nature Climate Change 3(3): 292–97.

National Park Service
U.S. Department of the Interior

Science Report NPS/SR—2025/291
https://doi.org/10.36967/2311589

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

NPS 963/197123, May 2025