



Analysis of Stream Types in Klamath Network Parks Based on Physical Habitat and Chemical Characters



Stream crew surveying site CRLAWQ16, Unnamed Tributary of Bybee Creek, in Crater Lake National Park.
NPS / KLAMATH INVENTORY AND MONITORING NETWORK

Analysis of stream types in Klamath Network parks based on physical habitat and chemical characters

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Abstract

This is the first “Analysis and Synthesis” report required by the Klamath Inventory and Monitoring Network’s stream monitoring protocol. This report synthesizes the physical and chemical attributes of streams surveyed by the Klamath Network between 2011 and 2018 in the following parks: Crater Lake National Park, Lassen Volcanic National Park, Whiskeytown National Recreation Area, Redwood National and State Parks, and Oregon Caves National Monument and Preserve). Where possible, it categorizes individual streams into groups using multivariate exploratory analyses and assigns statistical significance to the groups via Similarity Profile analyses.

Streams are sorted into similar groups for eight different metric categories: Channel Morphology (e.g., bank angle, width, depth, etc.), Habitat Complexity (amount and types of cover), Large Woody Debris (categories of length and diameter of fallen wood), Riparian Characters (e.g., percent cover of tree, shrub, and groundcover types), Slope and Sinuosity, Stream Substrate (e.g., percent fine substrate, median substrate size), Water Chemistry (e.g., nutrients and salts), and Water Quality (e.g., dissolved oxygen, turbidity).

Secondary to the categorization of streams within each park, the streams are compared among parks to identify which parks may have similar streams. Similar streams potentially share both common stressors and common management practices for resource management.

The analyses in this report form the foundation of future work; they are “basic” results. Follow-up work will use these basic results more fully, such as for analyses that incorporate biological data and support trend reports.

The main body of the report presents a high-level overview of individual park results and inter-park comparisons. The appendices present full results for each park, including numerous figures and maps. Oregon Caves National Monument and Preserve results are limited by small sample size ($n = 3$) and the hand-selected sampling scheme we used instead of a probabilistic sampling scheme. However, including Oregon Caves’ sites in this analysis puts them into a larger network context.

Executive Summary

This is the first “Analysis and Synthesis” report required by the Klamath Network’s stream monitoring protocol. This report synthesizes the physical and chemical attributes of streams monitored from 2011 to 2018 in five Klamath Network parks: Crater Lake National Park, Lassen Volcanic National Park, Whiskeytown National Recreation Area, Redwood National and State Parks, and Oregon Caves National Monument and Preserve. It differentiates (groups) stream types based on those attributes within a park, and it compares streams between and across parks to identify commonalities. This gives managers a baseline to monitor change across their parks’ landscapes and provides insight into how management actions on one type of stream may or may not be applicable to other stream types. Along with describing the diversity of streams within the parks, these results 1) identify stream groups (i.e., strata) that may increase power to detect trends in future analyses and 2) lay a foundation for understanding the relationship between physical habitat and biotic assemblages.

Multivariate exploratory data analyses examined stream characteristics in eight metric categories: Channel Morphology (e.g., bank angle, width, depth, etc.), Habitat Complexity (amount and types of cover), Large Woody Debris (categories of length and diameter of fallen wood), Riparian Characters (e.g., percent cover of tree, shrub, and groundcover types), Slope and Sinuosity, Stream Substrate (e.g., percent fine substrate, median substrate size), Water Chemistry (e.g., nutrients and salts), and Water Quality (e.g., dissolved oxygen, turbidity).

For context, the report provides a brief overview of stream survey methods based on the Klamath Network wadeable streams protocol. The analytical groupings of stream type are based on data from one to three years of monitoring; where multiple visits occurred (most of the time), values are averaged across visits. For the data analysis, a Euclidian distance is first calculated between each stream. A clustering algorithm and a test of significant clusters are used to determine which streams belong in each group. Visualization and separation are done with ordination, and separating characters are used from the clustering. Groups are then displayed on the park landscape to reveal spatial patterns, if any. Similar analyses are used across parks for each of the characteristic groups to elucidate any similarities between parks for shared management purposes.

Secondarily, metric categories within parks are compared to examine correlation. Understanding how metric categories are related can provide insight into how park management may impact multiple characteristics of the stream ecosystems. For example, a high degree of correlation among Large Woody Debris, Riparian Characters, and Habitat Complexity may help managers understand the relationship between wood accumulation or riparian thinning and fish habitat, which is directly related to habitat complexity.

The analyses in this report form the foundation of future work; they are “basic” results. Follow-up work will use these basic results more fully, such as for analyses that incorporate biological data and support trend reports.

The main body of the report presents a high-level overview of individual park results and inter-park comparisons. The appendices present full results for each park, including numerous figures and maps. Oregon Caves National Monument and Preserve results are limited by small sample size ($n = 3$) and the hand-selected sampling scheme we used instead of a probabilistic sampling scheme. However, including Oregon Caves' sites in this analysis puts them into a larger network context.

A brief summary of findings for each park is presented below, in Tables 1–4. Specific results for inter-park comparisons are dependent upon the metric category. However, the general pattern is that although streams between parks share many commonalities, the higher elevation parks of Lassen Volcanic NP and Crater Lake NP tend to be more similar, while the lower elevation parks of Redwood NSP and Whiskeytown NRA are more distinct from all other parks. Oregon Caves NM&P sites tended to be more similar to either Redwood NSP or Whiskeytown NRA, depending on the metric category.

Table 1. Key findings for stream classifications by metric category for 30 stream reaches in Crater Lake National Park.

Metric Category	Number of Significant Groups	Key Notes
Channel Morphology	9	Four streams were different enough to each represent an individual group
Habitat Complexity	8	Groups were distinguished largely based on the amount of habitat cover
Large Woody Debris	10	Rogue River highest in number of pieces
Riparian Characters	12	Complex assortment of variables determine groups
Slope and Sinuosity	4	Most sites in two groups
Stream Substrate	11	Sun Creek has largest substrate
Water Chemistry	4	Differences in groups due to nutrients
Water Quality	1	Homogeneous water quality at all sites

Table 2. Key findings for stream classifications by metric category for 25 stream reaches in Lassen Volcanic National Park.

Metric Category	Number of Significant Groups	Key Notes
Channel Morphology	6	Most sites fall within two groups
Habitat Complexity	5	Relatively even distribution of sites across groups ranging from high complexity to low complexity
Large Woody Debris	10	Five of 10 groups were relatively similar
Riparian Characters	12	Groups and plots show high complexity and diversity of streams

Table 2 (continued). Key findings for stream classifications by metric category for 25 stream reaches in Lassen Volcanic National Park.

Metric Category	Number of Significant Groups	Key Notes
Slope and Sinuosity	2	Streams in N and S of park are steeper than central portion of park
Stream Substrate	4	Separation of groups mainly by amount of substrate larger than coarse gravel
Water Chemistry	4	Most sites within two groups
Water Quality	3	Most sites within a single group

Table 3. Key findings for stream classifications by metric category for 27 stream reaches in Redwood National and State Parks.

Metric Category	Number of Significant Groups	Key Notes
Channel Morphology	9	Thalweg depth is the main separator of groups
Habitat Complexity	7	Redwood Creek sites were all in the low complexity group
Large Woody Debris	8	Most sites in single group of relatively low woody debris
Riparian Characters	10	No clear pattern of separation
Slope and Sinuosity	7	No clear findings
Stream Substrate	6	One creek (McArthur Creek) notable for high amounts of fine sediment
Water Chemistry	5	One group of Redwood Creek sites was high in sulfate; another group of multiple creeks was high in Chloride
Water Quality	5	Redwood Creek sites all higher in temperature

Table 4. Key findings for stream classifications by metric category for 22 stream reaches in Whiskeytown National Recreation Area.

Metric Category	Number of Significant Groups	Key Notes
Channel Morphology	2	All sites within a single group, with the exception of one very deep site (Clear Creek)
Habitat Complexity	6	Of the six groups, one was most notable because its three members (Clear Creek, Willow Creek, and Whiskey Creek) were all characterized by low complexity

Table 4 (continued). Key findings for stream classifications by metric category for 22 stream reaches in Whiskeytown National Recreation Area.

Metric Category	Number of Significant Groups	Key Notes
Large Woody Debris	7	Most groups had low amounts of debris, with only subtle differences among groups
Riparian Characters	9	Most sites had high amounts of cover
Slope and Sinuosity	3	Most sites fell into one large group
Stream Substrate	7	Most groups associated with high amounts of large substrates
Water Chemistry	6	One group of two sites on Willow Creek was high in nutrients and salts
Water Quality	1	All sites relatively homogeneous

Acknowledgments

At its core, this report was made possible by the actual on-the-ground monitoring accomplished by hard-working field crews since 2011. The data they have painstakingly labored to collect day after day and year after year in consistent manners helps the parks and public understand status and trends of park natural resources. The field crews in these prior years and also in forthcoming years deserve the highest acknowledgments. Park resource specialists have also helped both in the development and implementation of the vital sign protocol. Special thanks to the staff of the Klamath Inventory and Monitoring Network, from the development stages to the implemented protocol: Daniel Sarr, Alice Chung-MacCoubrey, Sean Mohren, Allison Snyder, Sean Smith, Lauren Neel, and Sonya Daw. Lastly, thanks to Ashley Rawhouser and Andi Heard for helping to improve the report.

Introduction

Managing natural resources requires understanding *what* is being managed (Noon et al. 1999). Knowledge of the *what*, as well as the *where*, goes a long way in instructing science-based management—the *how*. Previous stream monitoring reports for Klamath Network parks have been annual reports, focused on status and condition at the time of sampling (Dinger 2015; Dinger 2017).

This is the first “Analysis and Synthesis” report required by the Klamath Network’s stream monitoring protocol. It helps inform land managers about the attributes of the streams in the following network parks: Crater Lake National Park, Lassen Volcanic National Park, Whiskeytown National Recreation Area, Redwood National and State Parks, and Oregon Caves National Monument and Preserve. It also helps managers understand the different types of streams based on those attributes. We focus on using physical habitat and chemical parameters to characterize and group the stream reaches. A future Analysis and Synthesis report will use biological characters for a similar purpose. The last Analysis and Synthesis report prior to analyzing trends will characterize the streams based on all three categories (physical, chemical, and biological) and how each influences the other (e.g., how do stream habitat characters correlate with aquatic macroinvertebrate assemblages) (Dinger et al. 2013).

Knowledge of stream attributes and stream classification is key to managing aquatic resources (Armitage 2006; Chessman et al. 2006). Direct management of streams and lakes can often include biologically manipulating vertebrate communities (e.g., piscicide applications—Gresswell 1991; Finlayson et al. 2000; McClay 2000; Buktenica et al. 2013), but physical structure, riparian components, and flow can also be managed for conservation priorities, such as biodiversity (Stanford et al. 1996; Frissell et al. 1986). Linkages between the aquatic community and geomorphology, habitat, and landscape features are vital to both basic ecological understanding, such as the River Continuum Concept (Vannote et al. 1980), and bioassessment tools (Clarke et al. 2003).

This report presents a basic summary of what the crews have seen and collected to date and identifies similarities across the sampled sites. However, it is not “basic” in the sense of simple analyses—but rather “basic” in the context of forming the *base* upon which future reports, trends, and status assessments can be made. Groups identified based on physical attributes or chemical parameters may form *a priori* strata for trend testing in future analyses where there is evidence of different stream types/groups exhibiting divergent trends. Identified groups may also be distinguishable as resources that are more susceptible to specific disturbances or management actions. For example, an identified group composed of low flow, high gradient, and warm temperature stream reaches may be the most imperiled during a drought, while a low flow, low gradient, and large substrate streambed group may be more of a concern for increased sedimentation from recreational or management activities. Additionally, analyses across parks may reveal efficiencies if a single stream group type occurs in multiple parks, so that multiple parks may learn from management techniques or actions in other parks.

Note that categorizing streams and discerning the key parameters that distinguish “distinct” groups is a *post hoc* process, done via exploratory analyses. Being *post hoc*, the tested hypotheses are centered on distinguishing groups, and there is an arbitrary component to the analyses. For example, what degree of difference constitutes separate groups? Or for another example, what set of parameters should be used for characterization?

An additional important caveat in this Analysis and Synthesis report is that the analyses are based on correlation, not causation. For example, if streams with key characteristic A also have characteristic B, we cannot assume that character A caused character B. Rather, there may be a third, unmeasured or unused character that is causative.

Klamath Inventory and Monitoring Network

The Klamath Inventory and Monitoring Network comprises six national park units in northern California and southern Oregon (Figure 1). A seventh national park unit (Tule Lake National Monument) occurs in the region but is not monitored by the network because the monument was created in 2019, after the inception of Klamath Network. Additionally, Lava Beds National Monument does not have any perennial flowing surface water and thus is not addressed by the network’s aquatic communities or water quality vital signs.

Inventory and monitoring networks contain park units that share similar geographic and natural resource characteristics for the purpose of improving efficiency and reducing costs (National Park Service 2008). However, a brief overview of the biophysical environment of the Klamath Network shows that it:

“spans a region of exceptional complexity... Steep climatic, geologic, and topographic gradients and varied disturbance regimes in the region yield biological diversity exceeded by few similar sized areas within North America or temperate regions worldwide (DellaSala et al. 1999). Across the Network, terrestrial habitats range from mesic coastal redwood forests with biomass accumulations among the highest recorded in terrestrial ecosystems (Fujimori 1977; Sawyer et al. 2000) to barren alpine tundra and xeric sagebrush steppe. Aquatic ecosystems include Pacific marine habitats, the deepest natural lake in the U.S., man-made reservoirs, a diverse array of wetlands, and many streams and rivers. Other unique habitats include karst and volcanic caves, hot springs, and lava flows.” (Sarr et al. 2007).

The large diversity of the parks and the landscapes within the parks suggest that common themes in biodiversity and park management may be difficult to discern. This defining theme of diversity across parks is important for interpreting multipark analyses.

The following brief descriptions of the parks monitored for wadeable streams are adapted from the Klamath Network vital signs monitoring plan (Sarr et al. 2007).

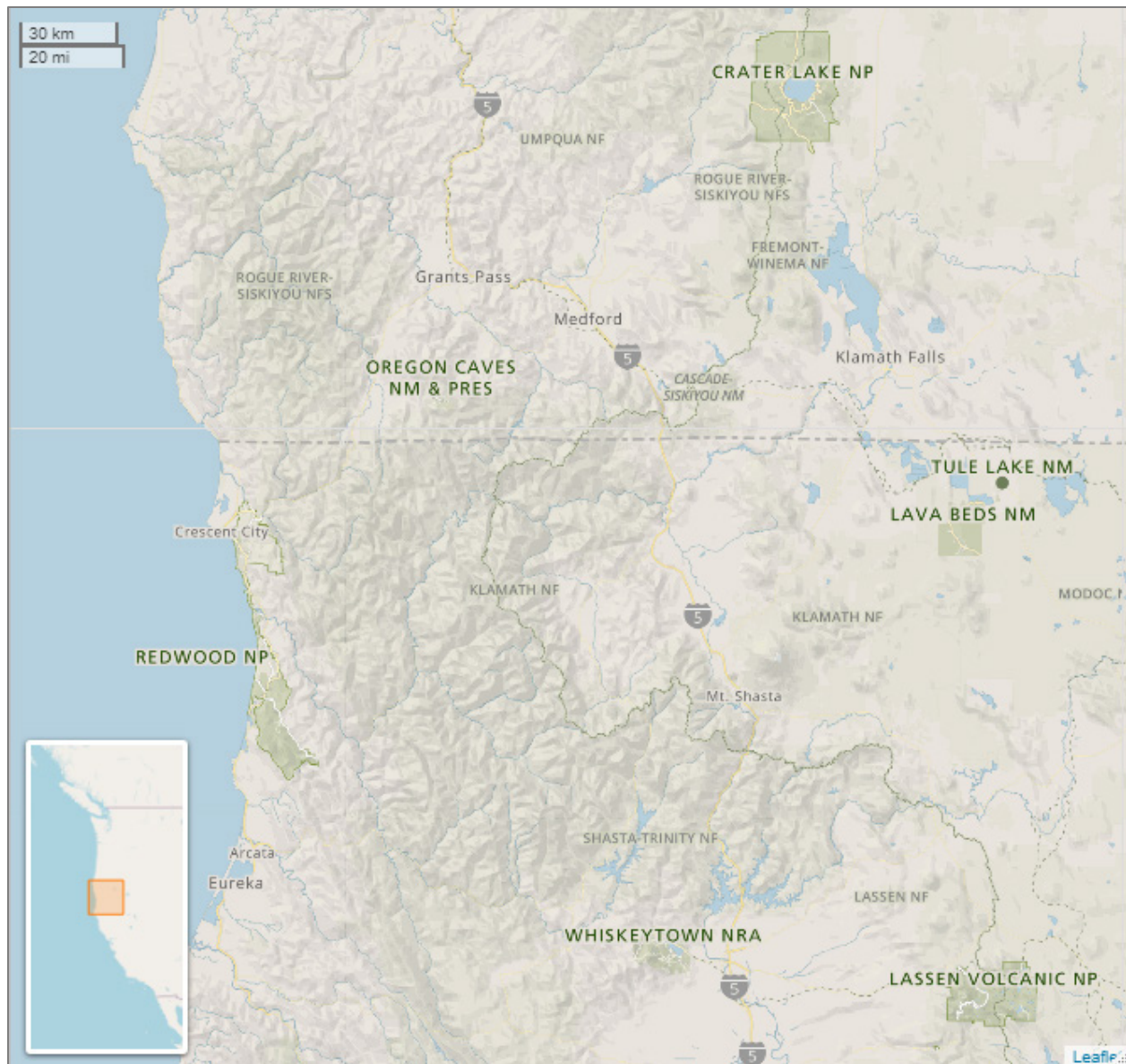


Figure 1. Klamath Inventory and Monitoring Network parks in northern California and southern Oregon.

Crater Lake National Park

Crater Lake National Park (NP) straddles the Cascade Mountains. The Crater Lake caldera (8×10 km) formed during the Mount Mazama eruption about 7000 years ago. Crater Lake is the deepest, clearest lake in the U.S. The park has a cool, mesic, varied climate and protects montane and subalpine coniferous forests, high montane meadows and wetlands, and pumice flats. It includes Sun Creek, a valued refuge for threatened bull trout.

Lassen Volcanic National Park

Lassen Volcanic National Park (NP) is in the Cascade Mountains near the junction with the Sierra Nevada Range, with the Great Basin to the east. Several types of volcanoes and active thermal features dominate the landscape. Lassen Peak last erupted between 1914 and 1921 and is one of the

world's largest plug dome volcanoes. The park is composed of mid-elevation and subalpine conifer forests, undulating lake and meadowlands, forested and meadow streams, and glaciated alpine terrain.

Oregon Caves National Monument and Preserve

Situated in the Siskiyou Mountains, Oregon Caves National Monument and Preserve (NMP) is a small but ecologically diverse unit due to its relief, high soil and vegetation heterogeneity, and presence of karst cave environments. Old-growth conifer forests, montane meadows, oak woodlands, and endemic cave-dwelling species are resource highlights. Oregon Caves includes the only underground river in the wild and scenic river system, the River Styx.

Redwood National and State Parks

Redwood National and State Parks (NSP) is a jointly managed entity composed of one national and three state park units along the Pacific coast, with elevations ranging from below sea level to 996 m (3267 ft). Its prime resources are its 15,782 ha (38,982 acres) of old-growth redwood forests, anadromous fish runs, and relatively pristine coastline.

Whiskeytown National Recreation Area

Whiskeytown National Recreation Area (NRA) is located at the southeastern edge of the Klamath Mountains. It contains an exceptional diversity of plant communities, including a variety of xeric shrublands, oak woodlands, and montane forests surrounding Whiskeytown Lake. It is also home to the only known population of Howell's alkali grass (*Puccinellia howellii*). Clear Creek is an important tributary to the Sacramento River from which anadromous fish come to spawn below the reservoir. The streams of Shasta Bally are clear and cold, and streams in the northern section of the park are historical acid mine drainages.

Wadeable Streams Vital Sign

The development, rationale, and implementation plan for monitoring Klamath Network park streams are detailed in Dinger et al. (2013). However, the following brief summary and status of sampling so far provides context for this report.

Wadeable Streams Protocol Objectives

Monitoring wadeable streams as a Klamath Inventory and Monitoring Network vital sign was first implemented in 2011, approved in 2012, and the protocol was published in 2013 (Dinger et al. 2013). The protocol contains the following monitoring objectives:

1. Determine the status and trends of ecological conditions in Klamath Network wadeable streams.
2. Assist parks with the "impaired quality waters," also known as "303d" lists as defined by the Clean Water Act.
3. Assist parks with monitoring of "Outstanding National Resource Waters" or Tier 3 waters as defined by the Clean Water Act.

We utilize the Environmental Protection Agency's (EPA's) definition of "ecological condition," which is defined as the "state of the physical, chemical, and biological characteristics of the environment, and the processes and interactions that connect them." (U.S. EPA 2008)

Monitoring objective 1 is being met by sampling the park streams every three years, via a wide range of physical, chemical, and biological variables. We use established EPA field techniques, originally developed under the Wadeable Streams Assessment (U.S. EPA 2006) and now implemented via the National Rivers and Streams Assessment program (U.S. EPA 2019). Monitoring objectives 2 and 3 are met by providing the data collected for objective 1 to the parks for actions in support of the Clean Water Act.

This report meets a measurable objective of the protocol—to produce in-depth Analysis and Synthesis reports. These Analysis and Synthesis reports explore data patterns to help interpret status and trends. Exploring the patterns of stream ecosystems in the Klamath Network landscape can enhance our scientific understanding of ecosystems.

Wadeable Streams Protocol Design

In brief, a sampling design determines critical elements of the interpretation of data and results. Sampling design largely dictates the location of sampling on the landscape, and the method of site selection from the sampling frame then dictates the amount of inference that can be made.

In the Klamath Network wadeable streams protocol, three constraints were used to define the sampling frame (or target population):

1. Wadeable perennial streams. Wadeable streams are stream orders 1–5; perennial streams flow all year and are not subject to occasional periods of desiccation.
2. Less than 1000 m from a passable road or trail (for purposes of safety and accessibility).
3. Stream gradients with stream slope less than 15 % (further ensures safe sampling and feasibility of crew sampling efforts).

These constraints to the sampling frame reduce the amount of inference in each park. Our results can be inferred to between 47% of stream kilometers in Redwood National and State Parks and 73% of stream kilometers for Whiskeytown National Recreation Area. The practical outcome is that results, be they status, trends, or the current report's results, cannot be attributed and applied to every stream kilometer. For example, streams with gradients over 15% may exhibit different statuses or groupings than can be detected in the existing sample frame.

The second aspect of sampling design that is key to interpretation is how the sites were selected from the delineated sample frame. In the Klamath Network wadeable streams sampling protocol, a probabilistic sampling routine known as Generalized Random Tessellation Stratified sampling (GRTS) was used for generating sampling sites (Stevens and Olson 2004). The use of GRTS, when exercised properly, helps to maximize the dispersion of sites, minimize spatial auto-correlation, and allow for inference to the entire sampling frame. When using GRTS or other site selection tools,

sampling designs can also include a panel design, where certain sites are sampled in one year but not again for a few years. These panel designs can increase the overall sample size, increasing the general confidence of status assessments, but they can also delay statistical power for trend assessment. The Klamath Network chose a non-panel design, where we attempt to resample sites every sampling year (generally termed “always revisit design,” or [1–0] using the notation of McDonald (2003)).

The final aspect is the temporal sampling scheme. The Klamath Network implements a rotating sampling scheme, so that parks and their habitats are resampled every three years (Table 5). Due to the small size and limited streams in Oregon Caves National Monument and Preserve, only three judgment sites—nonrandomly selected by park staff—are sampled. While this report includes Oregon Caves in the analyses and synthesis, the results are not representative of the remaining stream sections of Oregon Caves. (Table 5 also shows the revisit schedule for lake sampling, which is a different vital sign monitored by the network.)

Table 5. Temporal revisit design for aquatic ecosystem sampling in Klamath Network parks. After 2015, the cycle repeats, as sites are resampled every three years. X = visit.

Habitat type	Park Unit	2011	2012	2013	2014	2015	2016
Lakes	Lassen Volcanic National Park	–	–	X	–	–	X
	Crater Lake National Park	–	–	X	–	–	X
	Redwood National and State Parks	–	–	X	–	–	X
Wadeable Streams	Whiskeytown National Recreation Area	X	–	–	X	–	–
	Lassen Volcanic National Park	X	–	–	X	–	–
Wadeable Streams	Oregon Caves National Monument	–	X	–	–	X	–
	Redwood National and State Parks	–	X	–	–	X	–
	Crater Lake National Park	–	X	–	–	X	–

Sampling Effort

The protocol aims for sampling 30 sites per park for four network parks (Whiskeytown National Recreation Area, Lassen Volcanic National Park, Redwood National and State Parks, and Crater Lake National Park), and three sites for Oregon Caves National Monument and Preserve. As mentioned previously, there is no sampling at Lava Beds National Monument due to the absence of perennial flowing surface water. While 30 sites remain the target for annual sampling at the four parks, a variety of logistical issues suggest that obtaining 30 sites per year can jeopardize safety and data quality. In six years of data collection, the number of sampled sites at the four parks has ranged from 20 to 29 (Table 6). The total number of unique sites may differ from the annual effort since a site sampled in the first year may have been unsampleable in a later year. As an example, a stream sampled in 2011 that was dry in 2014 would not be resampled. Because of this, the total number of unique sites per park can be greater than those sampled in any one sampling year.

Table 6. Sampling sites accomplished during six years of monitoring from 2011 to 2018 in Klamath Network parks. NA indicates that the park was not scheduled to be sampled in that year.

Year	Whiskeytown NRA	Lassen Volcanic NP	Oregon Caves NMP	Redwood NSP	Crater Lake NP
2011	22	24	NA	NA	NA
2012	NA	NA	3	23	23
2014	21	22	NA	NA	NA
2015	NA	NA	3	26	29
2017	20	24	NA	NA	NA
2018	NA	NA	3	27	29
Total Unique Sites	22	25	3	27	30

Methods

A brief overview of the Klamath Network's wadeable streams protocol is provided here for context. Full field methods and details of the protocol's development, background, rationale, and objectives can be found in Dinger et al. (2013).

At each selected sample site, a sample reach 40 times longer than the typical wetted width of the stream at the time of first sampling was established and 11 equally spaced transects perpendicular to stream flow were marked with temporary flagging (Figure 2). A minimum reach length of 150 m and a maximum reach length of 500 m were imposed.

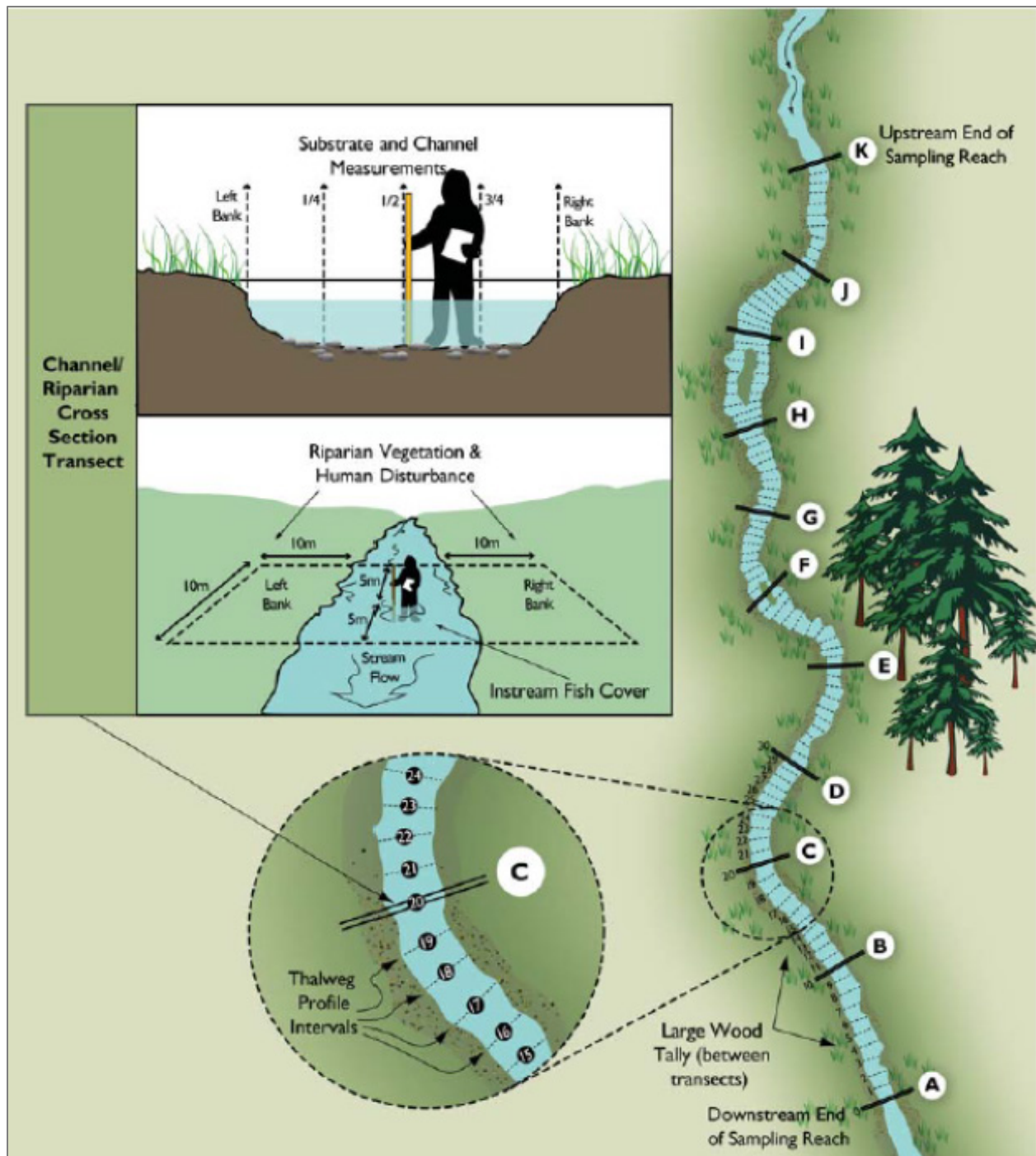


Figure 2. Schematic of sampling site reach layout (from EPA Wadeable Streams Assessment, 2006, Figure 11).

Water Quality

Measurements of temperature ($^{\circ}\text{C}$), pH, specific conductivity ($\mu\text{S}\cdot\text{cm}^{-1}$), dissolved oxygen ($\text{mg}\cdot\text{L}^{-1}$), and turbidity (NTU) were made at mid-depth in seven locations along a cross-section that extended perpendicular to stream flow in a well-mixed riffle using a Eureka Environmental “Manta” water

quality probe. Specific conductivity was used to ensure that the riffle was well mixed by assessing the seven cross-section measurements for variability. If the specific conductivity varied more than a $5 \mu\text{S}\cdot\text{cm}^{-1}$ differential across the stream, the measurement was repeated in an upstream riffle until a well-mixed riffle was confirmed.

Water Chemistry

When a well-mixed riffle was confirmed, a 2 L amber high-density poly-ethylene (HDPE) sample bottle was submerged to collect a water sample. On shore, using a 60 ml syringe and filter holder, a portion of each water sample was filtered through a $0.45 \mu\text{m}$ nylon membrane filter into an amber, acid washed 250 ml HDPE bottle for cation (Ca^{2+} , Na^{+} , K^{+} , and Mg^{2+}) and anion (SO_4^{2-} and Cl^{-}) analyses. An additional unfiltered 250 ml of water was decanted into an identical bottle for nutrient analyses (Total Nitrogen, Total Phosphorous). Both bottles were kept on ice until we were able to freeze them (generally <4 hours). Additionally, 120 mL of water were filtered through precombusted glass fiber filters into an acid-washed, precombusted glass vial for Dissolved Organic Carbon (also kept on ice and later refrigerated). These samples were then shipped to the Cooperative Chemical Analytical Laboratory at Oregon State University, Corvallis. See Dinger et al. (2013) for details on detection limits and analytical techniques for each parameter.

Stream Habitat/Riparian Corridor Characteristics

For the length of the reach, we assessed the following geomorphic characteristics: channel constraint type and percent constrained, channel pattern (braided, anastomosing, single), and evidence of recent torrents. Anastomosing channels are multithreaded but are much more stable than braided channels and commonly have thick clay and silt banks and occur at lower gradients of the stream bed.

At each of the 11 transects, we measured cross-sectional information including wetted width, bank angles, undercut banks, presence and height of incised banks, and bankfull width and height. Across the transect (left bank, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and right bank), we measured depth, substrate embeddedness (proportion of large substrate encased in fine substrates), and substrate size.

On each bank and in the middle of the stream at each transect, we collected measures of overhead shading with a convex, spherical densiometer. We estimated an areal categorization of fish habitat cover 5 m above and 5 m below the transect in the following classes: artificial substrate, boulders, filamentous algae, large wood, macrophytes, overhanging banks, roots, small wood, and undercut banks. In a 10×10 m quadrat next to the transect, we also estimated measures of riparian structure (dominant vegetation type; cover classes [sparse, moderate, heavy, very heavy] of small trees and large trees, herbs, grasses, etc.) in the ground layer (<0.5 m), understory (0.5 to 5.0 m), and overhead canopy (>5 m). In this same quadrat, we quantified the presence of human influences (e.g., walls, dikes, inlet/outlet pipes, camping, etc.).

We also measured thalweg depths along a longitudinal profile that extended throughout the length of the reach, taking equally spaced measurements of max depth, presence of soft or small sediments, and channel form type (pool, glide, riffle, rapid, etc.) (see Figure 2). At the midpoint between transects, we repeat the cross-section measurements (as above) of substrate type and algal thickness.

Inter-transect measures of downed woody debris were also made for the length of the reach. Woody debris was tallied for categories of length and diameter, both within the bankfull stream channel and in adjacent areas above bankfull height.

Stream gradient was measured between transects using a stadia rod and handheld level. An observer with the hand level stood at the approximate halfway point, and a stadia rod was placed at the transects; the difference between upstream and downstream was recorded for the rise. In this way, the total slope and variation in stream gradient can be measured.

Metrics

Metrics are defined as a summary measure of raw field collected values. They form the quantitative basis of the analytical groupings we present in this report. Metrics vary in their complexity and can range from a simple mean of the seven cross-sectional water quality measurements (e.g., Average Dissolved Oxygen), to a predictive ratio of observed substrate sediment size to an expected ratio based on the stream hydraulic radius and stream slope (i.e., Relative Bed Stability of Kaufmann 1999). Metrics used for grouping analyses are presented in Appendix A, along with a brief description and method of calculation. All metrics were calculated using the code developed for the statistical package, R (R Core Team 2017).

Metric Categories

Eight categories of physical habitat and water quality/chemistry were used to encapsulate the possible groupings of streams in the park landscape. They are:

1. Channel Morphology—metrics such as bank angle, stream width and depth, ratios of habitat cross-section, and proportion of fast and slow water habitat.
2. Habitat Complexity— metrics developed by the U.S. EPA to describe natural complexity, usually called fish habitat cover.
3. Large Woody Debris—metrics that describe the amount of large woody debris in the stream channel, both within the bankfull channel and pieces that bridge the bankfull channel in multiple size categories (e.g., long and narrow versus short and wide).
4. Riparian Characters—metrics that describe the amount of riparian community development, including stream shading, percent ground cover, percent understory, percent canopy, and percentage of vegetation type (e.g., conifer and deciduous).
5. Slope and Sinuosity—metrics encompassing the stream gradient, variability of the gradient, and the amount of curvature in a stream.
6. Stream Substrate—metrics describing the streambed substrates, such as percent fines, percent large substrates, embeddedness, median substrate size, and Relative Bed Stability.
7. Water Chemistry—measures of the nutrients and salts (cations/anions) of the stream water.
8. Water Quality—measures of the in-situ parameters of stream water, such as temperature, pH, specific conductivity, dissolved oxygen, and turbidity.

Within each of these eight categories, we sought to identify discrete groupings or types of streams in each of the park landscapes.

Analytical Methods

Figure 3 illustrates the broad analysis plan to discern significant groups of stream characteristics. The first step is to create a resemblance matrix using Euclidean distance between each stream site. Second, a subset of metrics that best represents the entire suite of metrics is derived when five or more metrics are used. Third, a cluster analysis is performed that separates the sites into a tree-like diagram, with similar sites on the same branch, and dissimilar sites on different branches. This cluster technique uses divisive techniques that separate based on the subset of metrics. The fourth step is to test for statistically significant differences among the cluster branches using a randomization technique to aid in a “stopping rule” for interpreting branches. The fifth step is to graphically display the spread of groups across the park landscape. The sixth step is to use metric Multi-dimensional Scaling ordination [– as in Kruskal (1964), with some variations. We used actual distance instead of ranked distance, which is used in nonmetric Multi-dimensional Scaling (nMDS)], to display the groups. Also, where separation is judged to be a single gradient (e.g., low amounts of Large Woody Debris versus high amounts of Large Woody Debris), we provided manually entered split lines and discriminating thresholds (Step Fa in Figure 3). When separation of groups is judged to be multiple gradients (e.g., riparian metrics with high/low amounts of understory vegetation along one axis and low/high of herbaceous ground cover on a second axis), we used correlative vector biplots to explore which groups are associated with individual metrics (Step Fb in Figure 3). Each step of the analysis is detailed below, and the software Primer-E was used for all analyses (Clarke et al. 2014).

We use two techniques for follow-up analyses. First, we perform a second stage Multi-dimensional Scaling of the metric groups together to inform how, for example, Stream Substrate metrics of the park’s streams relate to Large Woody Debris. While correlations in second stage Multi-dimensional Scaling are still correlations and not causation, they can provide insight into how the two metrics interact. Second, a broader analysis of inter-park comparisons for each metric group is performed to understand how parks might collaborate based on commonality in their streams. These two analyses are also detailed below.

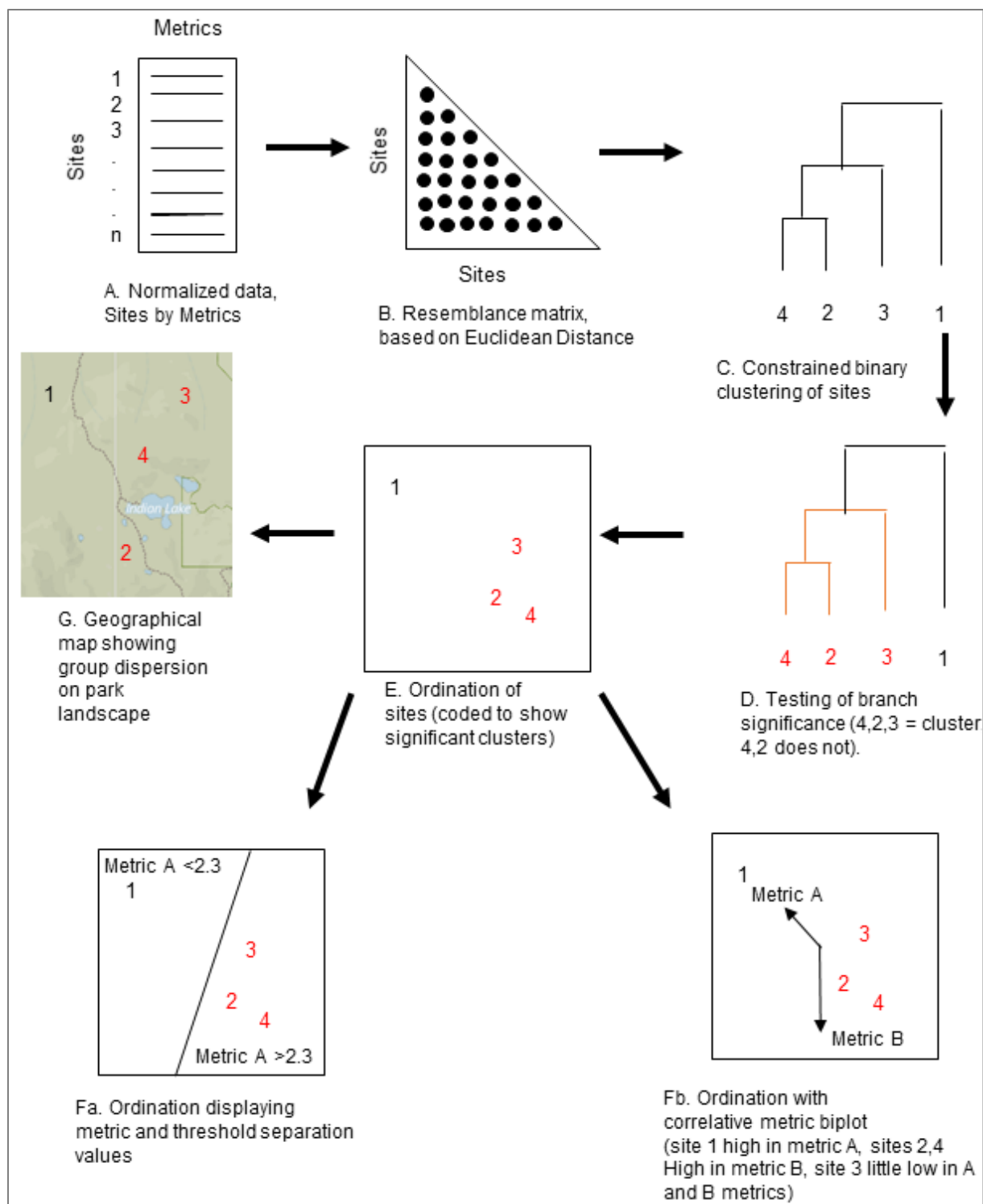


Figure 3. Analytical process for discerning significant groups of stream characteristics for a hypothetical example, demonstrating each step. For step F, only Fa or Fb is performed (not both), depending on exploratory analyses. The analytical process ends at step F, and step G presents the results spatially on the park landscape. For G (geographical display), no map was made if there was a single group. We do not show the selection process for a subset of metrics that occurs when there are more than five metrics in a group.

Step A: Normalizing Metrics

Prior to creating a resemblance matrix, metrics are averaged across years (Figure 3, Step A). If a site was sampled in all three years, it is the mean of the three years. If it was only sampled once, then the single value is used. After averaging for a single site value of the metric, the metric is normalized. Normalization sets the mean of the metric 0, and the standard deviation to 1, utilizing the following formula:

$$Normal\ Score = \frac{x_i - \bar{x}}{\sigma}$$

Where x_i is the site score, $\bar{x}$ is the parkwide average for that metric, and σ is the standard deviation of the metric. This has the effect of treating each metric equally, even if the metrics are on different scales (common to environmental measures).

Step B: Resemblance Matrix

Euclidean distance is then calculated for each site-to-site distance using the following formula:

$$D_1 = \sqrt{\sum_i (y_{i1} - y_{i2})^2}$$

Where y_{i1} and y_{i2} are the normalized metric values from site 1 and site 2, respectively. When calculated for all site comparisons, the result is a triangular resemblance matrix of distance, where high values equal high dissimilarity (or low similarity) (Figure 3, Step B).

Where there was a missing value, the Euclidean distance for that specific site comparison is calculated with the missing value's metric omitted. Because the Euclidean distance based on few metrics is inherently less than a distance based on more, a corrective factor is applied to the calculated distance where there are missing data. This correction is to multiply the summation value by (p/p') . Missing metrics/sites are presented in Appendix B.

Step C: Cluster Analysis

Clustering is carried out with constrained binary divisive clustering. In this method, division and subdivision occur where an explanatory variable exists to separate the branches (Figure 3, Step C). For this analysis, the explanatory variables are the underlying individual metrics when the metric list is less than five, or a subset of the best metrics when the original metric list is greater than five. For deriving subsets, an analytical routine (BIOENV) that maximizes the correlation of the original set to the smaller subset was used. These subsets provide a smaller set of variables that can “explain” much of the underlying original structure in the data. In cases where fewer metrics provided a correlation over 90%, fewer than five variables were utilized as the explanatory variables. The best split in the cluster is determined by maximizing a statistic known as R , which is based on the difference of mean ranks between groups and within groups. Note that this R statistic is commonly used in an Analysis of Similarities test (ANOSIM), but here is used as a measure of separation for the clustering in

multivariate space. We used the constrained clustering method to be able to concisely communicate to park managers the variables or metrics that separate or define identified groups.

Step D: Test of Cluster Significance

The number and composition of stream habitat or chemical groups were determined using Similarity Profile Test (SIMPROF) in the multivariate analysis package Primer-E (Clarke et al. 2014) (Figure 3, Step D). SIMPROF works as an iterative process, testing individual nodes of the cluster analysis. At each node, SIMPROF tests for underlying structure. Samples below a node are ranked by similarity, forming a “similarity profile,” and a null model of no structure is derived by randomizing the allocation of species at a site, and repeating the rank profile (many times to develop a mean randomized profile). A departure statistic π is then calculated as the deviation of the observed profile against the mean randomized profile. A null distribution of π is then calculated by repeated permutation of the randomized site by species matrix. The observed departure statistic, π , can then be compared to the null distribution of π . The null hypothesis of no significant structure in that node can then be rejected using the standard permutation tests (Manly 2007) at the level of $P < (\# \text{ observed greater or equal values of } \pi + 1) / (\# \text{ of randomizations} + 1)$. All randomization procedures used in this manuscript used 999 randomizations.

SIMPROF’s advantage is that it is iterative and provides a stopping rule for unwarranted analysis of the substructure of each node. Additionally, each cluster is considered separately, so that an arbitrary amount of similarity is not used to determine ecological significance, allowing some clusters to have ecologically significant sub-groups while others have absence of structure. However, due to a large sample size, significance can occur with subtle similarities. To account for statistical significance interfering with habitat significance, we selected a lower than typical α if the total number of groups was over 10 (over 10, $\alpha = 1\%$ under 10, $\alpha = 5\%$). The end result of SIMPROF is an *a posteriori* physical habitat or chemical grouping scheme derived from the environmental data.

Step E: Metric Multi-Dimensional Scaling

Ordination of stream reaches in two dimensional space was done using metric Multi-Dimensional Scaling (mMDS) using Primer-E (Figure 3, Step E). mMDS used the Euclidean distance from the cluster analysis to display the relationship between stream reaches. Using mMDS in addition to the cluster analysis has the advantage of showing not only how site A relates to Site B, but also to Site C, all of which may belong to different SIMPROF groups. Because the SIMPROF groups have already been determined using cluster analysis on the underlying resemblance matrix, traditional follow-up analyses for significance of groups is inappropriate and unnecessary (e.g., Analysis of Similarities).

Step F: mMDS Interpretation

Ordination via mMDS is instructive in how sites relate to each other in a configuration, but further interpretation is necessary to understand how or why sites are configured closely or distantly to each other. Two techniques were utilized to assist in interpretation: Linkage Trees and Vector Biplots. The selection of which to use is determined subjectively based on the complexity of the ordination. The more complex ordinations are better interpreted with biplots, and simpler ordinations are better interpreted with linkage trees; this framed the subjective decision of which method to use.

Step Fa: Linkage Trees

Linkage trees are a way of linking cluster patterns to variables (and are termed CART [Classification and Regression Trees] and Multivariate Regression Trees [MRT] by others) (Figure 3, Step Fa).

Linkage Trees used here look at the metrics in combination and select the subset that best separates the clusters. For each node, they describe metrics and threshold separation values for each group.

Splits in the ordination are then graphed and threshold values are provided.

Step Fb: Vector Biplots

Specific habitat or chemistry metrics that are correlated with SIMPROF groups are investigated using correlative biplots or vectors, where the direction and length define higher values of the individual metrics (Figure 3, Step Fb). This is done by a linear regression of the metric to the mMDS axes coordinates. This creates a vector length that when projected on the mMDS diagram represents the Pearson correlation co-efficient of that metric with each axis. These vectors can then increase understanding about how the plotted stream sites are associated with each plotted metric. To assist in interpretation and clarity, only metrics above a threshold rho are presented. The threshold for display varies and is selected on a per park/ordination basis.

Step G: Graphical Mapping of Landscape Patterns

The spatial distribution of SIMPROF groups on the park landscape is displayed using graphing functions of the software R and the leaflet package (Figure 3, Step G). SIMPROF provides arbitrary letter groupings to the *a posteriori* groups. If clustering determined only a single group, then no map was created.

Second Stage Multi-dimensional Scaling

Each resulting resemblance matrix for metric groups is symmetrical to the other resulting resemblance matrix for the remaining groups. For example, each Euclidean distance between two stream reaches for each metric has an identical comparison in the other groups. The resemblance matrices can be linearized and correlated. This correlation between the two metric groups' matrices in turn is used in a resemblance matrix between each metric group that can be used in a non-metric Multi-dimensional Scaling (nMDS), as described above but with rank-based distances. Stream characters that can be hypothesized to be closely related, for example, Water Quality and Water Chemistry, can then be visualized.

Oregon Caves National Monument and Preserve

The small sample size of stream sites at Oregon Caves National Monument and Preserve precludes using these techniques, and the park's sites are hence omitted from the previous analytical scheme. Having three sample sites, the resulting cluster analysis always results in an identical configuration, with two sites connected, and the third separated. The low sample size also prohibits attributing significance to this configuration, which would suggest it is unwise to interpret which two sites are "closer" to each other. Lastly, the nonrandom site selection prohibits any broader inference.

Analysis of the stream characters of Oregon Caves is hence focused on the following inter-park comparisons between streams of Oregon Caves and streams in other parks of the Klamath Network.

Inter-Park Comparisons

The parks of the Klamath Network, although diverse in many ways (Sarr et al. 2007), have sought to leverage natural resource similarities and employees for more efficient management. To this end, this report also compares the eight metric groups across parks. It effectively asks the question, “Which parks have similar streams that might have similar responses to stressors over time or might benefit from similar management?”

For inter-park comparisons, we use Metric Multi-dimensional Scaling based on normalized data to the entire dataset of all stream reaches. Parks with similar streams will be displayed as overlapping layers of individual stream reaches, whereas parks with different stream “types” will show non-overlapping dispersion of stream reaches. In most ecological situations, information like this would be examined for the significance of non-overlap—are the two populations different? However, here the desired information is where and which parks overlap or do not overlap. Significant differences (the scenario where one park’s streams are significantly different from other parks) are tested with Analysis of Similarity. Analysis of similarity (ANOSIM) uses a test statistic, R , which reflects the average rank similarities within the classes versus the average rank similarities between the different parks. R is closer to 1 if plots within the environmental classes are more similar to each other than any plots from other classes (i.e., complete separation of classes), and is close to 0 if the similarity is the same between and within classes (i.e., little or no segregation of classes). Significance can be attributed by again permuting the class membership, creating a distribution of R under the null model of no differences. However, small differences between groups can lead to statistical significance despite a large amount of overlap between groups, leading to the case of “statistical significance but no biological significance” when there are ample sample sizes. Hence, interpretation should include a higher than typical P value, and also consider the size of the R statistic, where a low R indicates similar streams between parks. Here, significance is assessed at a P value of 0.1%. This analysis can also be used to identify unusual or atypical streams for the parks of the Klamath Network.

Results and Discussion

Park-Specific Results

The analytical methods produce two types of data products (figures) per metric group. A map of the group distribution across the park landscape provides a potential third figure. With eight metric groups, each park has a potential of 24 figures (no map is provided if there are no statistically separate groups within a metric). An in-depth discussion of each figure is not tenable, and due to the exploratory nature of this report, not every figure or analysis may produce an immediate discussion point. However, for future use and interpretation, it is still important to present the full set of results.

Hence, bulk results are provided in Appendices C–F for clarity. Each appendix starts with bulleted key results, when observed, for park managers.

Second Stage Multi-dimensional Scaling—How Metric Groups Relate

Second stage MDS analyses identified if metric categories were correlated with each other, which may give insight into mechanisms. For example, if Stream Substrate was highly correlated with Slope and Sinuosity, this would suggest that the substrate is largely dependent upon the edaphic factors of the stream. As a correlative analysis, overinterpretation is cautioned against. Because the relationships between metric groups are based on Spearman's rho, we report rho for stronger relationships of interest.

Crater Lake National Park

Table 7 summarizes mMDS analysis of individual metric categories (e.g., Channel Morphology, Habitat Complexity, etc.), the number of significant groups, and key summary notes. More detailed results and interpretation for the mMDS are provided in Appendix C, with figures showing cluster and group significance and mMDS ordination.

Table 7. Significant groupings within metric categories to identify stream classifications from 30 stream reaches in Crater Lake National Park.

Metric Category	Number of Significant Groups	Key Notes
Channel Morphology	9	Four streams were different enough to each represent an individual group
Habitat Complexity	8	Groups were distinguished largely based on the amount of habitat cover
Large Woody Debris	10	Rogue River highest in number of pieces
Riparian Characters	12	Complex assortment of variables determine groups
Slope and Sinuosity	4	Most sites in two groups
Stream Substrate	11	Sun Creek has largest substrate
Water Chemistry	4	Differences in groups due to nutrients
Water Quality	1	Homogeneous water quality at all sites

Two key results are apparent in the relation of metric categories for Crater Lake using second stage nMDS (Figure 4, Table 8). First, substrate metrics appear unrelated to other components, such as habitat complexity, morphology, or slope. Second, large woody debris (LWD), habitat complexity, and the riparian metrics are all highly related (Figure 4). This suggests that streams with a complex riparian zone are associated with stream habitat complexity, which is often viewed as a measure of available fish habitat. Likewise, the joint relationship of the riparian metrics and habitat complexity with large woody debris suggests association. Large woody debris is viewed as an important structural component for fish habitat because stream reaches with high large woody debris support larger and older populations of salmonid fish in Pacific Northwest streams (Fausch and Northcote 1992). Large woody debris has been shown to provide habitat for fish by providing shelter from high velocities and building jams that cause deep pools and fish habitat (Harmon et al. 1986; Maser and Sedell 1994).

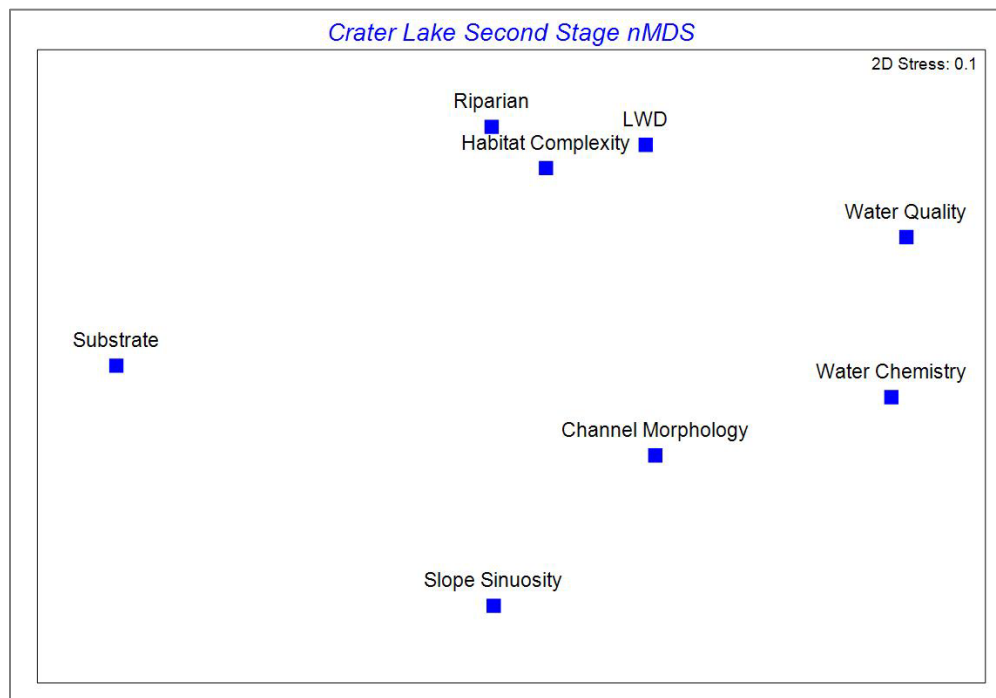


Figure 4. Relationships among metric categories of sampled stream reaches in Crater Lake National Park. Proximity suggests correlation among metric groups, and distance suggests independence. LWD = Large Woody Debris, Riparian = Riparian Characters, Substrate = Stream Substrate.

Table 8. Spearman rho correlations for Crater Lake National Park stream metric categories. As a correlation matrix, only the bottom half of the table is displayed. Each value represents the correlation between two different metric groups, with large positives indicating that high values in one metric correspond with high values in the second group—they are positively related. High negative values (e.g., close to -1) indicate that low values in one metric correspond with high values in the second group—they are inversely related. Values close to zero indicate no appreciable correspondence between the metric categories.

Metric Category	Channel Morphology	Habitat Complexity	Large Woody Debris	Riparian Characters	Slope and Sinuosity	Stream Substrate	Water Chemistry
Channel Morphology	–	–	–	–	–	–	–
Habitat Complexity	0.265	–	–	–	–	–	–
Large Woody Debris	0.266	0.541	–	–	–	–	–
Riparian Characters	0.023	0.354	0.276	–	–	–	–
Slope and Sinuosity	0.248	–0.058	–0.083	0.147	–	–	–
Stream Substrate	0.000	0.028	–0.118	–0.104	–0.035	–	–
Water Chemistry	0.286	0.087	0.082	0.027	–0.060	–0.175	–
Water Quality	0.067	0.141	0.273	0.097	0.003	–0.166	0.352

Substrate is an important defining characteristic for macroinvertebrate communities and fish spawning habitat. Crater Lake streams have the smallest mean and median particle size of any park within the Klamath Network (Dinger, unpublished data). However, coarse gravel and larger substrate sizes are important for the interstitial spaces they provide between the particles, providing refuge and habitat for macroinvertebrates. Research has shown that coarse gravel habitat is important for salmonid spawning habitat in the Pacific Northwest as well (e.g., Riebe et al. 2014). The separation of substrate from any other metric categories in Crater Lake is notable and suggests that substrate is not likely to be affected by the management of other components (e.g., large woody debris, riparian zone thinning, etc.). In this case, it is probably more a function of the underlying geologic composition of the pumice substrate (KellerLynn 2013). The prevalence of upslope pumice soils, with smaller sizes and lighter densities, undoubtedly led to the observed dominance of smaller-sized substrates within the streams.

Lassen Volcanic National Park

Table 9 provides the summary of mMDS on individual metric categories (e.g., Channel Morphology, Habitat Complexity, etc.), the number of significant groups, and key summary notes. More detailed results and interpretation for the mMDS are provided in Appendix D, with figures showing cluster and group significance and mMDS ordination.

Table 9. Significant groupings within metric categories to identify stream classifications from 25 stream reaches in Lassen Volcanic National Park.

Metric Category	Number of Significant Groups	Key Notes
Channel Morphology	6	Most sites fall within two groups
Habitat Complexity	5	Relatively even distribution of sites across groups ranging from high complexity to low complexity
Large Woody Debris	10	Five of 10 groups were relatively similar
Riparian Characters	12	Groups and plots show high complexity and diversity of streams
Slope and Sinuosity	2	Streams in N and S of park are steeper than central portion of park
Stream Substrate	4	Separation of groups mainly by amount of substrate larger than coarse gravel
Water Chemistry	4	Most sites within two groups
Water Quality	3	Most sites within a single group

The lack of strong clustering in the 2nd stage nMDS plot suggests that metric categories within Lassen Volcanic National Park are less tightly associated with each other than compared to Crater Lake (Table 10, Figure 5). Similar to Crater Lake, Large Woody Debris and Habitat Complexity are weakly associated with one another, but neither appear closely related to the riparian metrics. Channel Morphology appears to have a weak correlation with Stream Substrate composition.

Table 10. Spearman rho correlations for Lassen Volcanic National Park metric categories. As a correlation matrix, only the bottom half of the table is displayed. Each value represents the correlation between two different metric categories, with large positives indicating that high values in one metric correspond with high values in the second group—they are positively related. High negative values (e.g., close to -1) indicate the low values in one metric correspond with high values in the second group—they are inversely related. Values close to zero indicate no appreciable correspondence between the metric categories.

Metric Category	Channel Morphology	Habitat Complexity	Large Woody Debris	Riparian Characters	Slope and Sinuosity	Stream Substrate	Water Chemistry
Channel Morphology	0.070	–	–	–	–	–	–
Large Woody Debris	0.267	0.094	–	–	–	–	–
Riparian Characters	0.149	0.187	0.053	–	–	–	–
Slope and Sinuosity	–0.059	0.088	0.057	0.076	–	–	–

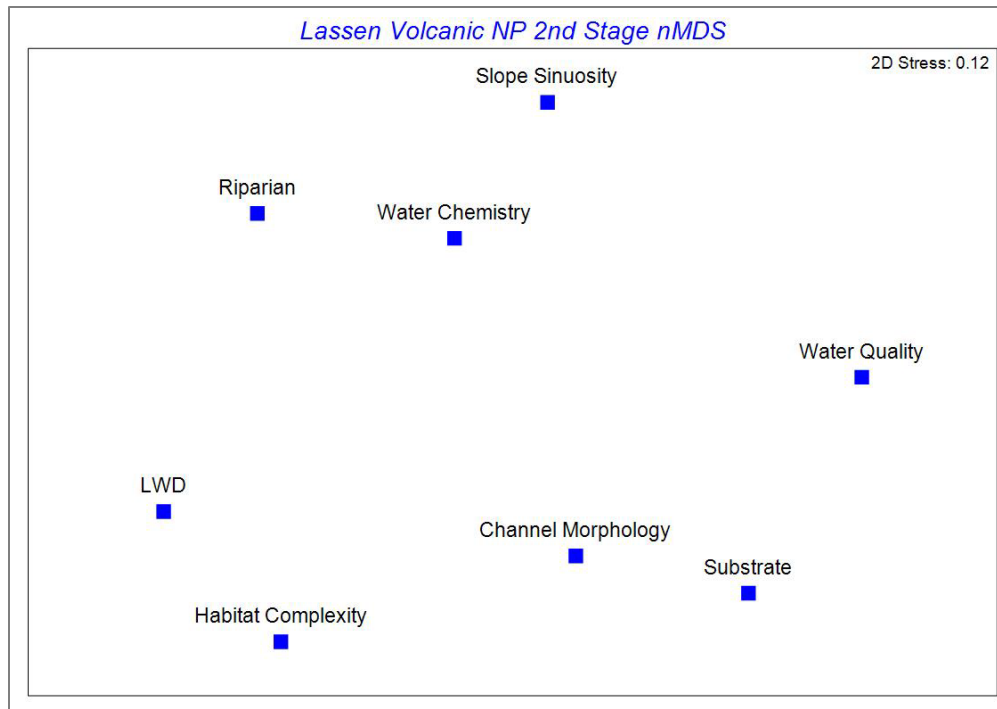


Figure 4. Relationships among metric categories of sampled stream reaches for Lassen Volcanic National Park. Proximity suggests correlation among metric categories, and distance suggests independence. LWD = Large Woody Debris, Riparian = Riparian Characters, Substrate = Stream Substrate.

The Spearman's rho correlation between Large Woody Debris and Habitat Complexity was 0.267, and the rho between Channel Morphology and Stream Substrate was 0.239. In contrast, the correlation for Crater Lake Habitat Complexity and Large Woody Debris was 0.54. The relatively low observed correlations compared to Crater Lake suggest alternative characteristics may better inform management, e.g., if existing levels of Large Woody Debris are not correlated with Habitat Complexity, then maybe Habitat Complexity is a function of watershed factors, elevation, or existing forest structure?

Oregon Caves National Monument and Preserve

The low sample size of streams from Oregon Caves, coupled with the non-probabilistic selection of the stream reaches, minimizes the usefulness of a second stage nMDS ordination between metric categories. With only three sites, it is possible for apparent correlation to appear perfect in the correlation matrix (e.g., Spearman's rho of 1.0 or -1.0) despite two metric categories being uncorrelated in the ordination (Table 11, Figure 6). Both the correlation matrix and ordination suggest Channel Morphology and Slope and Sinuosity are tightly coupled; however, there are no real management implications, and due to the low sample size, we urge against overinterpretation.

Table 11. Spearman rho correlations for Oregon Caves National Monument and Preserve metric categories. As a correlation matrix, only the bottom half of the table is displayed. Each value represents the correlation between two different metric categories, with large positives indicating that high values in one metric correspond with high values in the second group—they are positively related. High negative values (e.g., close to -1) indicate the low values in one metric correspond with high values in the second group—they are inversely related. Values close to zero indicate no appreciable correspondence between the metric categories.

Metric Category	Channel Morphology	Habitat Complexity	Large Woody Debris	Riparian Characters	Slope and Sinuosity	Stream Substrate	Water Chemistry
Habitat Complexity	-0.50	–	–	–	–	–	–
Large Woody Debris	-1.00	0.50	–	–	–	–	–
Riparian Characters	-0.50	-0.50	0.50	–	–	–	–
Slope and Sinuosity	1.00	-0.50	-1.00	-0.50	–	–	–
Stream Substrate	-0.50	-0.50	0.50	1.00	-0.50	–	–
Water Chemistry	1.00	-0.50	-1.00	-0.50	1.00	-0.50	–
Water Quality	0.50	-1.00	-0.50	0.50	0.50	0.50	0.50

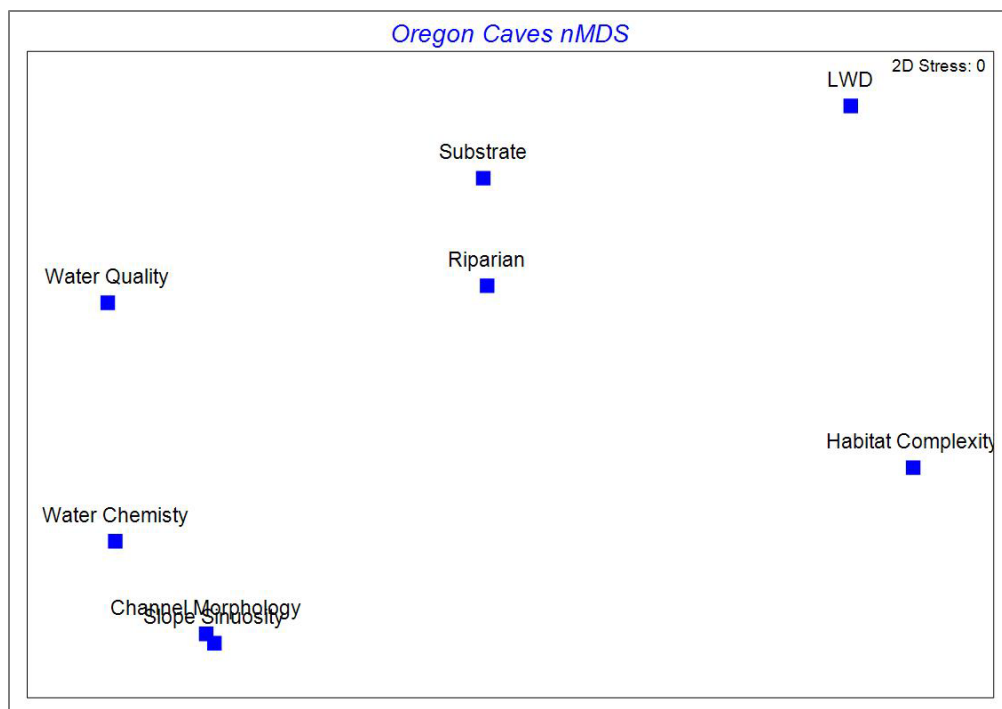


Figure 5. Relationships among metric categories of sampled stream reaches for Oregon Caves National Monument and Preserve. Proximity suggests correlation among metric categories, and distance suggests independence. LWD = Large Woody Debris, Riparian = Riparian Characters, Substrate = Stream Substrate.

Redwood National and State Parks

Table 12 provides the summary of mMDS on individual metric categories (e.g., Channel Morphology, Habitat Complexity, etc.), the number of significant groups, and key summary notes. More detailed results and interpretation for the mMDS are provided in Appendix E, with figures showing cluster and group significance and mMDS ordination.

Table 12. Significant groupings within metric categories to identify stream classifications from 27 stream reaches in Redwood National and State Parks.

Metric Category	Number of Significant Groups	Key Notes
Channel Morphology	9	Thalweg depth is the main separator of groups
Habitat Complexity	7	Redwood Creek sites were all in the low complexity group
Large Woody Debris	8	Most sites in single group of relatively low woody debris
Riparian Composition	10	No clear pattern of separation

Table 12 (continued). Significant groupings within metric categories to identify stream classifications from 27 stream reaches in Redwood National and State Parks.

Metric Category	Number of Significant Groups	Key Notes
Slope and Sinuosity	7	No clear findings
Stream Substrate	6	One creek (McArthur Creek) notable for high amounts of fine sediment
Water Chemistry	5	One group of Redwood Creek sites was high in sulfate; another group of multiple creeks was high in chloride
Water Quality	5	Redwood Creek sites all higher in temperature

Within the sampled streams of Redwood National and State Parks (NSP), Large Woody Debris, Habitat Complexity, and Slope and Sinuosity demonstrated some correlative affinity (Table 13, Figure 7). The strongest correlation was between Large Woody Debris and Slope and Sinuosity, with a Spearman's rho of 0.631. This suggests that steeper streams in Redwood NSP may have relatively higher amounts of woody debris, but since this protocol does not include slopes higher than 15%, this relationship may not hold at all stream gradients. If this is important to park managers, I recommend follow-up studies that target higher gradient streams and investigate the causative mechanism.

Also note that the substrate metrics in Redwood NSP seem uncorrelated to any of the other categories, suggesting relative independence.

Table 13. Spearman rho correlations for Redwood National and State Parks metric categories. As a correlation matrix, only the bottom half of the table is displayed. Each value represents the correlation between two different metric categories, with large positives indicating that high values in one metric correspond with high values in the second group—they are positively related. High negative values (e.g., close to -1) indicate the low values in one metric correspond with high values in the second group—they are inversely related. Values close to zero indicate no appreciable correspondence between the metric categories.

Metric Category	Channel Morphology	Habitat Complexity	Large Woody Debris	Riparian Characters	Slope and Sinuosity	Stream Substrate	Water Chemistry
Habitat Complexity	0.092	–	–	–	–	–	–
Large Woody Debris	-0.145	0.372	–	–	–	–	–
Riparian Characters	0.305	0.247	0.033	–	–	–	–
Slope and Sinuosity	-0.052	0.336	0.631	0.162	–	–	–
Stream Substrate	-0.158	0.065	0.006	-0.198	-0.086	–	–
Water Chemistry	0.266	0.195	0.034	0.278	0.045	0.325	–
Water Quality	0.416	0.178	-0.031	0.325	-0.046	0.015	0.345

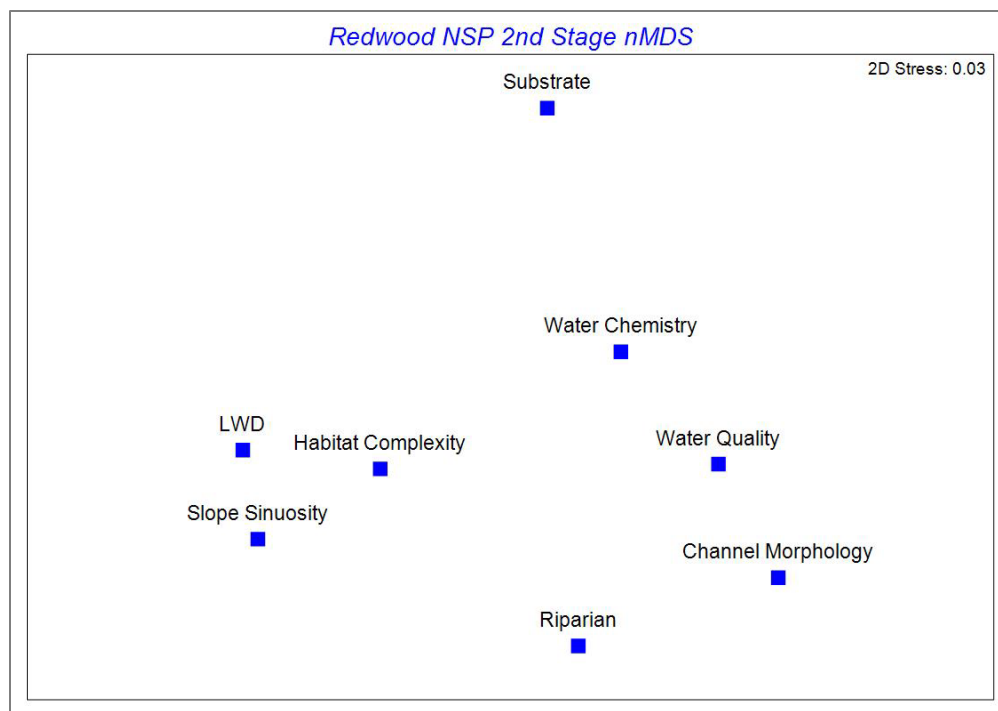


Figure 7. Relationships among metric categories of sampled stream reaches for Redwood National and State Parks. Proximity suggests correlation among metric categories, and distance suggests independence. LWD = Large Woody Debris, Riparian = Riparian Characters, Substrate = Stream Substrate.

Whiskeytown National Recreation Area

Table 14 provides the summary of mMDS on individual metric categories (e.g., Channel Morphology, Habitat Complexity, etc.), the number of significant groups, and key summary notes. More detailed results and interpretation for the mMDS are provided in Appendix F, with figures showing cluster and group significance and mMDS ordination.

Table 14. Significant groupings within metric categories to identify stream classifications from 22 stream reaches in Whiskeytown National Recreation Area.

Metric Category	Number of Significant Groups	Key Notes
Channel Morphology	2	All sites within a single group, except for one very deep site (Clear Creek)
Habitat Complexity	6	Of the six groups, one was most notable because its three members (Clear Creek, Willow Creek, and Whiskey Creek) were all characterized by low complexity
Large Woody Debris	7	Most groups had low amounts of debris, with only subtle differences among groups
Riparian Composition	9	Most sites had high amounts of cover

Table 14 (continued). Significant groupings within metric categories to identify stream classifications from 22 stream reaches in Whiskeytown National Recreation Area.

Metric Category	Number of Significant Groups	Key Notes
Slope and Sinuosity	3	Most sites fell into one large group
Stream Substrate	7	Most groups associated with high amounts of large substrates
Water Chemistry	6	One group of two sites on Willow Creek was high in nutrients and salts
Water Quality	1	All sites relatively homogeneous

Relationships between metric categories for Whiskeytown National Recreation Area were largely subtle (Figure 8, Table 15). Water Chemistry, Water Quality, and Slope and Sinuosity appear correlated, possibly because some of the lower gradient streams (e.g., Willow Creek and Whiskey Creek) share high salt concentrations. Similar to other parks of the network, Stream Substrate metrics are only weakly associated with other metric categories, suggesting the relative independence of particle size from other factors, such as stream gradient or structure. Large Woody Debris, Habitat Complexity, and Riparian Character metrics are also correlated, suggesting that well-developed riparian zones of Whiskeytown streams promote both the structure provided by Large Woody Debris and Habitat Complexity.

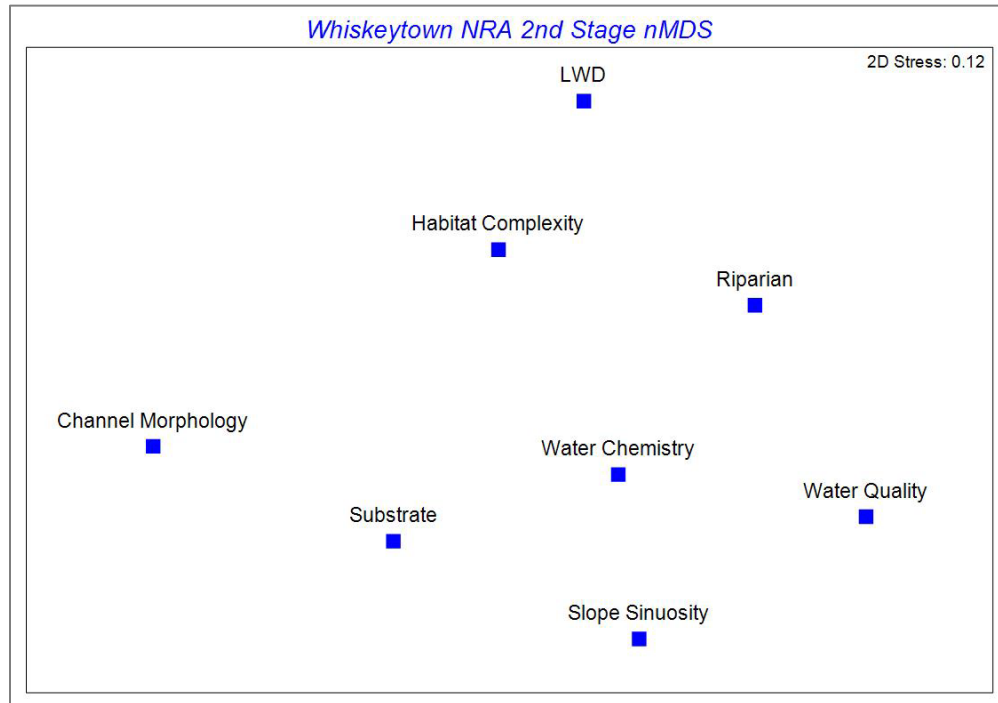


Figure 8. Relationships among metric categories of sampled stream reaches for Whiskeytown National Recreation Area. Proximity suggests correlation among metric categories, and distance suggests independence. LWD = Large Woody Debris, Riparian = Riparian Characters, Substrate = Stream Substrate.

Table 15. Spearman rho correlations for Whiskeytown National Recreation Area metric categories. As a correlation matrix, only the bottom half of the table is displayed. Each value represents the correlation between two different metric categories, with large positives indicating that high values in one metric correspond with high values in the second group—they are positively related. High negative values (e.g., close to -1) indicate the low values in one metric correspond with high values in the second group—they are inversely related. Values close to zero indicate no appreciable correspondence between the metric categories.

Metric Category	Channel Morphology	Habitat Complexity	Large Woody Debris	Riparian Characters	Slope and Sinuosity	Stream Substrate	Water Chemistry
Habitat Complexity	0.057	–	–	–	–	–	–
Large Woody Debris	0.082	0.317	–	–	–	–	–
Riparian Characters	-0.030	0.323	0.318	–	–	–	–
Slope and Sinuosity	0.089	-0.005	0.037	0.177	–	–	–
Stream Substrate	0.155	0.161	0.140	0.076	0.250	–	–
Water Chemistry	0.022	0.329	0.080	0.221	0.155	0.276	–
Water Quality	-0.146	0.019	0.104	0.307	0.316	0.047	0.484

Inter-Park Comparisons

Channel Morphology

Ordination of park stream sites based on Channel Morphology shows that Redwood NSP has the greatest variation in stream channel morphology (Figure 9). The sites plotted on the left of the ordination are on Redwood Creek, indicating that Channel Morphology of these streams is largely unique in the Klamath Network. Aside from Oregon Caves NMP, with only three sites, the park with the least variation was Whiskeytown NRA. While most parks were significantly different from each other (due to large sample sizes), Crater Lake NP was the most different from Whiskeytown NRA (R statistic of 0.466) (Table 16). Oregon Caves NMP was not significantly different from any other park and was the most similar to Redwood NSP (R statistic of -0.061).

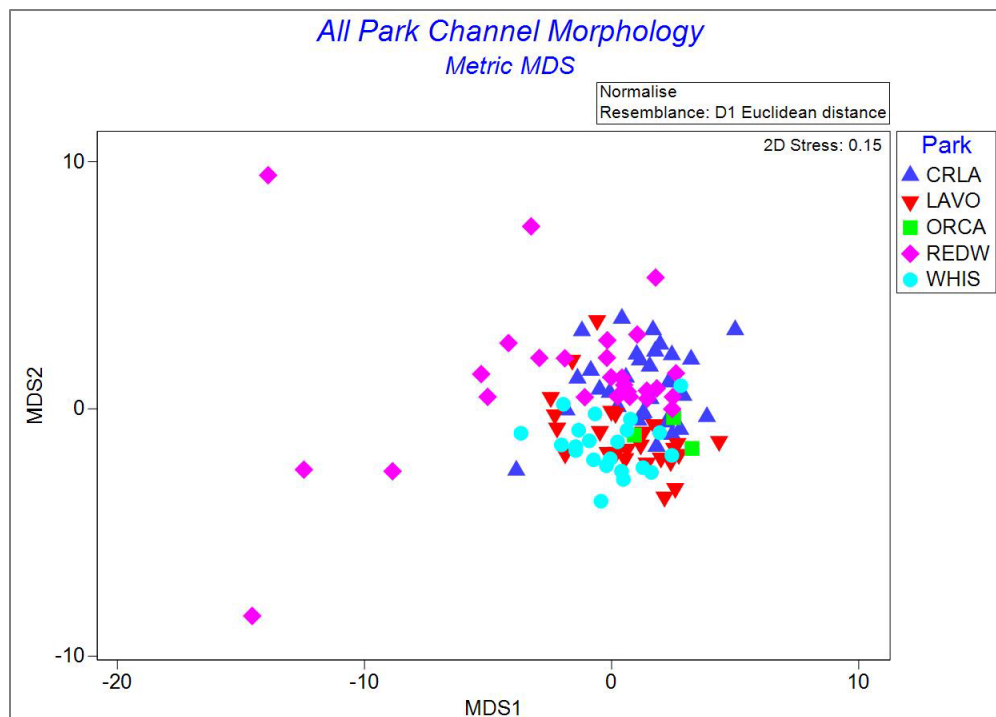


Figure 9. Ordination of Klamath Network park stream sites using channel morphology metrics to show how parks and sites relate to each other. Dots in close proximity are more similar and dots farther from one another are dissimilar. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA.)

Table 16. Analysis of Similarity (ANOSIM) pair-wise comparisons for Klamath Network parks based on channel morphology. The R statistic is a measure of how different parks are (high value indicates larger differences). Inter-park comparisons are sorted based on largest differences first. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA).

Parks	R Statistic	Sig Level
CRLA, WHIS	0.466	0.001
CRLA, LAVO	0.29	0.001
LAVO, REDW	0.256	0.001
ORCA, WHIS	0.244	0.107
LAVO, WHIS	0.189	0.002
REDW, WHIS	0.189	0.001
CRLA, REDW	0.161	0.001
CRLA, ORCA	0.095	0.263
LAVO, ORCA	0.059	0.322
ORCA, REDW	-0.061	0.548

Habitat Complexity

While ordination of park stream sites based on Habitat Complexity shows relatively similar levels of variation within each of the parks, Crater Lake NP had slightly more variation and Whiskeytown NRA had the least amount of variation (Figure 10.) The Crater Lake stream site to the left of the figure is Rogue River site CRLAWQ04 in the northwest portion of the park. The high amount of overlap across parks suggests that parks are largely similar in terms of overall Habitat Complexity, demonstrated by low R statistics. The strongest indicator of parks differing in Habitat Complexity was between Redwood NSP and Whiskeytown NRA, with an R of 0.134 (Table 17).

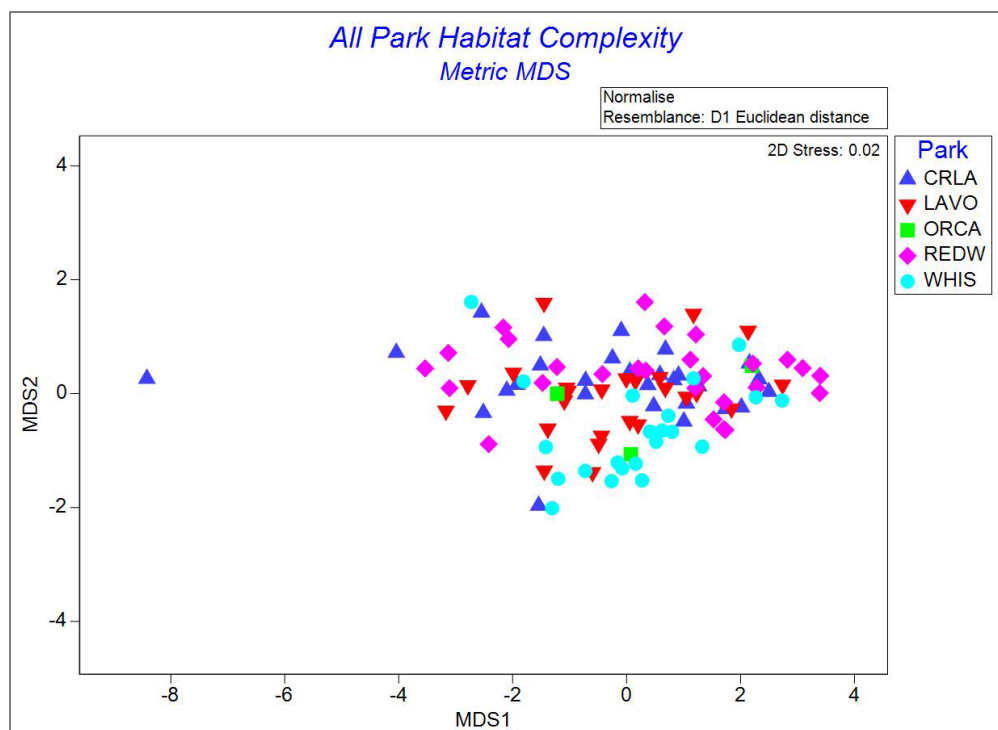


Figure 10. Ordination of Klamath Network park stream sites using habitat complexity metrics to show how parks and sites relate to each other. Dots in close proximity are more similar and dots farther from one another are dissimilar. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA.)

Table 17. Analysis of Similarity (ANOSIM) pair-wise comparisons for Klamath Network parks based on habitat complexity. The R statistic is a measure of how different parks are (high value indicates larger differences). Inter-park comparisons are sorted based on largest differences first. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA).

Parks	R Statistic	Sig Level
REDW, WHIS	0.134	0.004
CRLA, WHIS	0.117	0.004
ORCA, WHIS	0.076	0.322
LAVO, REDW	0.068	0.041
LAVO, WHIS	0.061	0.037
CRLA, REDW	0.02	0.166
CRLA, LAVO	0.005	0.33
CRLA, ORCA	-0.008	0.464
LAVO, ORCA	-0.011	0.537
ORCA, REDW	-0.038	0.561

Large Woody Debris

Ordination of park stream sites based on Large Woody Debris (LWD) shows that Whiskeytown NRA has relatively low variation, relative to the other parks (Figure 11). Crater Lake NP and Redwood NSP both exhibit large amounts of spread, indicating a variety of LWD in their park streams. The Crater Lake NP site on the lower left of the figure is the Rogue River (CRLAWQ04), and the Redwood NSP site in the upper left is Bond Creek (REDWWQ29), both of which have large amounts of LWD. The largest difference in parks is between Oregon Caves NMP and Whiskeytown NRA, with an R statistic of 0.738. This was a significant difference, even accounting for the low sample size from Oregon Caves (Table 18). Comparisons between Crater Lake NP and Lassen Volcanic NP, as well as Lassen Volcanic NP and Redwood NPS, also showed significant differences, but with very small R statistics, 0.048 and 0.051, indicating subtle, small differences that are probably not “biologically significant.”

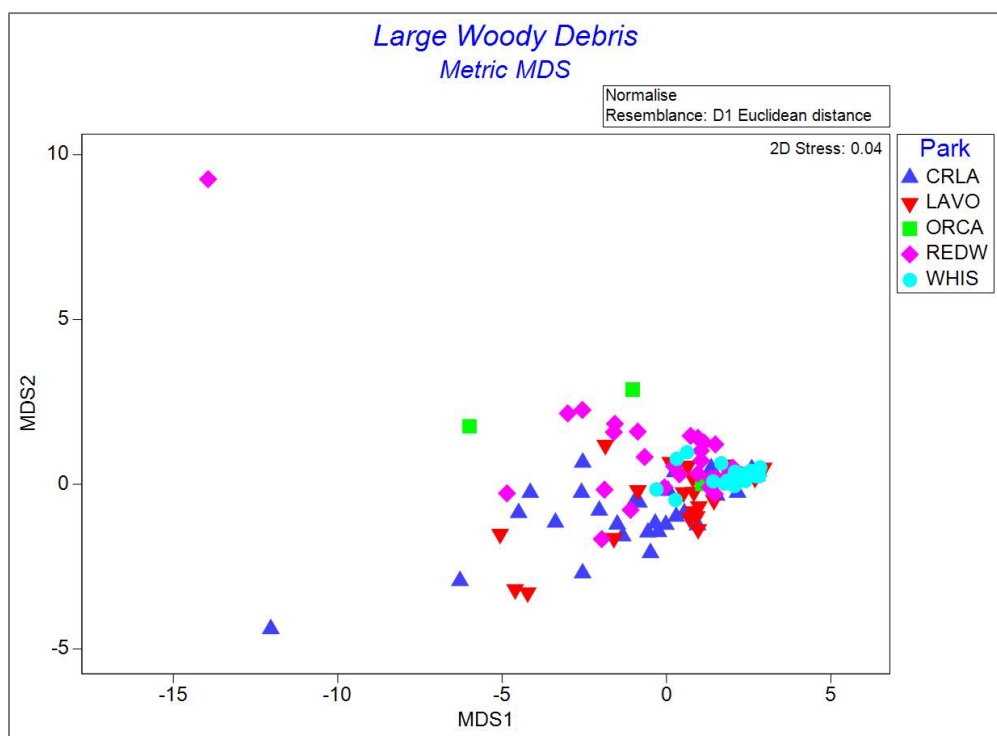


Figure 11. Ordination of Klamath Network park stream sites using Large Woody Debris metrics to show how parks and sites relate to each other. Dots in close proximity are more similar and dots farther from one another are dissimilar. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA.)

Table 18. Analysis of Similarity (ANOSIM) pair-wise comparisons for Klamath Network parks based on Large Woody Debris. The R statistic is a measure of how different parks are (high value indicates larger differences). Inter-park comparisons are sorted based on largest differences first. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA).

Parks	R Statistic	Sig Level
ORCA, WHIS	0.738	0.006
LAVO, ORCA	0.338	0.081
CRLA, ORCA	0.307	0.063
ORCA, REDW	0.251	0.136
CRLA, WHIS	0.215	0.001
REDW, WHIS	0.183	0.001
CRLA, REDW	0.091	0.011
LAVO, WHIS	0.08	0.002
LAVO, REDW	0.051	0.035
CRLA, LAVO	0.048	0.048

Riparian Characteristics (Characters)

Ordination of park stream sites based on Riparian Characters shows Whiskeytown NRA as largely distinct, with some overlap with Redwood NSP streams (Figure 12). Crater Lake NP and Lassen Volcanic NP sites have a large amount of overlap. Oregon Caves NMP streams are most similar to Lassen Volcanic NP and Crater Lake NP stream sites. The largest difference between parks was between Whiskeytown NRA and Crater Lake NP ($R = 0.755$, Table 19). The two parks with the least differences were Oregon Caves NMP and Lassen Volcanic NP).

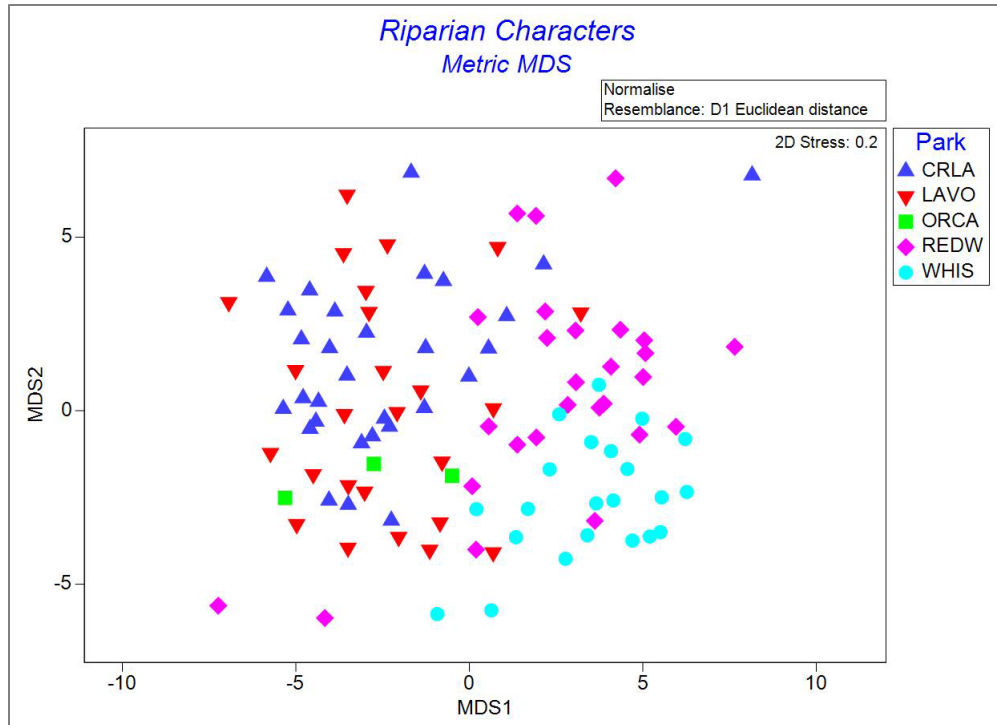


Figure 12. Ordination of Klamath Network park stream sites using riparian character metrics to show how parks and sites relate to each other. Dots in close proximity are more similar and dots farther from one another are dissimilar. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA.)

Table 19. Analysis of Similarity (ANOSIM) pair-wise comparisons for Klamath Network parks based on Riparian Characters. The R statistic is a measure of how different parks are (high value indicates larger differences). Inter-park comparisons are sorted based on largest differences first. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA).

Parks	R Statistic	Sig Level
CRLA, WHIS	0.755	0.001
ORCA, WHIS	0.729	0.003
LAVO, WHIS	0.649	0.001
CRLA, REDW	0.559	0.001
LAVO, REDW	0.536	0.001
ORCA, REDW	0.395	0.042
REDW, WHIS	0.274	0.001
CRLA, LAVO	0.098	0.002
CRLA, ORCA	0.055	0.33
LAVO, ORCA	-0.063	0.591

Slope and Sinuosity

Parks largely overlap in Slope and Sinuosity, which is probably influenced by the limited sampling frame that confined the slope of streams to under 15%. Stream sites within Oregon Caves NMP were the exception to this sampling frame. Figure 13 shows these Oregon Caves NMP sites as largely distinct from other parks, being steeper than those generally selected. Oregon Caves NMP sites were strongly distinct from the other parks in pair-wise comparisons ($R = 0.999$ between Oregon Caves NMP and Lassen Volcanic NP, for example) (Table 20). Other park comparisons were also often significantly different but had low R values, which indicates statistical significance but low biological significance.

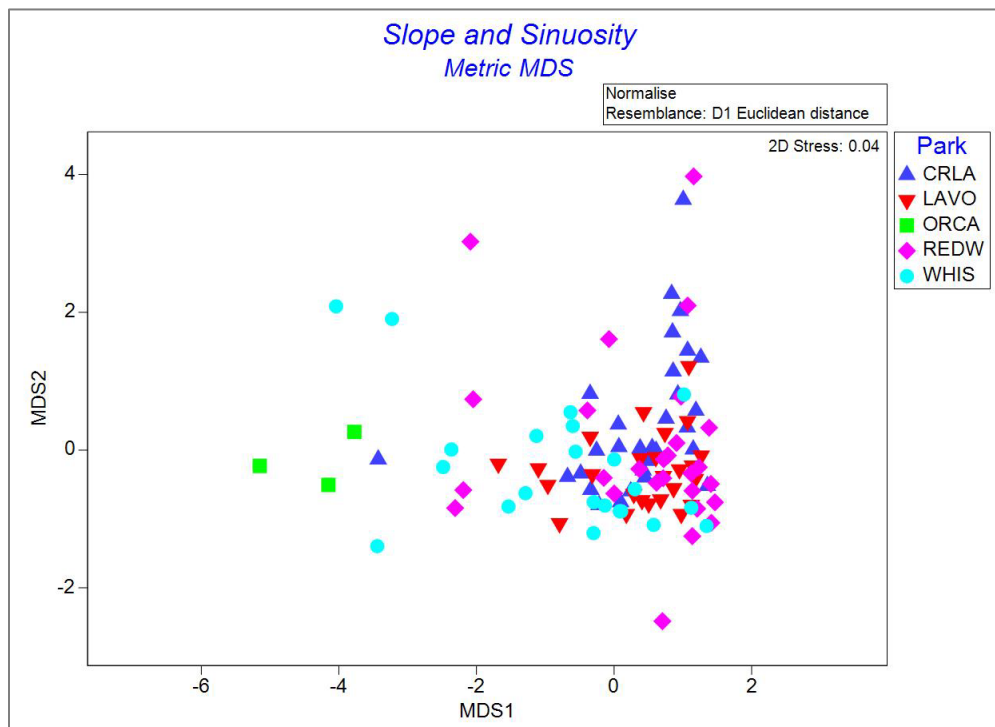


Figure 13. Ordination of Klamath Network park stream sites using Slope and Sinuosity metrics to show how parks and sites relate to each other. Dots in close proximity are more similar and dots farther from one another are dissimilar. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA.)

Table 20. Analysis of Similarity (ANOSIM) pair-wise comparisons for Klamath Network parks based on Slope and Sinuosity. The R statistic is a measure of how different parks are (high value indicates larger differences). Inter-park comparisons are sorted based on largest differences first. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA).

Parks	R Statistic	Sig Level
LAVO, ORCA	0.999	0.003
CRLA, ORCA	0.928	0.001
ORCA, REDW	0.866	0.001
ORCA, WHIS	0.669	0.002
CRLA, WHIS	0.175	0.001
LAVO, WHIS	0.138	0.001
REDW, WHIS	0.103	0.006
CRLA, REDW	0.064	0.016
CRLA, LAVO	0.048	0.6
LAVO, REDW	-0.002	0.447

Stream Substrate

Park streams sorted into largely distinct groups based on Stream Substrate, with some overlap between parks. Stream sites on the right of the ordination are generally characterized by smaller sediments, and the streams on the left are characterized by larger sediments (Figure 14). Two Oregon Caves NMP streams had the highest substrate size. Although all parks were different from each other, the largest difference was between Oregon Caves NMP and Crater Lake NP ($R = 0.828$). The smallest difference in the parks was between Crater Lake NP and Lassen Volcanic NP ($R = 0.172$) (Table 21). Other than Oregon Caves NMP, Whiskeytown NRA had the greatest amount of variation in their streams.

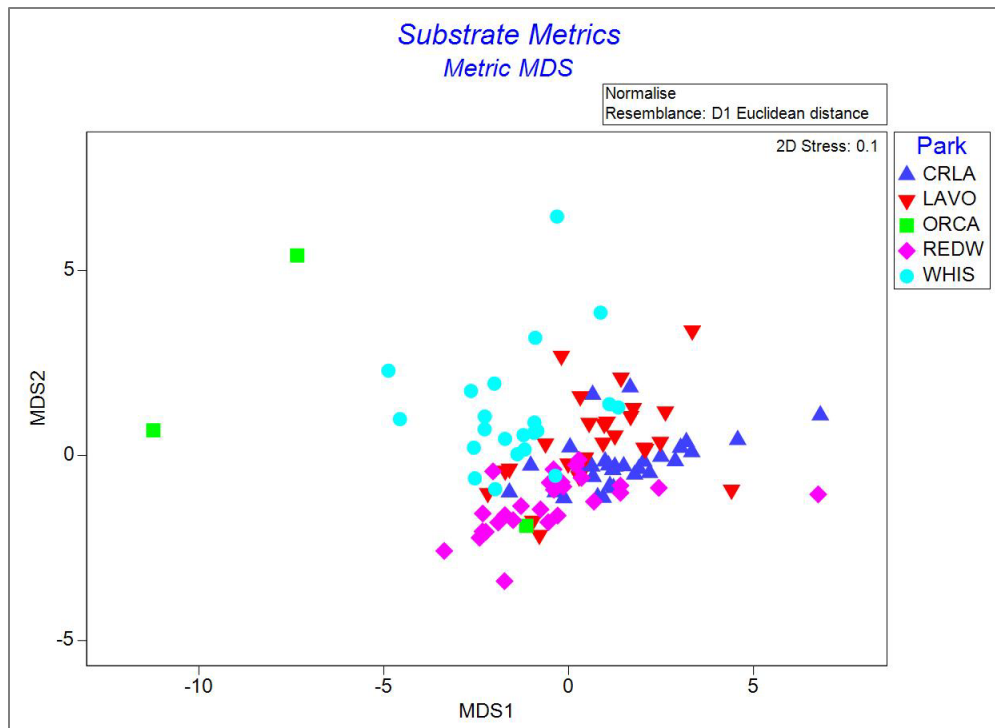


Figure 14. Ordination of Klamath Network park stream sites using Stream Substrate metrics to show how parks and sites relate to each other. Dots in close proximity are more similar and dots farther from one another are dissimilar. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA.)

Table 21. Analysis of Similarity (ANOSIM) pair-wise comparisons for Klamath Network parks based on Substrate metrics. The R statistic is a measure of how different parks are (high value indicates larger differences). Inter-park comparisons are sorted based on largest differences first. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA.)

Parks	R Statistic	Sig Level
CRLA, ORCA	0.828	0.001
LAVO, ORCA	0.773	0.001
ORCA, WHIS	0.697	0.008
ORCA, REDW	0.581	0.017
CRLA, WHIS	0.462	0.001
REDW, WHIS	0.303	0.001
CRLA, REDW	0.288	0.001
LAVO, WHIS	0.274	0.001
LAVO, REDW	0.269	0.001
CRLA, LAVO	0.172	0.001

Water Chemistry

Most parks had discrete stream groupings based on Water Chemistry, with only some overlap (Figure 15). The exception was Oregon Caves NMP, with low significance and low R values in comparisons with other parks (Table 22). The largest difference (with the highest R value) was between Crater Lake NP and Redwood NSP. Additionally, the park with the highest variation in Water Chemistry was Whiskeytown NRA, and Oregon Caves NMP had the least variation. Variation in Whiskeytown NRA is likely caused by higher cation and anion concentrations in its watershed with historical acid mine drainages.

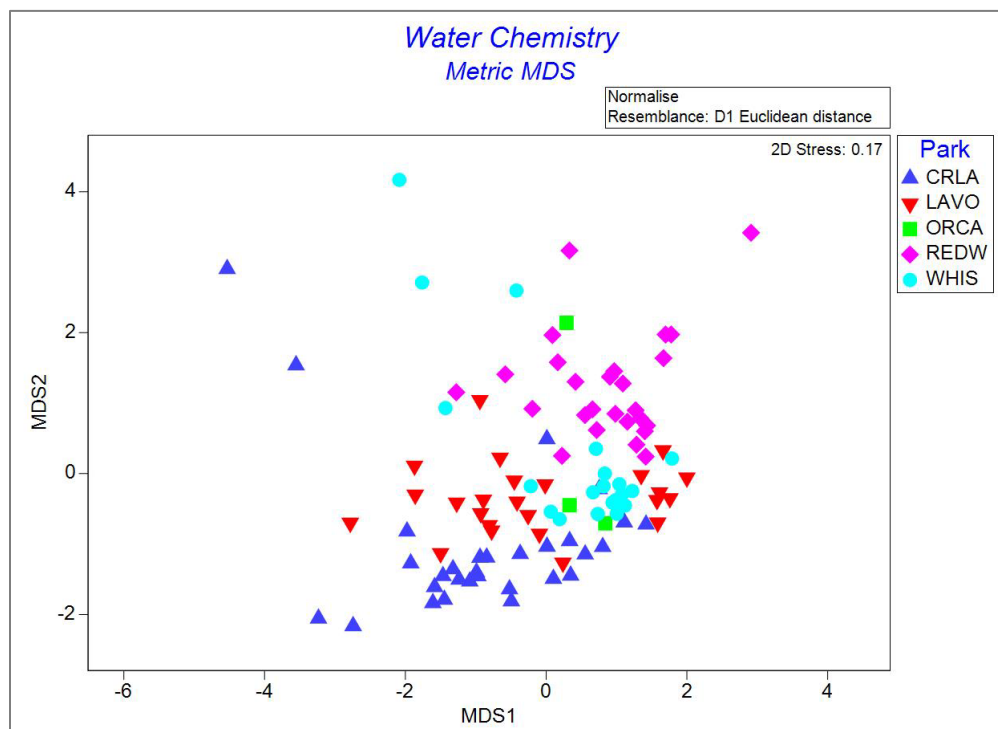


Figure 15. Ordination of Klamath Network park stream sites using Water Chemistry metrics to show how parks and sites relate to each other. Dots in close proximity are more similar and dots farther from one another are dissimilar. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA.)

Table 22. Analysis of Similarity (ANOSIM) pair-wise comparisons for Klamath Network parks based on Water Chemistry. The R statistic is a measure of how different parks are (high value indicates larger differences). Inter-park comparisons are sorted based on largest differences first. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA.)

Parks	R Statistic	Sig Level
CRLA, REDW	0.579	0.001
LAVO, REDW	0.395	0.001
CRLA, WHIS	0.303	0.001

Table 22 (continued). Analysis of Similarity (ANOSIM) pair-wise comparisons for Klamath Network parks based on Water Chemistry. The R statistic is a measure of how different parks are (high value indicates larger differences). Inter-park comparisons are sorted based on largest differences first. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA.)

Parks	R Statistic	Sig Level
ORCA, REDW	0.249	0.15
REDW, WHIS	0.233	0.001
CRLA, ORCA	0.212	0.137
LAVO, WHIS	0.139	0.003
ORCA, WHIS	0.136	0.244
CRLA, LAVO	0.117	0.002
LAVO, ORCA	0.006	0.441

Water Quality

Most parks sorted into distinct groupings based on Water Quality metrics such as dissolved oxygen, temperature, and conductivity. One notable overlap was between Crater Lake NP and Lassen Volcanic NP (Figure 16), which had the lowest R value (0.186, Table 23), indicating the lowest separation. One site from Oregon Caves NMP, Lake Creek, was similar to Crater Lake NP and Lassen Volcanic NP, but the other two sites were isolated. Crater Lake NP and Whiskeytown NRA were the most dissimilar (outside of Oregon Caves, with its low sample size), with an R value of 0.619. Across the parks, Whiskeytown NRA had the most variation, whereas Redwood NSP had the lowest variation.

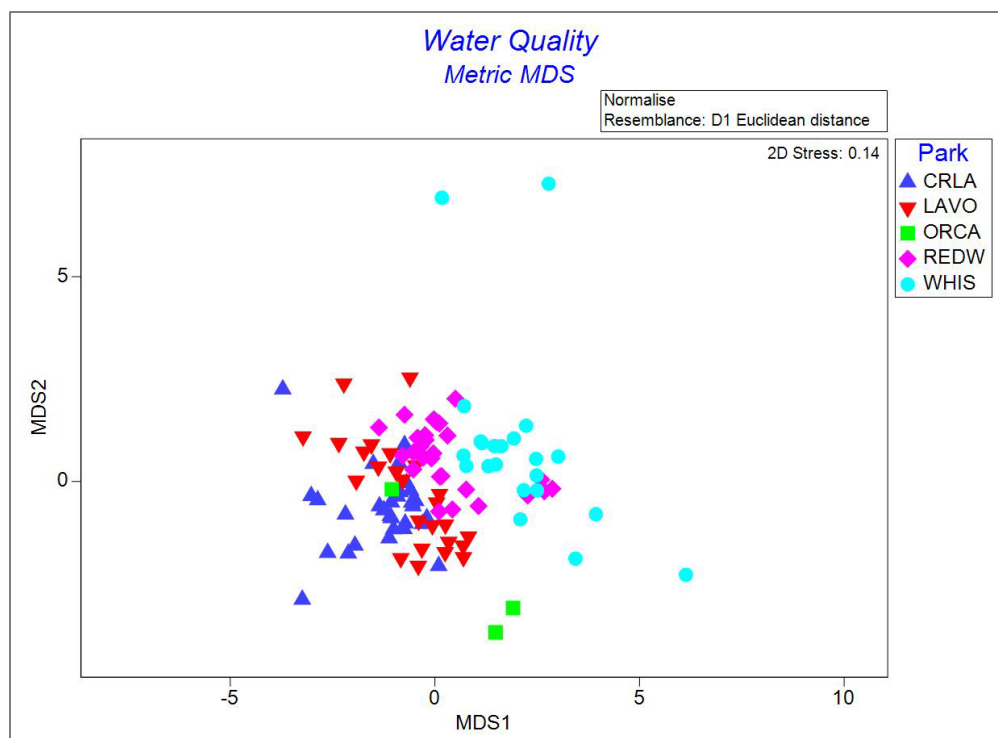


Figure 16. Ordination of Klamath Network park stream sites using Water Quality metrics to show how parks and sites relate to each other. Dots in close proximity are more similar and dots farther from one another are dissimilar. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwoods NSP, and WHIS = Whiskeytown NRA.)

Table 23. Analysis of Similarity (ANOSIM) pair-wise comparisons for Klamath Network parks based on Water Quality. The R statistic is a measure of how different parks are (high value indicates larger differences). Inter-park comparisons are sorted based on largest differences first. (CRLA = Crater Lake NP, LAVO = Lassen Volcanic NP, ORCA = Oregon Caves NMP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA.)

Parks	R Statistic	Sig Level
ORCA, REDW	0.715	0.005
CRLA, WHIS	0.619	0.001
LAVO, WHIS	0.546	0.001
LAVO, ORCA	0.483	0.013
CRLA, ORCA	0.475	0.027
ORCA, WHIS	0.441	0.052
CRLA, REDW	0.429	0.001
LAVO, REDW	0.372	0.001
REDW, WHIS	0.36	0.001
CRLA, LAVO	0.186	0.001

Conclusions

Streams have been categorized based on geomorphology or other habitat characters over large regions or countries (e.g., from headwaters to oceans; Vannote et al. 1980) and in small scale habitat type classifications (e.g., pools vs. riffles, depositional vs. erosional; Harper and Ferguson 1995). These classifications of streams and habitat types often correlate with biotic assemblages or species, both for vertebrates (Bond and Lake 2003) and invertebrates (Hawkins 1984). The exploratory categorization of Klamath Network park streams in this report 1) serves as a tool for understanding the diversity of stream types within park units, 2) provides potential strata for understanding and detecting trends in the future, and 3) lays a foundation for future understanding of biological assemblages within and across park units. As more data are collected, upcoming reports will make use of the strata for trends over time and seek to link stream types to biological assemblages.

This report identifies the diversity of streams within Klamath Network parks, but fully understanding diversity (be it in geomorphology, woody debris, water chemistry, or other) depends on knowing the why—why is the key to understanding and advancing ecological knowledge of the park. The “why,” however, may be a combination of factors, such as past management history, geology, soils, vegetation types, aspect, or other edaphic variables. Although an analysis that identifies the “why” for observed patterns described here is beyond the immediate scope of this report, this report sets the stage for future work into the “why.”

A core goal of the NPS Inventory and Monitoring Program is to detect and understand trends so that managers may then use the information within a Resist-Accept-Direct framework (Schuurman et al. 2020) to make natural resource management decisions. Detecting trends is complicated by high variation caused by sampling limitations (e.g., return intervals, sample sizes, etc.). The use of strata (or blocking variables) in the statistical analysis of trends can improve power to detect trends across the strata when trends vary between the strata. Providing potential *a priori* strata (whose trends may differ) can suggest analytical choices for future trend work. Another way to apply our stream classification analyses is that the resulting strata can be utilized as potential covariates in trend detection. An example of how one metric group may influence trends is the question: Do fine sediments increase over time in strata with high amounts of woody debris?

Lastly, the physical habitat and chemical composition of streams are the basis for their biology (e.g., Dunbar et al. 2010). Due to the linkages, changes and patterns in habitat variables affect the biodiversity of streams. The findings of this “basic” baseline report and exploratory data analysis likewise can be applied to increase understanding of biological communities and detect trends.

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Appendix A. Metrics and Groups

Appendix A describes the metrics (Tables 24–31) used for calculations and briefly describes why each metric was included in the analyses.

Table 24. Metrics for group-based analysis of Channel Morphology measures in Klamath Network parks. SD = standard deviation.

Metric	Description	Rationale/Purpose
Percent Fast Habitat	Percent of channel composed of riffle, rapid, cascades, or falls	Basic geomorphology descriptors
Percent Slow Habitat	Percent of channel composed of glides or pools	Basic geomorphology descriptors
Percent Pools	Percent of channel composed of pool habitat	Basic geomorphology descriptors
Mean Thalweg Depth	Mean depth of the deepest part of the stream channel	Basic geomorphology descriptors
Thalweg Depth SD	Variation in the thalweg depth	Increased variation suggests increased habitat complexity
Mean Wetted Width	Mean width of the stream	Basic geomorphology descriptors
Wetted Width SD	Variation in the mean stream width	Increased variation suggests increased habitat complexity
Mean Cross-section	Mean of approximate cross-sectional area (width × depth)	Basic geomorphology descriptors
Cross-section SD	Variation in the cross-sectional area	Increased variation suggests increased habitat complexity
Mean width/depth	Mean ratio of the stream width to depth	Basic geomorphology descriptors
Width/Depth SD	Variation in the ratio of the stream width to depth	Increased variation suggests increased habitat complexity
Mean Bank Angle	Mean angle of the stream bank	Basic geomorphology descriptors
Mean Bankfull Width	Mean width of the stream at bankfull	Basic geomorphology descriptors
Mean Bankfull Height	Mean height of the stream at bankfull	Basic geomorphology descriptors
Mean Bankfull Incised Height	Mean height of the stream incision	Basic geomorphology descriptors

Table 25. Metrics for group-based analysis of Habitat Complexity measures in Klamath Network parks.

Metric	Description	Rationale/Purpose
In-Stream Habitat Cover for All Classes	Summed areal coverage of in-stream habitat components	Measures complexity within a stream, with high values occurring only with multiple components
In-Stream Habitat Cover Big (Boulder, Wood, etc.)	Summed areal coverage of large natural covers (e.g., excludes brush)	Measures complexity within a stream, with high values occurring only with large components

Table 25 (continued). Metrics for group-based analysis of Habitat Complexity measures in Klamath Network parks.

Metric	Description	Rationale/Purpose
In-Stream Habitat Cover for Natural Covers	Summed areal coverage of natural covers (excludes concrete and artificial)	Measures complexity within a stream, with high values occurring only for high amounts of natural components
In-Stream Habitat Complexity, EPA metric	EPA-used metric for assessing habitat complexity condition	Applicable to EPA established condition thresholds

Table 26. Metrics for group-based analysis of Large Woody Debris (LWD) measures in Klamath Network parks.

Metric	Description	Rationale/Purpose
Large Woody Debris in the Active Stream Channel, Size Class 1	LWD inside the bankfull channel of all sized pieces	LWD provides habitat and structure to stream channel
Large Woody Debris in the Active Stream Channel, Size Class 2	LWD inside the bankfull channel of only Small to Extra Large pieces	LWD provides habitat and structure to stream channel
Large Woody Debris in the Active Stream Channel, Size Class 3	LWD inside the bankfull channel of only Medium to Extra Large pieces	LWD provides habitat and structure to stream channel
Large Woody Debris in the Active Stream Channel, Size Class 4	LWD inside the bankfull channel of only Large and Extra Large pieces	LWD provides habitat and structure to stream channel
Large Woody Debris in the Active Stream Channel, Size Class 5	LWD inside the bankfull channel of only Extra Large pieces	LWD provides habitat and structure to stream channel
Large Woody Debris in and above the Stream Channel, Size Class 1	LWD inside and above the bankfull channel of all sized pieces	LWD provides habitat and structure to stream channel
Large Woody Debris in and above the Stream Channel, Size Class 2	LWD inside and above the bankfull channel of only Small to Extra Large pieces	LWD provides habitat and structure to stream channel
Large Woody Debris in and above the Stream Channel, Size Class 3	LWD inside and above the bankfull channel of only Medium to Extra Large pieces	LWD provides habitat and structure to stream channel
Large Woody Debris in and above the Stream Channel, Size Class 4	LWD inside and above the bankfull channel of only Large and Extra Large pieces	LWD provides habitat and structure to stream channel
Large Woody Debris in and above the Stream Channel, Size Class 5	LWD inside and above the bankfull channel of only Extra Large pieces	LWD provides habitat and structure to stream channel

Table 27. Metrics for group-based analysis of Riparian Character habitat measures in Klamath Network parks.

Metric	Description	Rationale/Purpose
Mean Channel Shading	Mean shading in center of stream channel determined by densiometer	Descriptor of the actual overhead vegetation on the stream channel
Mean Bank Shading	Mean shading along banks of stream channel determined by densiometer	Descriptor of the actual overhead vegetation on the stream channel
Mean Cover of Large Canopy Trees	Mean area covered by large diameter trees over 5 meters	Basic descriptor of the amount of riparian vegetation
Mean Cover of Small Canopy Trees	Mean area covered by small diameter trees over 5 meters	Basic descriptor of the amount of riparian vegetation
Mean Cover of Mid-Story Woody Vegetation	Mean area covered by woody trees between 0.5 and 5 meters	Basic descriptor of the amount of riparian vegetation
Mean Cover of Mid-Story Herbaceous Vegetation	Mean area covered by herbaceous vegetation between 0.5 and 5 meters	Basic descriptor of the amount of riparian vegetation
Mean Cover of Groundcover Woody Vegetation	Mean area covered by woody vegetation under 0.5 meters	Basic descriptor of the amount of riparian vegetation
Mean Cover of Groundcover Herbaceous Vegetation	Mean area covered by herbaceous vegetation under 0.5 meters	Basic descriptor of the amount of riparian vegetation
Mean Cover of Bare Groundcover	Mean area covered by barren ground	Basic descriptor of the amount of riparian vegetation
Mean Cover of All Canopy	Mean area covered by all canopy vegetation	Basic descriptor of the amount of riparian vegetation
Mean Cover of All Mid-Story	Mean area covered by all mid-story vegetation	Basic descriptor of the amount of riparian vegetation
Mean Cover of All Groundcover Vegetation	Mean area covered by ground cover vegetation	Basic descriptor of the amount of riparian vegetation
Mean Cover of Canopy and Mid-Story Vegetation	Mean area covered by both canopy and mid-story vegetation	Basic descriptor of the amount of riparian vegetation
Mean Cover of Woody Canopy and Mid-Story Vegetation	Mean area covered by only woody canopy/mid-story vegetation	Basic descriptor of the amount of riparian vegetation
Mean Cover of All Canopy, Mid-Story, and Groundcover Vegetation	Mean area covered by all vegetation at all layers	Basic descriptor of the amount of riparian vegetation
Mean Cover of Woody Canopy, Mid-Story, and Groundcover Vegetation	Mean area covered by only woody vegetation at all layers	Basic descriptor of the amount of riparian vegetation
Percent of Canopy Composed of Coniferous Vegetation	Mean percent of the canopy formed by coniferous vegetation	Basic descriptor of the type of riparian vegetation

Table 27 (continued). Metrics for group-based analysis of Riparian Character habitat measures in Klamath Network parks.

Metric	Description	Rationale/Purpose
Percent of Canopy Composed of Deciduous Vegetation	Mean percent of the canopy formed by deciduous vegetation	Basic descriptor of the type of riparian vegetation
Percent of Canopy Composed of Mixed Vegetation	Mean percent of the canopy formed by both coniferous and deciduous vegetation	Basic descriptor of the type of riparian vegetation
Percent of Mid-Story Composed of Coniferous Vegetation	Mean percent of the mid-story formed by coniferous vegetation	Basic descriptor of the type of riparian vegetation
Percent of Mid-Story Composed of Deciduous Vegetation	Mean percent of the mid-story formed by deciduous vegetation	Basic descriptor of the type of riparian vegetation
Percent of Mid-Story Composed of Mixed Vegetation	Mean percent of the mid-story formed by both coniferous and deciduous vegetation	Basic descriptor of the type of riparian vegetation

Table 28. Metrics for group-based analysis of Slope and Sinuosity measures in Klamath Network parks.

Metric	Description	Rationale/Purpose
Sinuosity	The ratio of the length of the stream reach to the straight line distance between the top and bottom of the reach	Basic determinant of stream geomorphology
Slope	Total elevation drop divided by the length of the stream reach	Basic determinant of stream geomorphology
Slope Standard Deviation	Variation of the slope between transects	Increased variation suggests increased habitat complexity

Table 29. Metrics for group-based analysis of Stream Substrate measures in Klamath Network parks. SD = standard deviation.

Metric	Description	Rationale/Purpose
Mean Substrate Size Class	Mean substrate size (mm)	Basic measure of streambed, but influenced by extremely large substrates
SD Substrate Size Class	Standard deviation of substrate size (mm)	Measure of variation in streambed particles
Median Substrate Size Class	Median of substrate (mm)	Basic measure of streambed, but not influenced by extremely large substrates
Percent Coarse Gravel and Bigger	Percent of substrate larger than coarse gravel (size of a marble and larger)	Larger substrates are usually beneficial for stream biota
Percent Fine Gravel and Smaller	Percent of substrate smaller than fine gravel (marble size and smaller)	Smaller substrates tend to impact stream biota negatively

Table 29 (continued). Metrics for group-based analysis of Stream Substrate measures in Klamath Network parks. SD = standard deviation.

Metric	Description	Rationale/Purpose
Percent Fines and Sand	Percent of substrates composed of fine sediment or sand	Smaller substrates tend to impact stream biota negatively
Mean Embeddedness	Mean percent embeddedness	Embeddedness is a measure of how sediments have impacted larger sediments and underlying habitat
SD Embeddedness	Standard deviation of embeddedness	Measure of variation in embeddedness

Table 30. Metrics for group-based analysis of Water Chemistry measures in Klamath Network parks.

Metric	Description	Rationale/Purpose
Mean Total Nitrogen	Mean of single measurement across years	Key nutrient for aquatic ecosystems and indicator of eutrophication
Mean Total Phosphorus	Mean of single measurement across years	Key nutrient for aquatic ecosystems and indicator of eutrophication
Mean Sodium	Mean of single measurement across years	Basic descriptor of water body chemical composition
Mean Potassium	Mean of single measurement across years	Basic descriptor of water body chemical composition
Mean Sulfate	Mean of single measurement across years	Basic descriptor of water body chemical composition
Mean Chloride	Mean of single measurement across years	Basic descriptor of water body chemical composition
Mean Dissolved Organic Carbon	Mean of single measurement across years	Measure of organic matter in water body, and is tied into biological processes

Table 31. Metrics for group-based analysis of Water Quality measures in Klamath Network parks.

Metric	Description	Rationale/Purpose
Mean Temperature	Mean from per reach measurements at seven equidistant points across a transect	Key water quality component that impacts stream biota
Mean Conductivity	Mean from per reach measurements at seven equidistant points across a transect	Key water quality component that impacts stream biota
Mean Dissolved Oxygen (mg/L)	Mean from per reach measurements at seven equidistant points across a transect	Key water quality component that impacts stream biota
Mean Turbidity (NTUs)	Mean from per reach measurements at seven equidistant points across a transect	Key water quality component that impacts stream biota
Mean pH	Mean from per reach measurements at seven equidistant points across a transect	Key water quality component that impacts stream biota

Some metrics are based on a measure of central tendency (i.e., mean). Since variation within a site is an important component of habitat complexity, standard deviation of stream response variables is also used and it reflects the standard deviation at a stream site (and not across all the measured streams within a park). Standard deviation (SD) is calculated as:

$$SD \text{ or } \sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{N}}$$

Where x_i is the individual measured response variable, μ is the mean, and N is the sample size (number of times the response variable was measured at the site).

Appendix B. Missing Data

Table 32 specifies sites with missing data points.

Table 32. Missing metrics not included in stream classification analyses of Klamath Network parks. SD = standard deviation. (LAVO = Lassen Volcanic NP, REDW = Redwood NSP, and WHIS = Whiskeytown NRA.)

Park	Site	Stream Name	Metric Category	Metrics Missing
LAVO	LAVOWQ22	North Arm Rice Creek	Channel Morphology	Cross-section SD, width/depth SD
LAVO	LAVOWQ43	Lost Creek	Channel Morphology	Cross-section SD, width/depth SD, Mean Cross-section, Mean width/depth
LAVO	LAVOWQ43	Lost Creek	Water Chemistry	Turbidity
REDW	REDWWQ12	Little Lost Man Creek	Channel Morphology	Mean width/depth, width/depth SD
REDW	REDWWQ30	West Branch Mill Creek	Channel Morphology	Cross-section SD, width/depth SD, Mean Cross-section, Mean width/depth
WHIS	WHISWQ14	Unnamed Tributary to Brandy Creek	Channel Morphology	Cross-section SD, width/depth SD
WHIS	WHISWQ17	Boulder Creek	Channel Morphology	Cross-section SD, width/depth SD
WHIS	WHISWQ35	Unnamed Tributary to Crystal Creek	Channel Morphology	Cross-section SD, width/depth SD

Appendix C. Crater Lake National Park

This appendix provides analytical figures and brief text summarizing three analyses for the classification of stream groups based on physical and chemical characters. Following a narrative summary of key results, figures for each metric category (e.g., Channel Morphology, Water Quality, Water Chemistry, etc.) are presented that display the cluster analysis, resulting linktree group allocation via simprof, and a metric Multi-Dimensional Scaling (mMDS) ordination. The ordination shows how sites are grouped based on a similarity profile test with 5% significant threshold (SIMPROF5LINK) and is overlaid with lines and lettered groups based on linktree separation characters or a vector biplot, both showing more biologically significant correlations. Lastly, in cases where multiple significant groups occurred (e.g., two or more), a map of the park shows the spatial distribution of groups.

Table 33 shows the name, sampling site code, and coordinates of sites sampled.

Table 33. Site and stream names, location coordinates, and years site was sampled for Crater Lake National Park.

Site Code	Stream Name	Longitude	Latitude	Years Sampled
CRLAWQ01	Cavern Creek	-121.9883371	42.85455303	2012, 2015, 2018
CRLAWQ02	Sun Creek	-122.0470052	42.82790937	2012, 2015, 2018
CRLAWQ03	Sun Creek	-122.0864744	42.86560579	2012, 2015, 2018
CRLAWQ04	Rogue River	-122.2315558	43.06952532	2012, 2018
CRLAWQ05	Wheeler Creek	-122.029067	42.86317602	2012, 2015, 2018
CRLAWQ06	Munson Creek	-122.1440046	42.86714284	2012, 2015, 2018
CRLAWQ07	UT to Vidae	-122.0970693	42.8798496	2012, 2015, 2018
CRLAWQ08	UT to Union Creek	-122.2814508	42.88680034	2012, 2015, 2018
CRLAWQ09	Lost Creek	-122.0392954	42.87938901	2012, 2015, 2018
CRLAWQ10	Annie Creek, Middle Fork	-122.1361394	42.84631763	2012, 2015, 2018
CRLAWQ11	Bybee Creek	-122.2739247	42.93953944	2012, 2015, 2018
CRLAWQ12	Castle Creek	-122.2781111	42.91132289	2012, 2015, 2018
CRLAWQ13	Annie Creek	-122.0708749	42.79379484	2012, 2015, 2018
CRLAWQ14	UT to Munson	-122.1367279	42.89470871	2012, 2015, 2018
CRLAWQ15	UT to Bybee	-122.1976718	42.92903854	2012, 2015, 2018
CRLAWQ16	UT to Bybee	-122.2089598	42.91443775	2012, 2015, 2018
CRLAWQ17	Sand Creek	-122.0119576	42.85771661	2012, 2015, 2018
CRLAWQ19	Crater Creek	-122.2800943	42.98667748	2012
CRLAWQ21	UT to Sand	-122.033526	42.88608648	2012, 2015, 2018
CRLAWQ22	Annie Creek	-122.1297098	42.8384979	2012, 2015, 2018
CRLAWQ26	Munson Creek	-122.1372045	42.87937386	2012, 2015, 2018

Table 33 (continued). Site and stream names, location coordinates, and years site was sampled for Crater Lake National Park.

Site Code	Stream Name	Longitude	Latitude	Years Sampled
CRLAWQ28	UT to Castle	-122.1893804	42.89120746	2012, 2015, 2018
CRLAWQ29	Sand Creek	-121.980731	42.84776995	2012, 2015, 2018
CRLAWQ30	Sun Creek	-122.0423382	42.82360621	2015, 2018
CRLAWQ31	Sun Creek	-122.0788395	42.86183538	2015, 2018
CRLAWQ32	UT to Crater	-122.2652213	43.00212636	2015
CRLAWQ34	Munson Creek	-122.1381907	42.87520769	2012, 2015, 2018
CRLAWQ37	UT to Sand Creek	-122.0336567	42.90737036	2015, 2018
CRLAWQ38	Castle Creek	-122.1665792	42.89412782	2015, 2018
CRLAWQ39	Bybee Creek	-122.2178917	42.92583339	2015, 2018

Key Results

(Numbers in this section reference stream site codes from Table 33.)

Channel Morphology

- Nine groups were distinguished, with four of these groups represented by single streams (Figures 17–18):
 - Rogue River (04) was wide (width greater than 15.7 meters)
 - Unnamed Tributary to Sand Creek (37)(small amounts of thalweg depth variation)
 - Crater Creek (19) (largest amounts of thalweg depth variation)
 - Annie Creek (13) (intermediate width [9.4 meters wide])

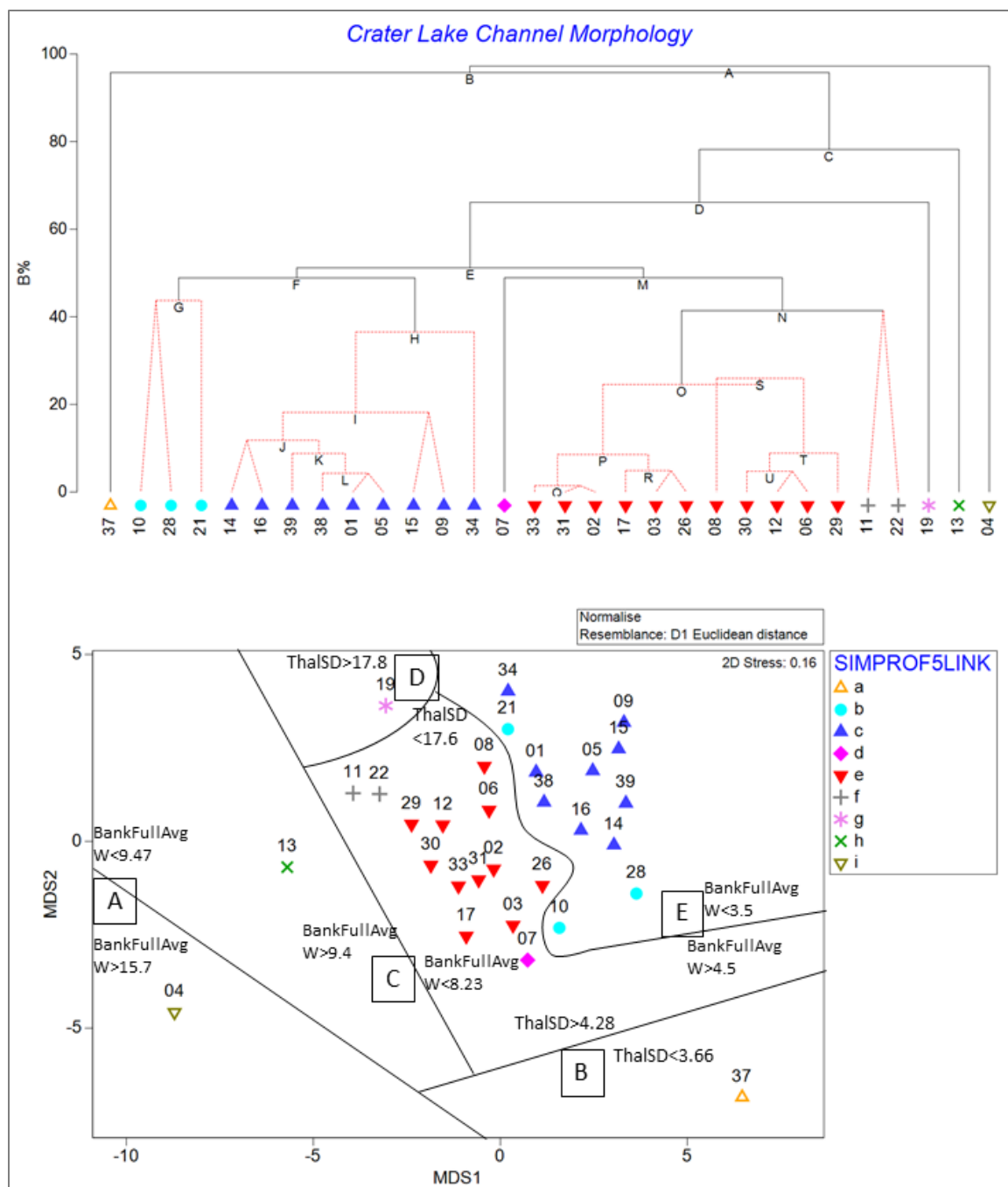


Figure 17. Stream classification results for Crater Lake National Park based on Channel Morphology metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Letters A–E indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A–E are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

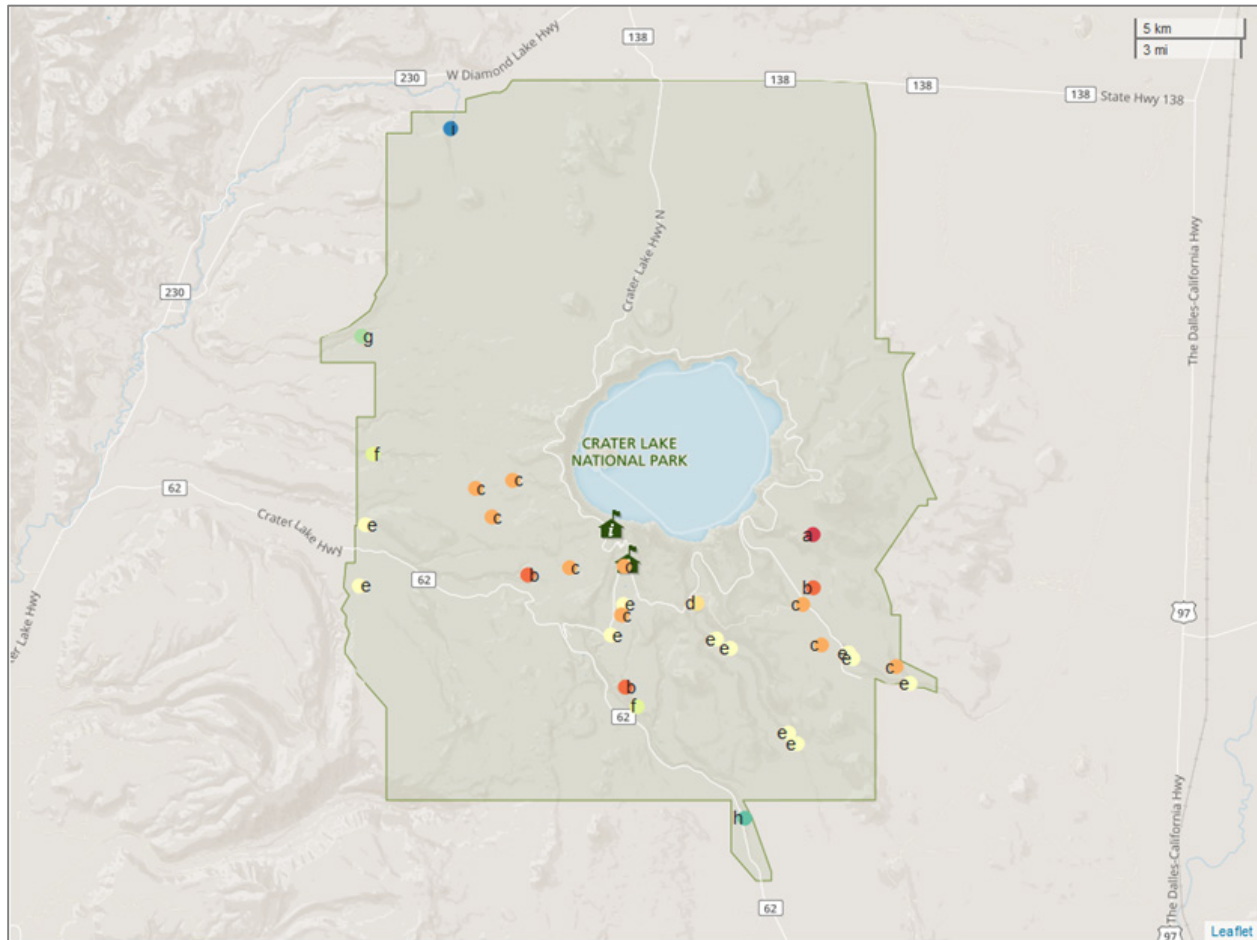


Figure 18. Distribution of stream category groupings based on Channel Morphology at Crater Lake National Park.

Habitat Complexity

- Eight groups were distinguished, although many groups were tightly related in ordination space (indicating only mild differences) (Figures 19–20)
- Separation of streams and groups was largely based on amount of total habitat coverage, with Rogue River (04) having the highest amount of coverage

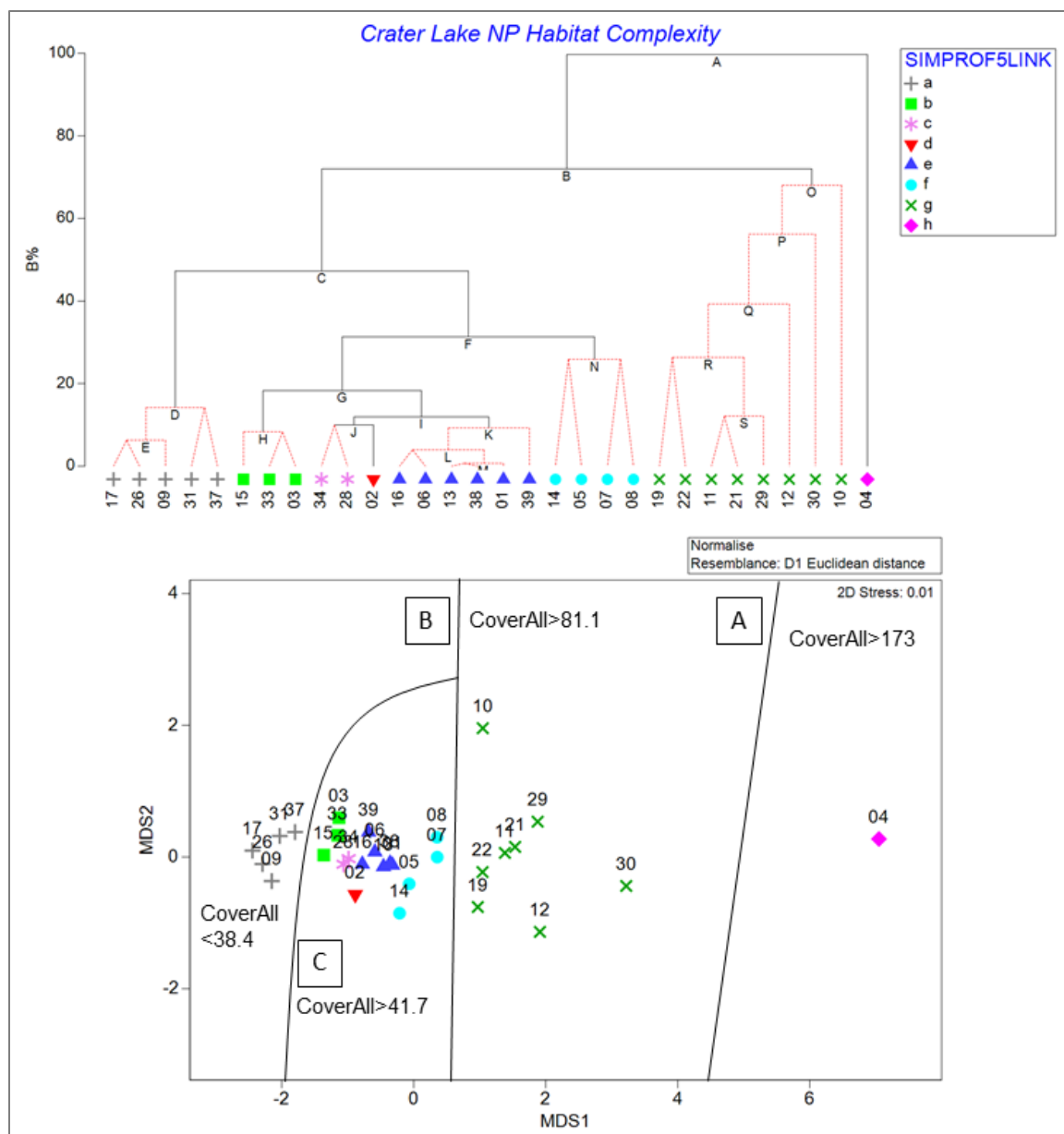


Figure 19. Stream classification results for Crater Lake National Park based on Habitat Complexity metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Letters A–C indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A–C are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

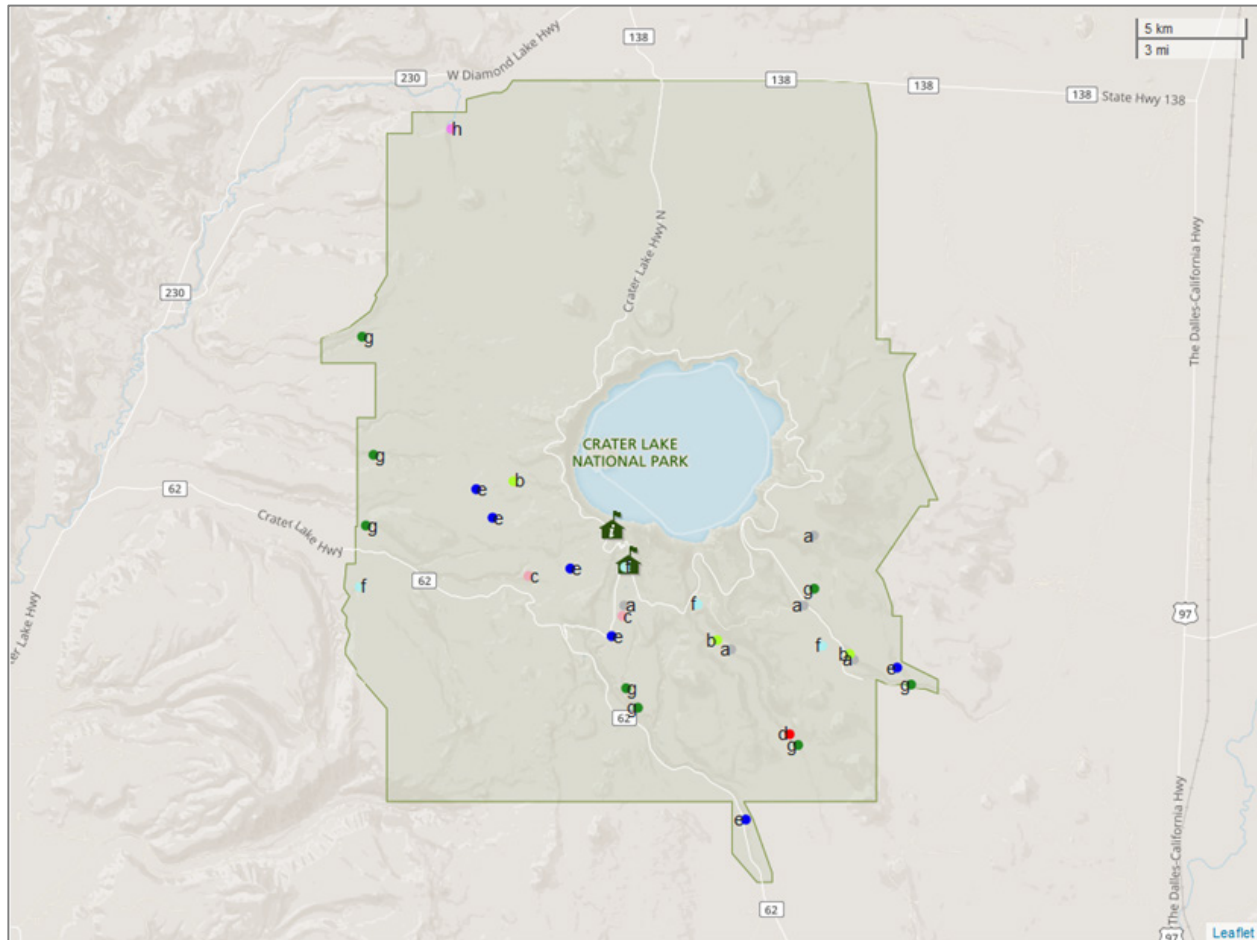


Figure 20. Distribution of stream category groupings based on Habitat Complexity at Crater Lake National Park.

Large Woody Debris

- Ten groups were distinguished (Figures 21–22)
- Separation was largely among pieces of woody debris in the active channel, with Rogue River (04) having the highest number

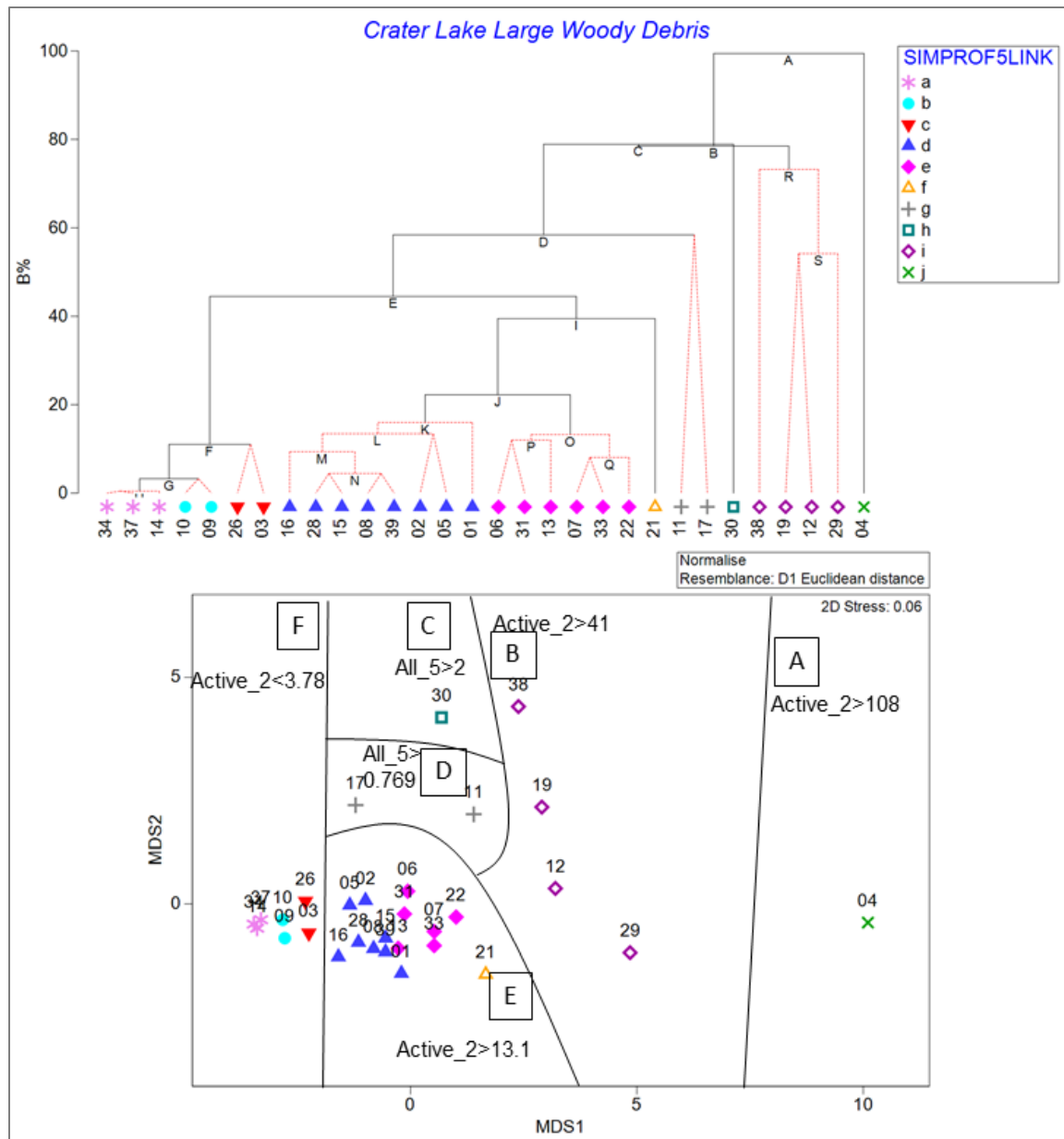


Figure 21. Stream classification results for Crater Lake National Park based on Large Woody Debris metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Letters A–F indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Active₂ = amount of woody debris in the active channel, All₅ = amount of woody debris in both the wetted and active channel. Letters A–F are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

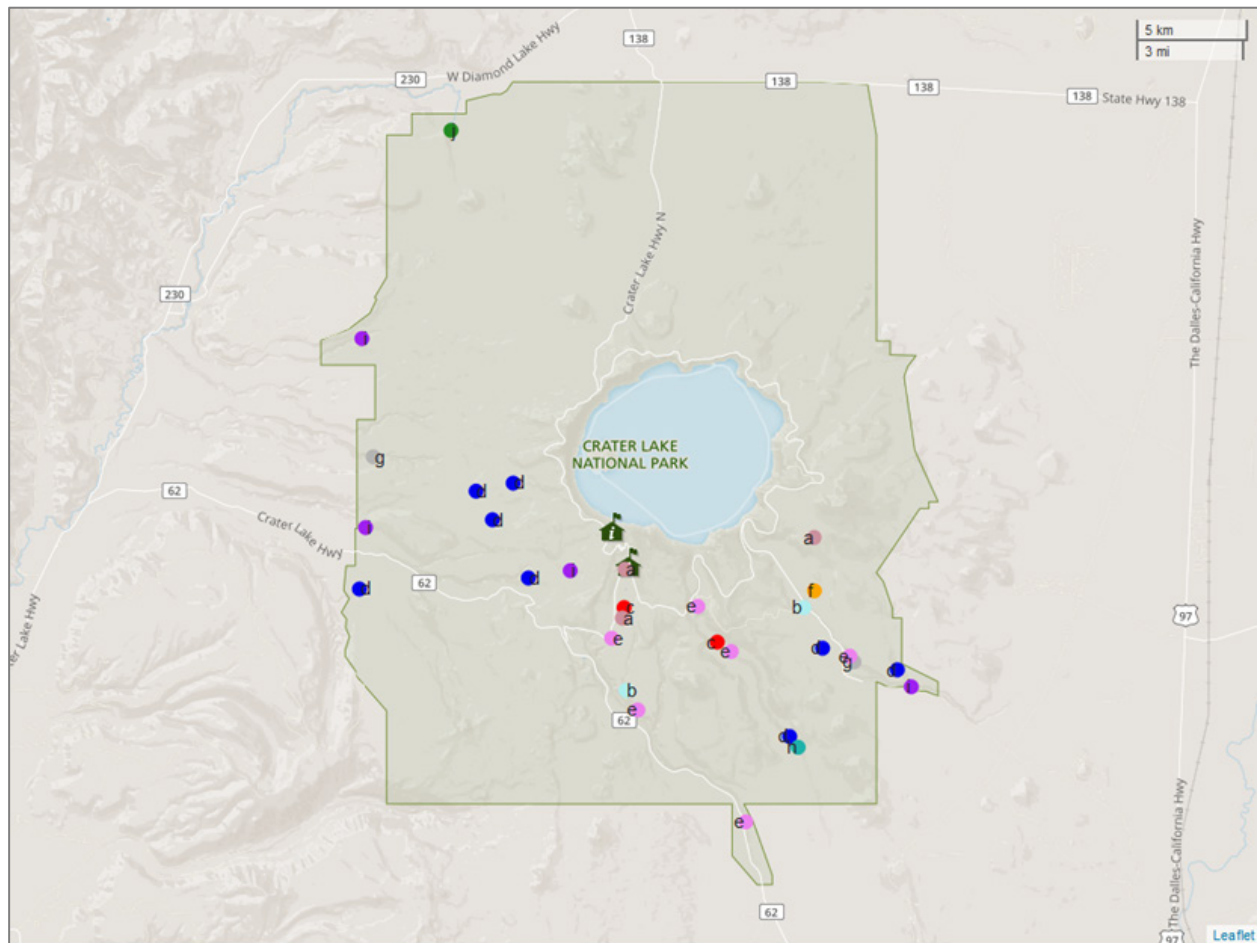


Figure 22. Distribution of stream category groupings based on Large Woody Debris at Crater Lake National Park.

Riparian Characters

- Twelve groups were distinguished (Figures 23–24)
- Groups and stream reaches were not associated with any single variable, but rather correlated with multiple gradients:
 - Mean herbaceous groundcover
 - Amount of understory deciduous cover
 - Mean canopy cover of all vegetation
 - Mean mid-story cover

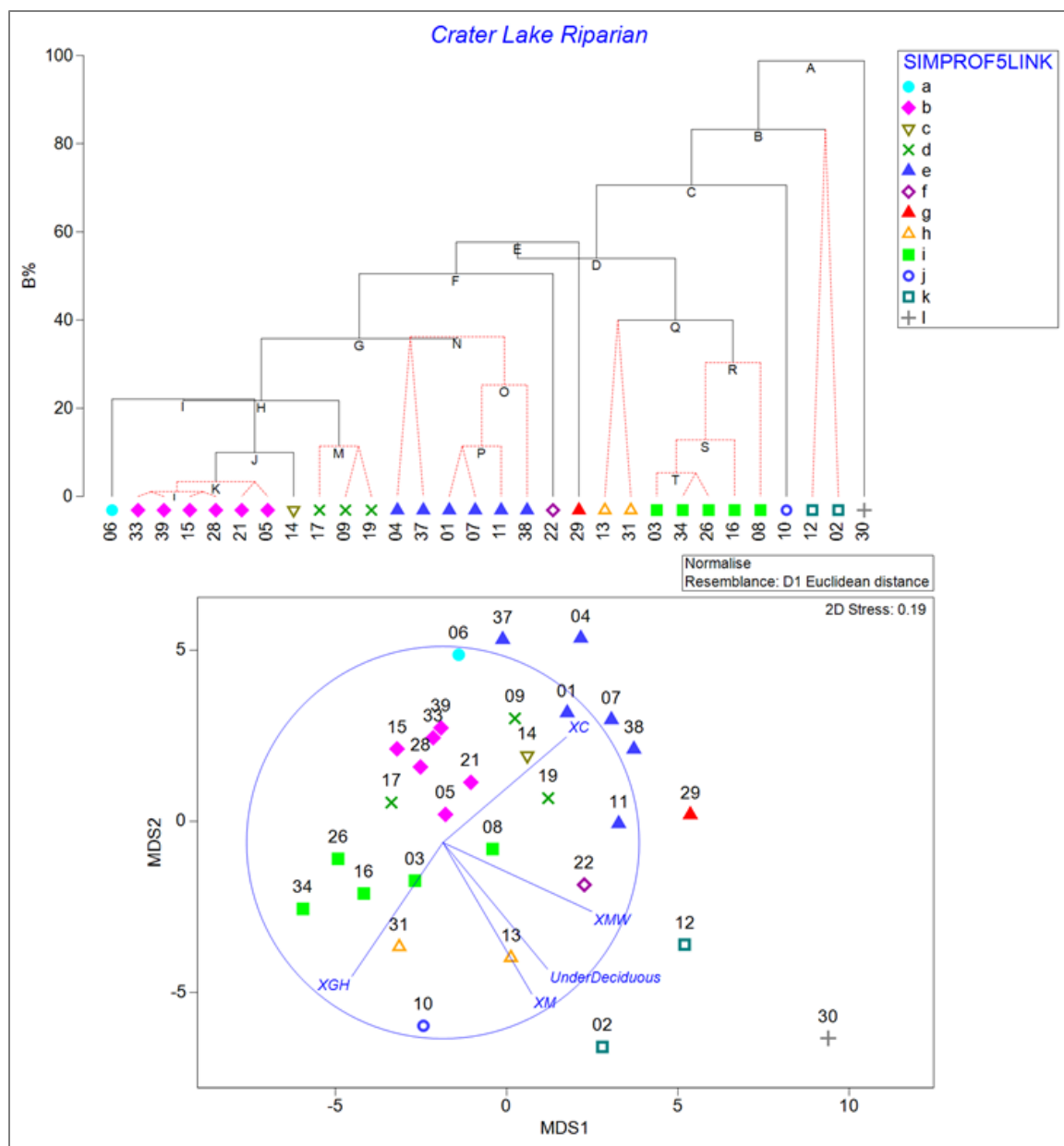


Figure 23. Stream classification results for Crater Lake National Park based on Riparian metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups. Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Vectors represent a further grouping for biological meaning based on correlations of sites to labeled metrics (step F in Figure 3). The outer edge of the circle represents a correlation value of 1; vectors for each parameter are defined by the direction and length, so that this direction in the ordination space is the direction of the parameter increasing. XC = mean cover of all canopy vegetation, XMW = mean cover of mid-story woody vegetation, XM = mean cover of all mid-story vegetation, XGH = mean cover of herbaceous groundcover. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

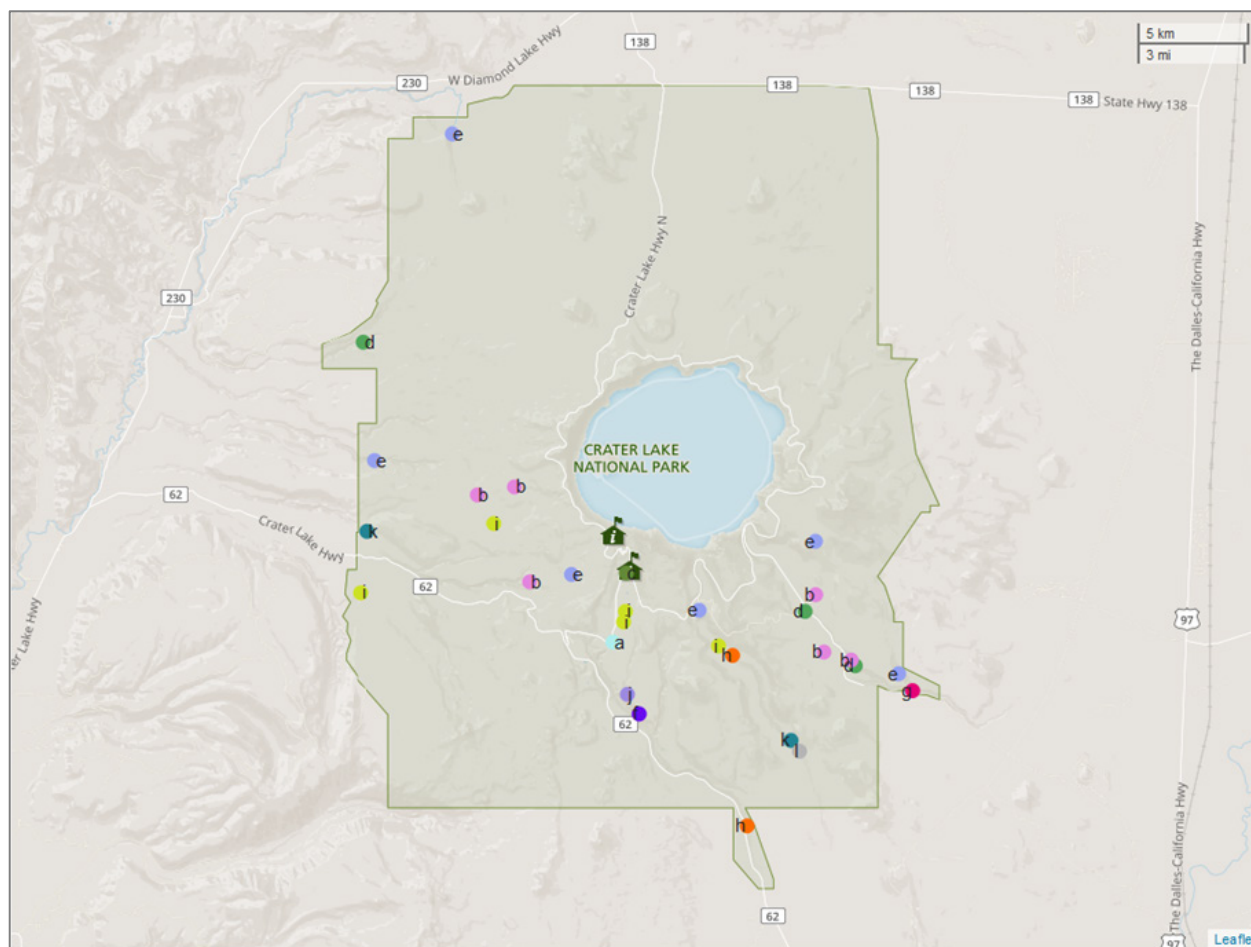


Figure 24. Distribution of stream category groupings based on Riparian Character at Crater Lake National Park.

Slope and Sinuosity

- Four groups were distinguished (Figures 25–26)
- Most stream reaches fell in one cluster, with the groups split based on slope
- Two streams reaches were unique to their groups:
 - Unnamed Tributary to Sand Creek (37) was the steepest stream sampled ($>12.9\%$)
 - Bybee Creek (11) was the most sinuous (>2.03)

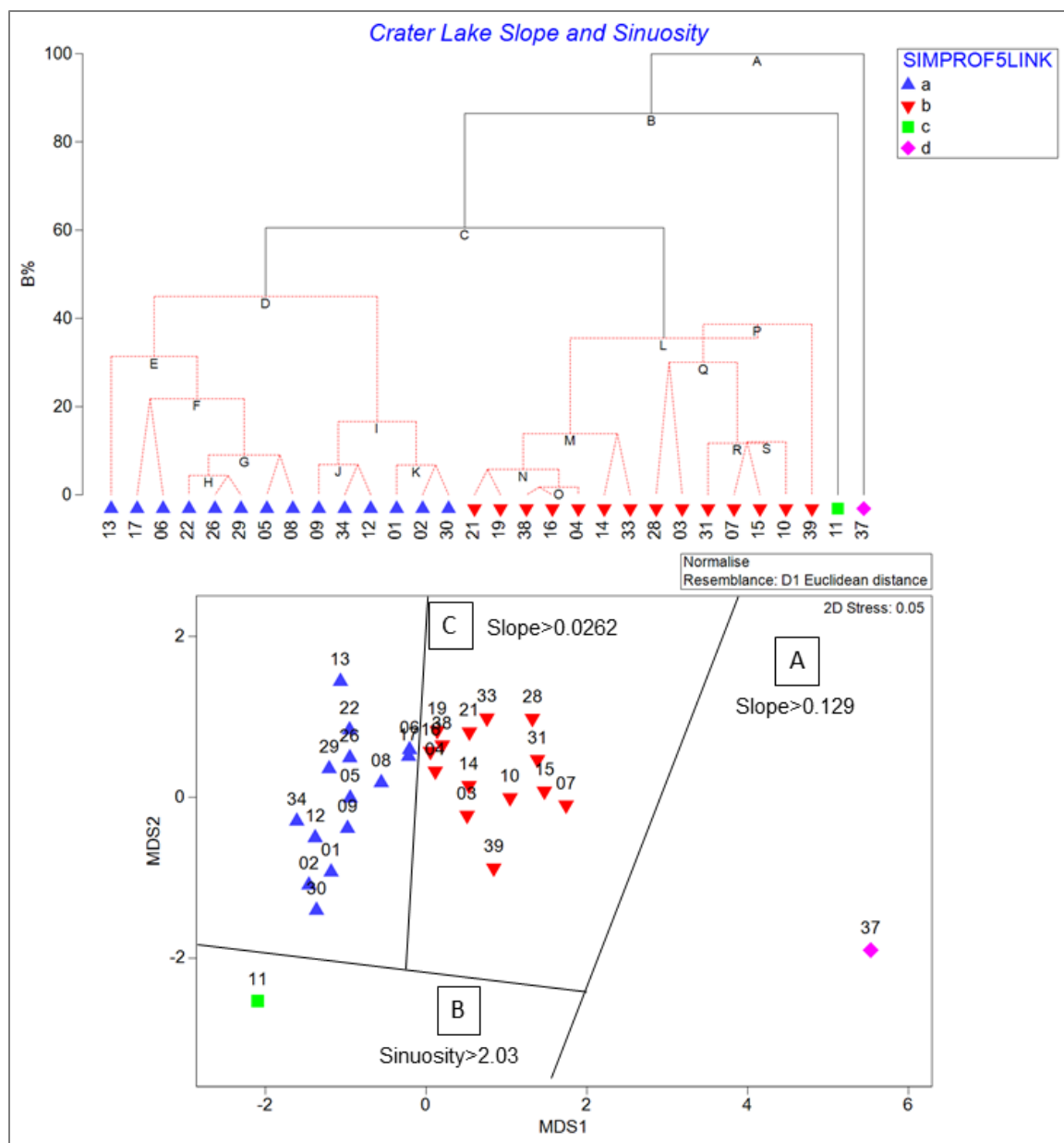


Figure 25. Stream classification results for Crater Lake National Park based on Slope and Sinuosity. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A–C indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A–C are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

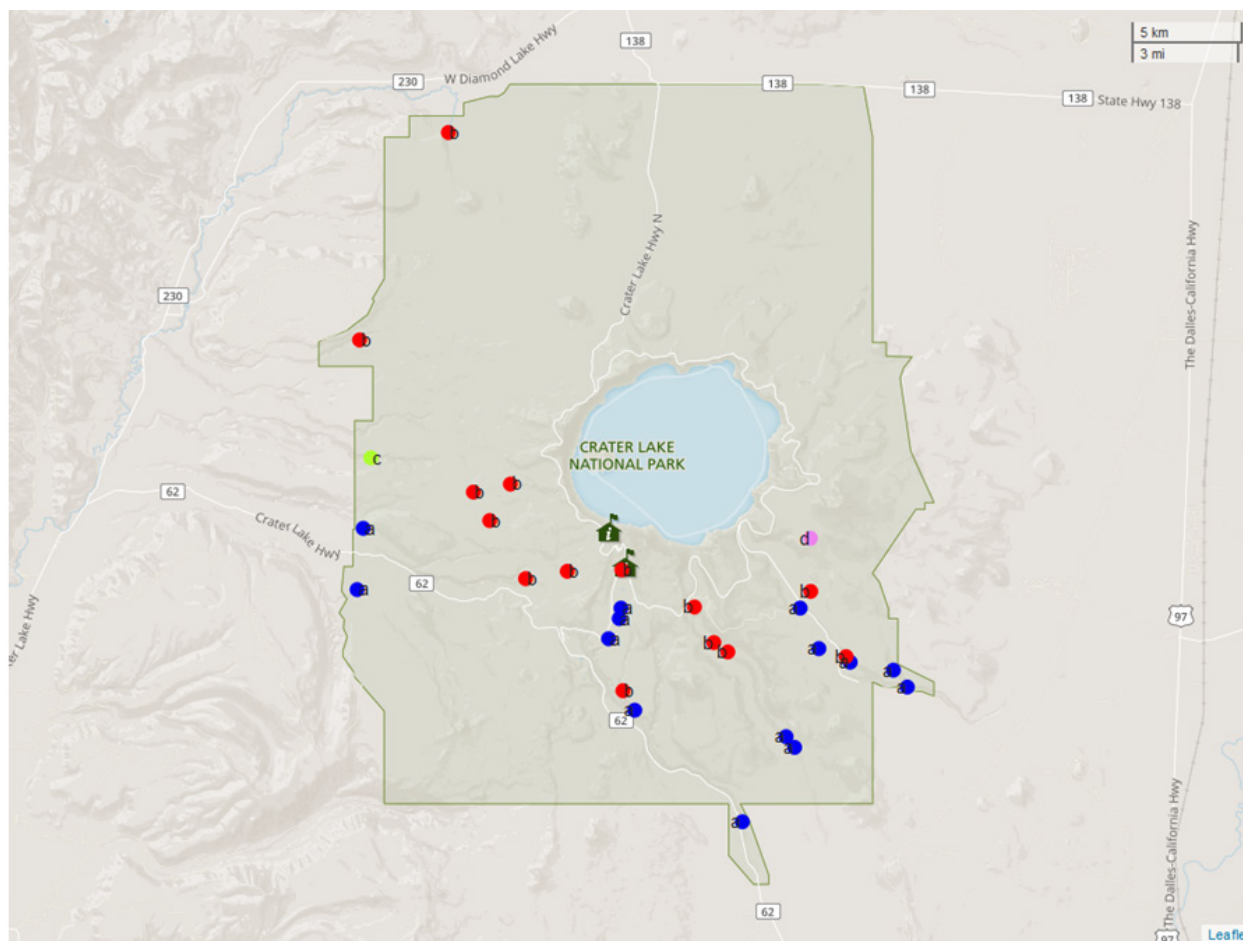


Figure 26. Distribution of stream category groupings based on Slope and Sinuosity at Crater Lake National Park.

Stream Substrate

- Eleven groups were distinguished (Figures 27–28)
- Separation of groups was largely along substrate size, with Sun Creek (03) being in a singleton group with the largest substrate size
- Another singleton group, Munson Creek (06), stood out as being the highest in substrate size variation

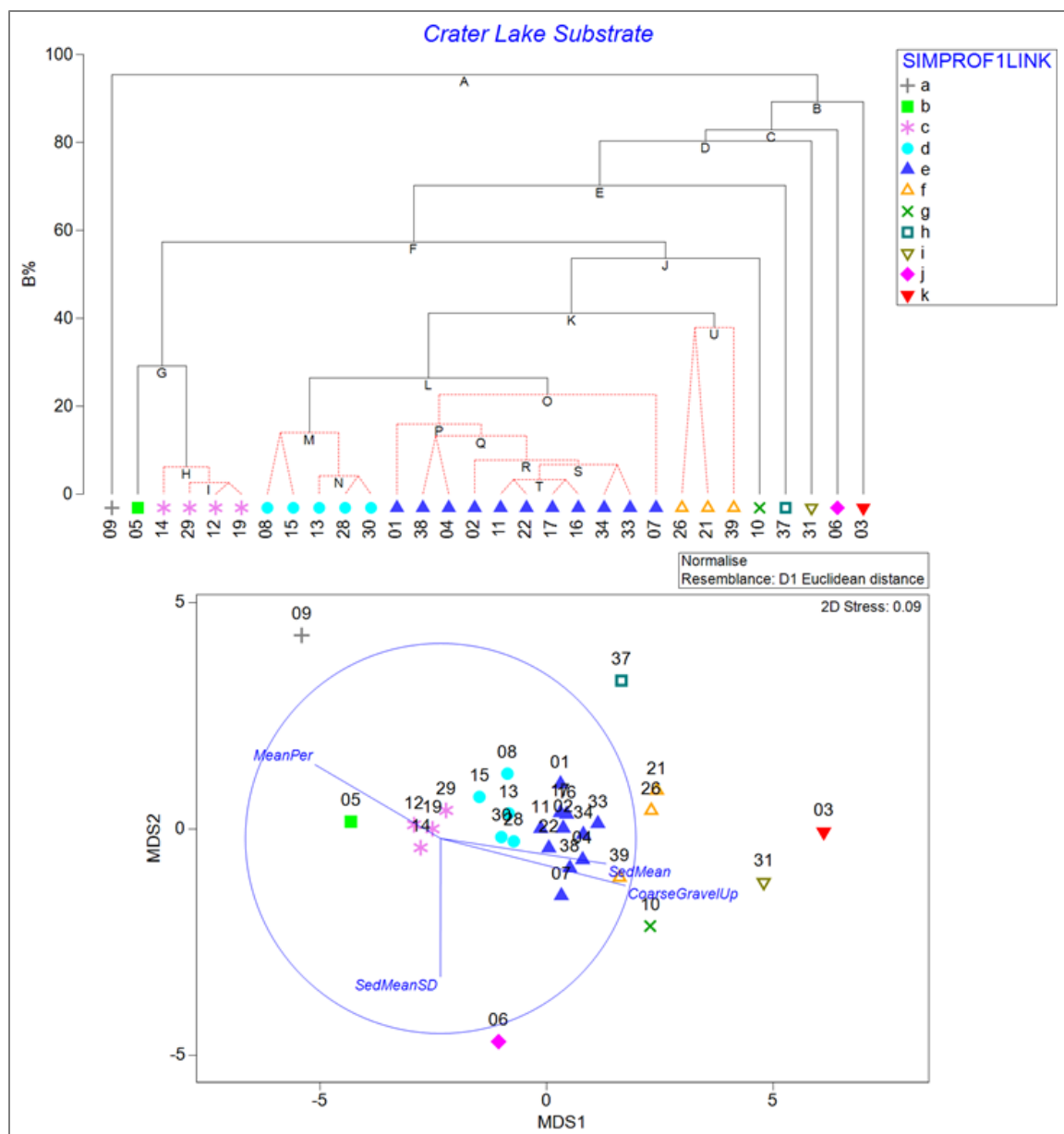


Figure 27. Stream classification results for Crater Lake National Park based on Stream Substrate. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Vectors represent a further grouping for biological meaning based on correlations of sites to labeled metrics (step F in Figure 3). The outer edge of the circle represents a correlation value of 1; vectors for each parameter are defined by the direction and length, so that this direction in the ordination space is the direction of the parameter increasing. MeanPer = mean percent embeddedness, SedMean = mean sediment size, CoarseGravelUp = the amount of coarse gravel, SedMeanSD = variation in mean sediment size. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

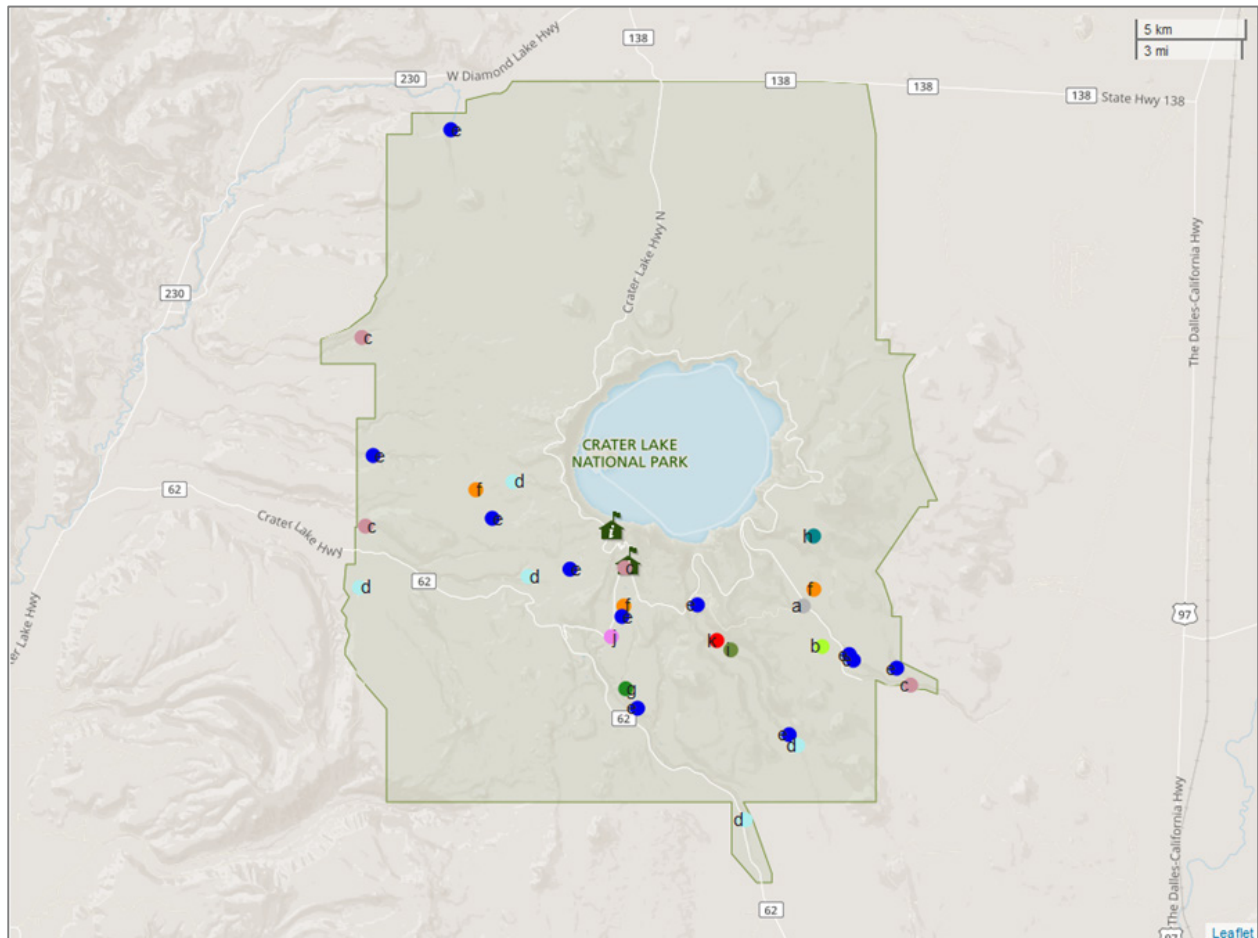


Figure 28. Distribution of stream category groupings based on Stream Substrate at Crater Lake National Park.

Water Chemistry

- Four groups were distinguished (Figures 29–30)
- One group included the majority of stream reaches, with the exception of four reaches:
 - One site on an Unnamed Tributary to Munson (14), and two sites on an Unnamed Tributary to Bybee Creek (15, 16), were all higher in Nitrogen
 - One site, Annie Creek (13), was higher in Phosphorous.

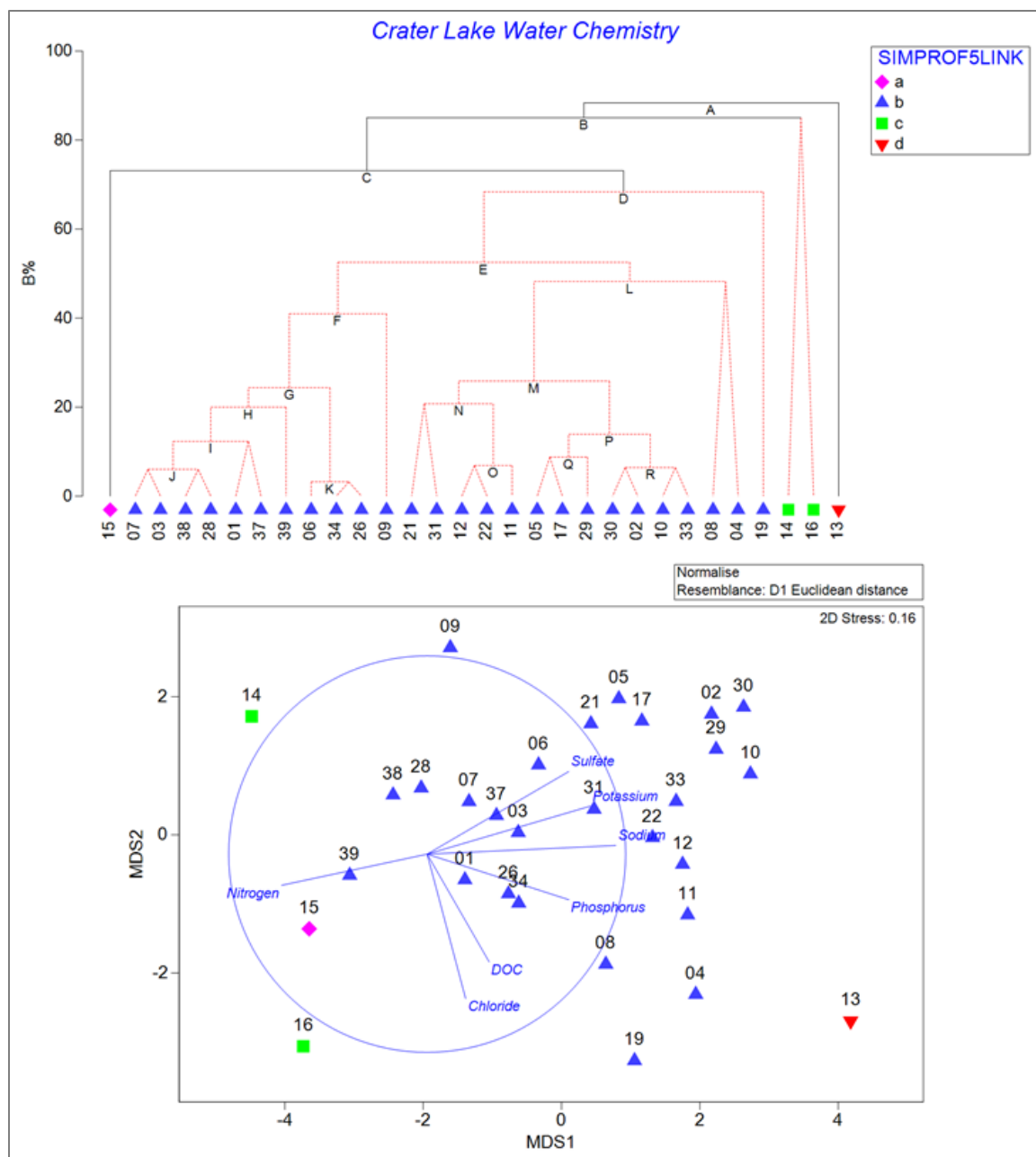


Figure 29. Stream classification results for Crater Lake National Park based on Water Chemistry. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Vectors represent a further grouping for biological meaning based on correlations of sites to labeled metrics (step F in Figure 3). The outer edge of the circle represents a correlation value of 1; vectors for each parameter are defined by the direction and length, so that this direction in the ordination space is the direction of the parameter increasing. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

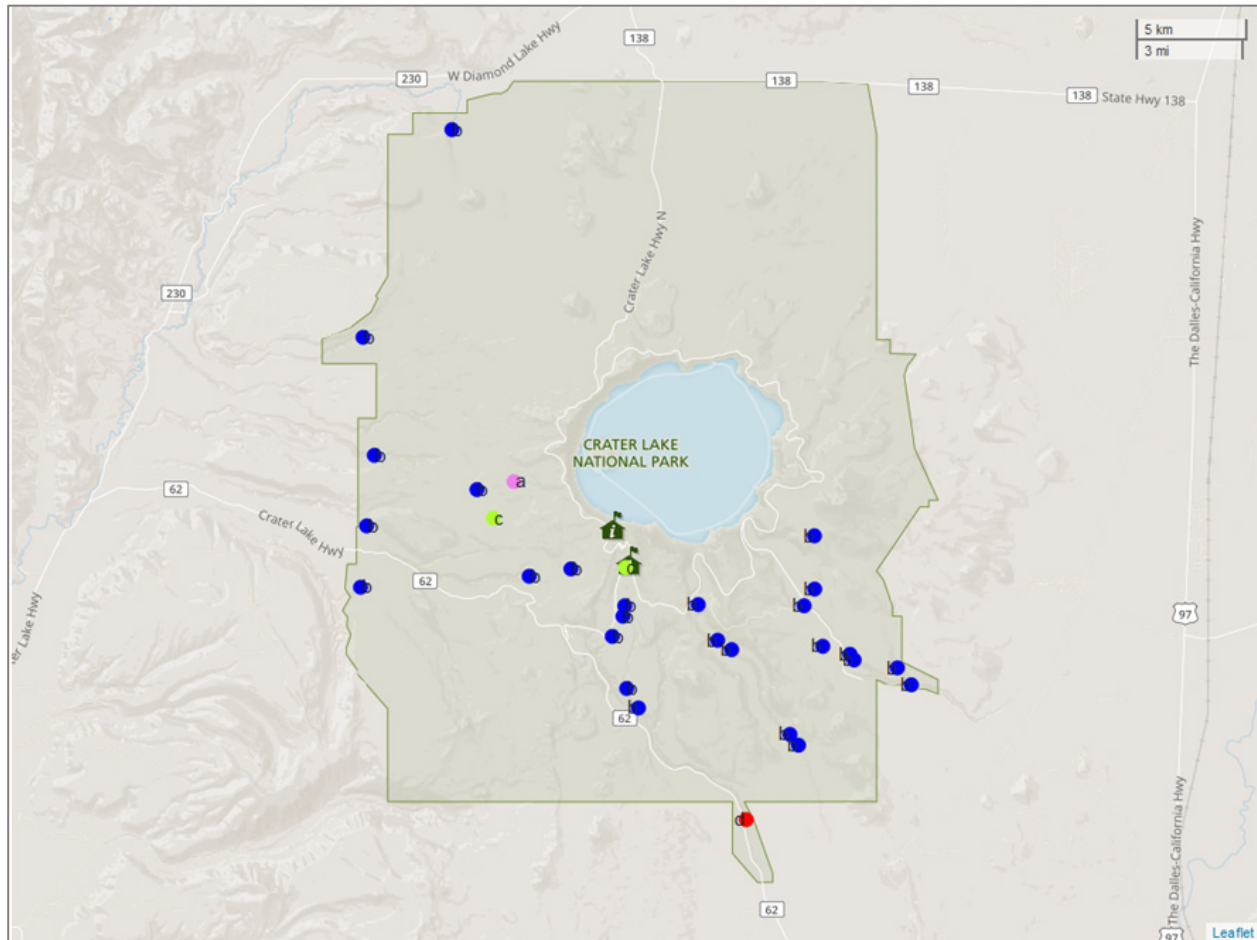


Figure 30. Distribution of stream category groupings based on Water Chemistry at Crater Lake National Park.

Water Quality

- All streams were in a single group, showing no significant differences among streams for water quality (Figure 31)
- One site, however, Sun Creek (30), does appear higher in Turbidity, pH, and Conductivity than other stream reaches (but not significantly)

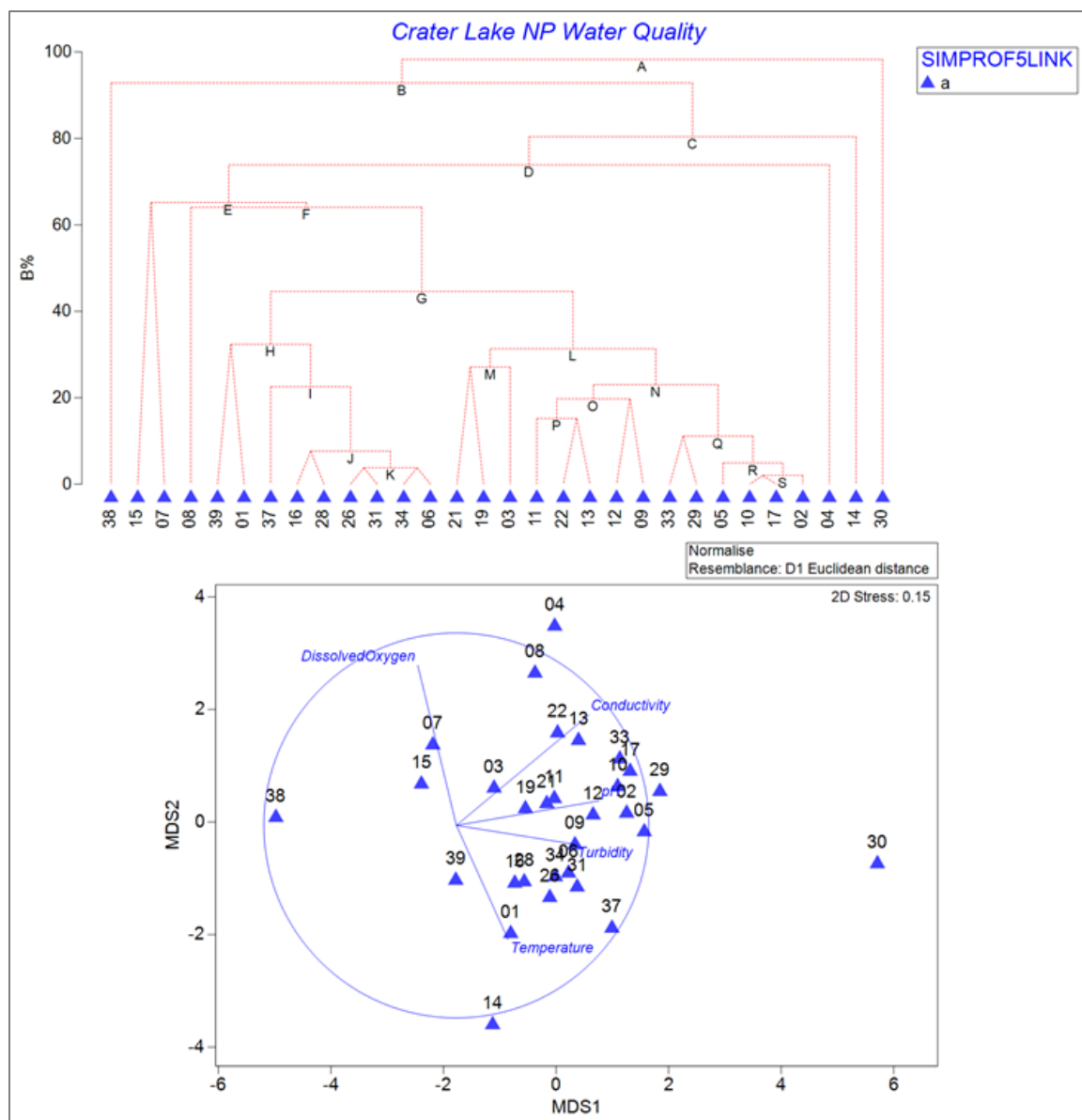


Figure 31. Stream classification results for Crater Lake National Park based on Water Quality. Top—cluster and group significance (red dotted lines indicate no significant separation). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Vectors represent a further grouping for biological meaning based on correlations of sites to labeled metrics (step F in Figure 3). The outer edge of the circle represents a correlation value of 1; vectors for each parameter are defined by the direction and length, so that this direction in the ordination space is the direction of the parameter increasing. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different. Since there is only one group, no map is provided.

Appendix D. Lassen Volcanic National Park

This appendix provides analytical figures and brief text summarizing three analyses for the classification of stream groups based on physical and chemical characters. Following a narrative summary of key results, figures for each metric category (e.g., Channel Morphology, Water Quality, Water Chemistry, etc.) are presented that display the cluster analysis, resulting linktree group allocation via simprof, and a metric Multi-Dimensional Scaling (mMDS) ordination. The ordination shows how sites are grouped based on a similarity profile test with 5% significant threshold (SIMPROF5LINK) and is overlaid with lines and lettered groups based on linktree separation characters or a vector biplot, both showing more biologically significant correlations. Lastly, in cases where multiple significant groups occurred (e.g., two or more), a map of the park shows the spatial distribution of groups.

Table 34 shows the name, sampling site code, and coordinates of sites sampled.

Table 34. Site and stream names, location coordinates, and years site was sampled for Lassen Volcanic National Park.

Site Code	Stream Name	Longitude	Latitude	Years Sampled
LAVOWQ01	Hat Creek	-121.435222	40.4866302	2011, 2014, 2017
LAVOWQ04	Lost Creek	-121.488361	40.5268961	2011, 2014, 2017
LAVOWQ05	Hat Creek	-121.442989	40.5023246	2011, 2014, 2017
LAVOWQ08	Hat Creek	-121.443052	40.5525244	2011, 2014, 2017
LAVOWQ09	West Fork Hat Creek	-121.467899	40.5016621	2011, 2014, 2017
LAVOWQ10	North Arm Rice Creek	-121.478742	40.4350545	2011, 2014, 2017
LAVOWQ12	West Fork Hat Creek	-121.455691	40.5158524	2011, 2014, 2017
LAVOWQ13	Summit Creek	-121.419831	40.4861383	2011, 2014, 2017
LAVOWQ15	Manzanita Creek	-121.559242	40.5350806	2011, 2014, 2017
LAVOWQ17	Kings Creek	-121.460436	40.4609821	2011, 2014, 2017
LAVOWQ20	Lost Creek	-121.492379	40.5436706	2011, 2014, 2017
LAVOWQ21	West Fork Hat Creek	-121.476064	40.4916415	2011, 2014, 2017
LAVOWQ22	North Arm Rice Creek	-121.475037	40.4305251	2011
LAVOWQ23	Manzanita Creek	-121.539856	40.5039866	2011, 2014, 2017
LAVOWQ24	West Fork Hat Creek	-121.456026	40.5150027	2011, 2014, 2017
LAVOWQ25	Kings Creek	-121.415928	40.4657727	2011, 2014, 2017
LAVOWQ27	Manzanita Creek	-121.561965	40.5357447	2011, 2014, 2017
LAVOWQ29	Hat Creek	-121.448958	40.5055916	2011, 2014, 2017
LAVOWQ32	Hat Creek	-121.441229	40.5380438	2011, 2014, 2017
LAVOWQ33	Kings Creek	-121.449811	40.4591683	2011, 2014, 2017
LAVOWQ36	Hat Creek	-121.446088	40.5330926	2011, 2014, 2017

Table 34 (continued). Site and stream names, location coordinates, and years site was sampled for Lassen Volcanic National Park.

Site Code	Stream Name	Longitude	Latitude	Years Sampled
LAVOWQ37	Kings Creek	-121.476289	40.461028	2011, 2014, 2017
LAVOWQ40	Hat Creek	-121.448288	40.5322433	2014, 2017
LAVOWQ43	Lost Creek	-121.47338	40.5132886	2017
LAVOWQ45	Hat Creek	-121.436201	40.5024568	2011, 2014, 2017

Key Results

(Numbers in this section reference stream site codes from Table 34.)

Channel Morphology

- Six groups were distinguished, but most stream reaches were within only two of those groups (Figures 32–33)
- Three groups showed substantial differences:
 - A group of four sites, all on Hat Creek (08, 32, 36, and 40), were characterized by the widest wetted widths (>6.99 meters)
 - A single site, Kings Creek (17), was singular in having a high percentage of slow moving habitat
 - A single site, Lost Creek (04), was singular in having a high amount of variation in the wetted width

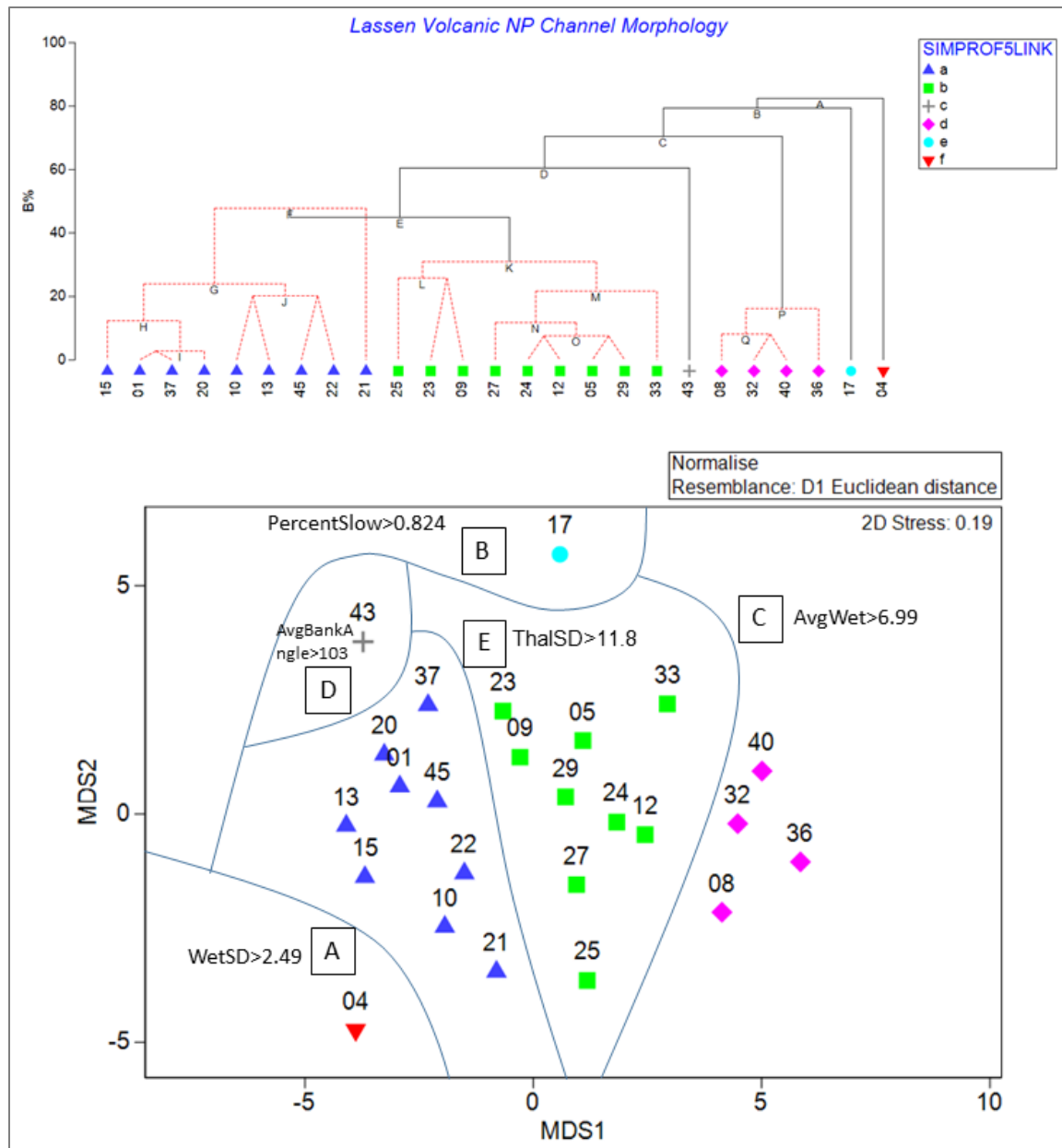


Figure 32 Stream classification results for Lassen Volcanic National Park based on Channel Morphology metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A–E indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A–E are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

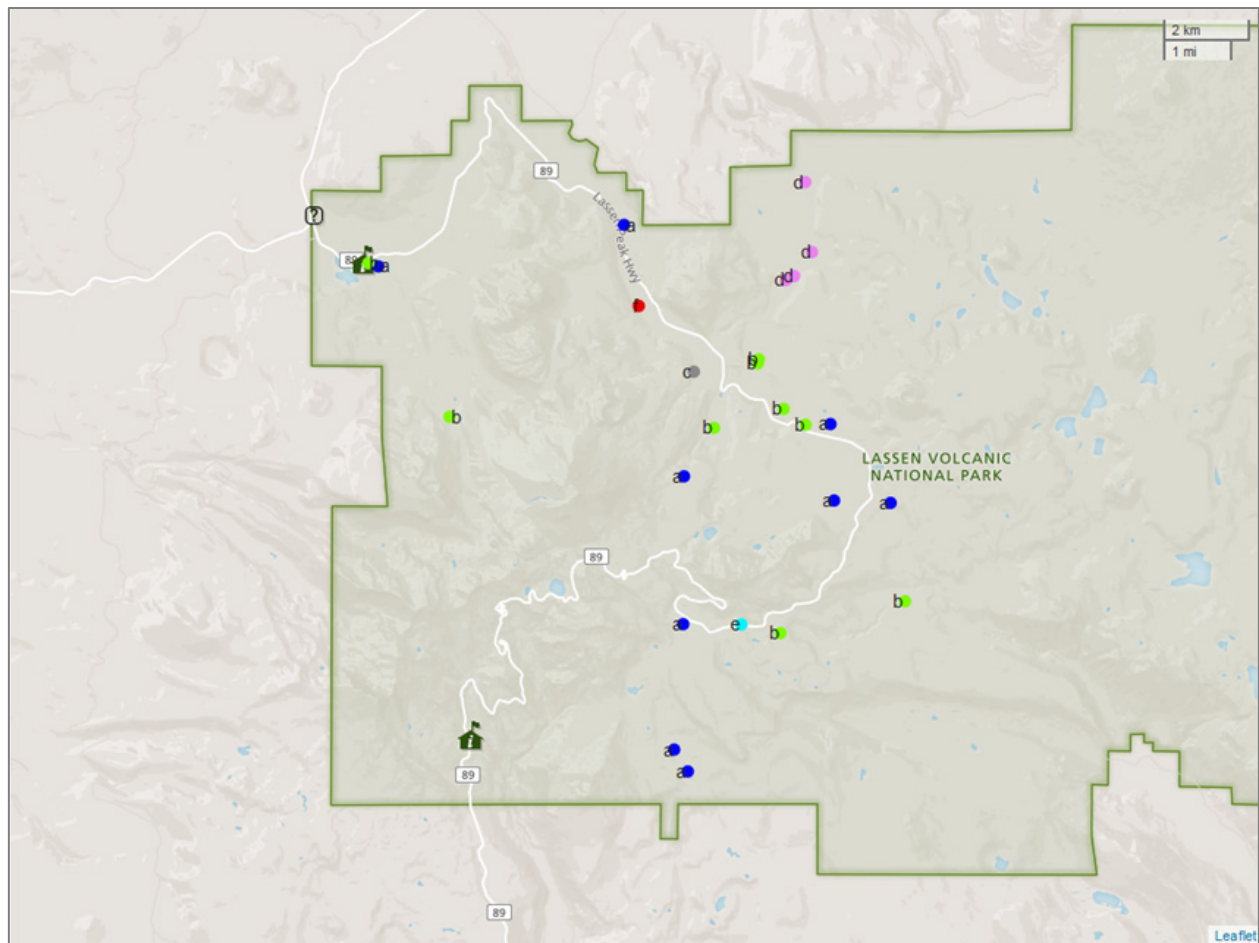


Figure 33. Distribution of stream category groupings based on Channel Morphology at Lassen Volcanic National Park.

Habitat Complexity

- Five groups were distinguished (Figures 34–35)
- Groups all had several stream reaches in each and generally went from a gradient of high complexity to low complexity
- No geographic pattern was discernible

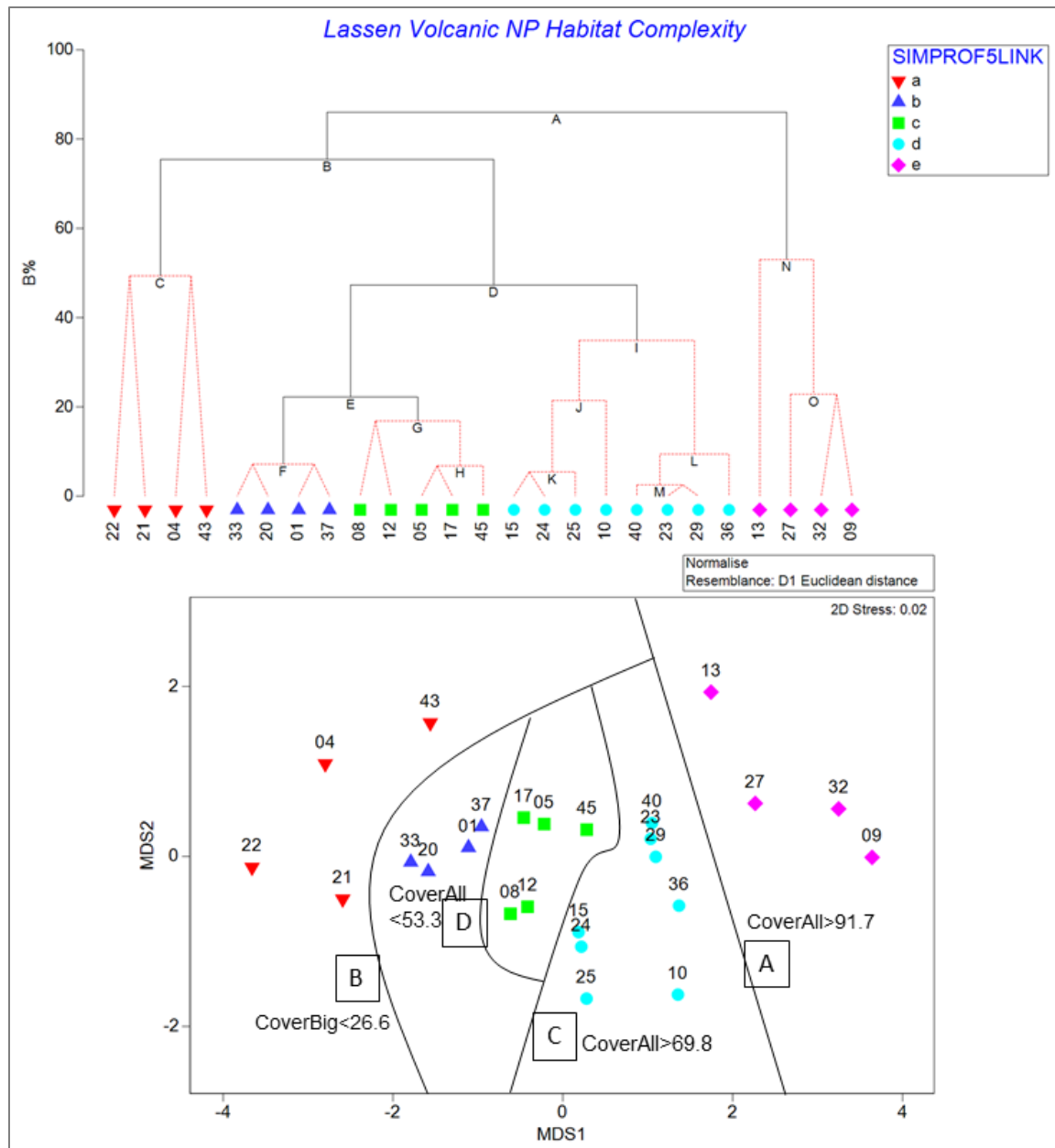


Figure 34. Stream classification results for Lassen Volcanic National Park based on Habitat Complexity metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A–D indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A–D are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

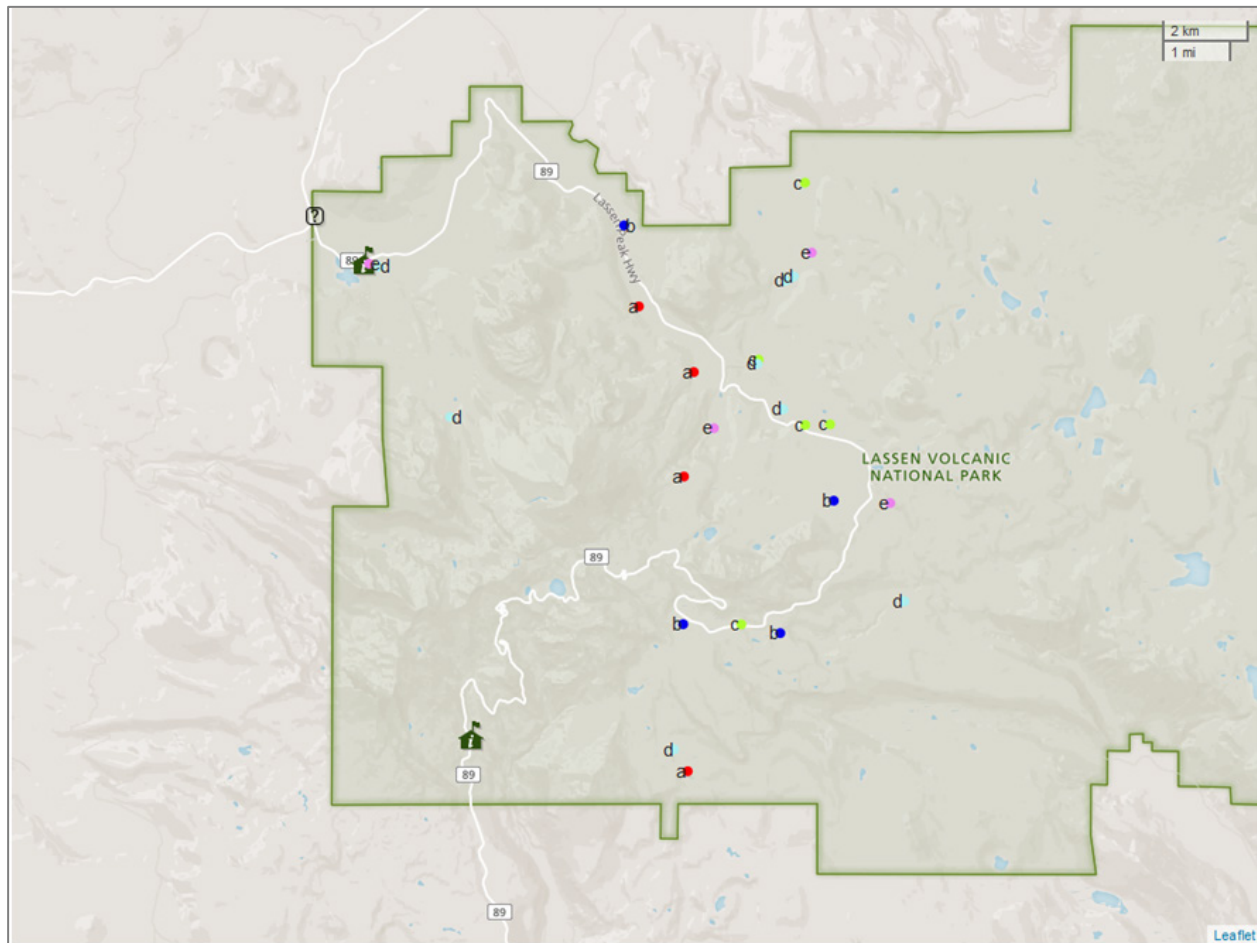


Figure 35. Distribution of stream category groupings based on Habitat Complexity at Lassen Volcanic National Park.

Large Woody Debris

- Ten groups were distinguished, although five were similar when plotted in MDS (Figures 36–37)
- Other groups were separated by having high amounts of woody debris; while some high debris sites were in fire areas, fire areas also included sites with lower amounts of woody debris.

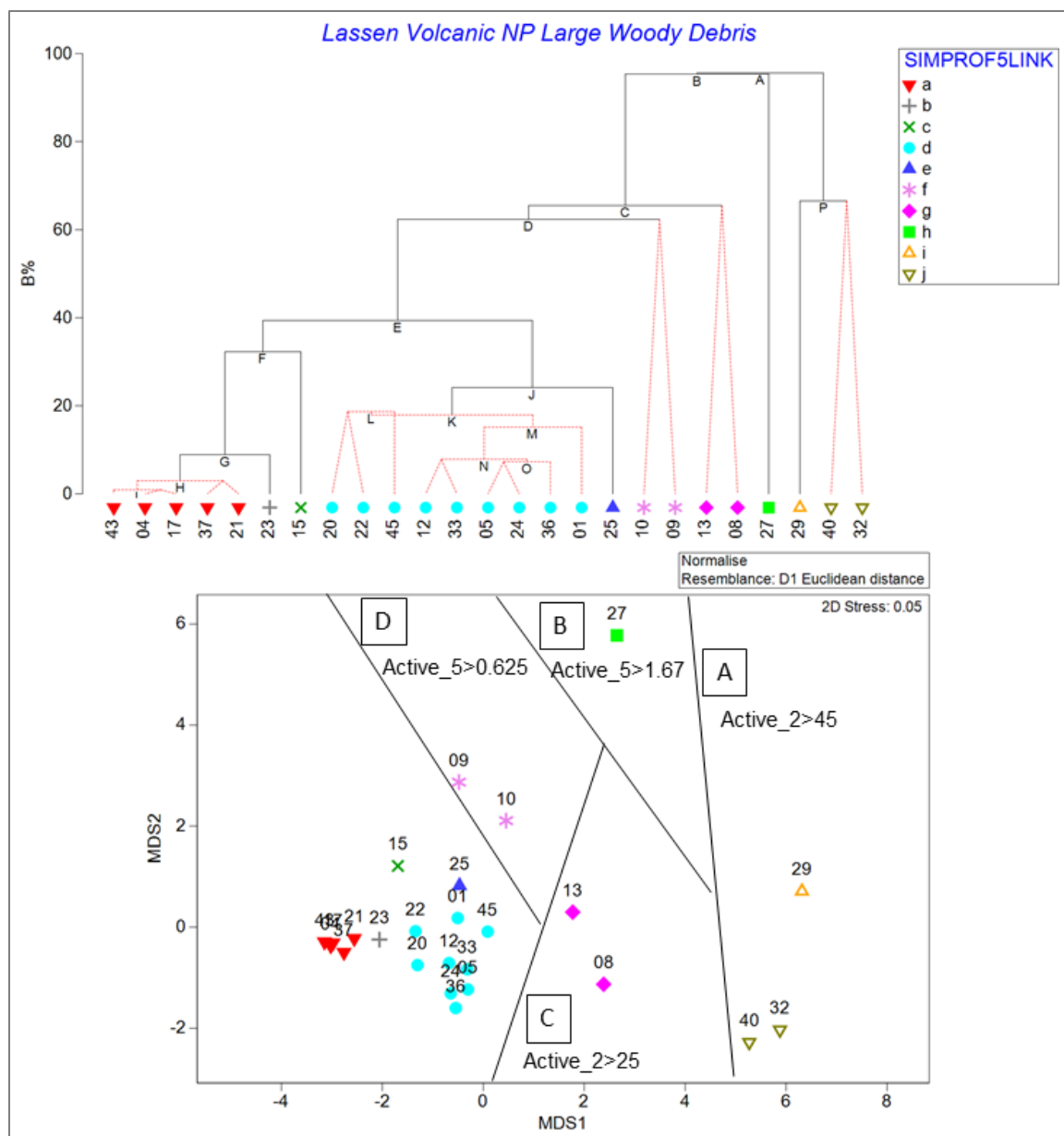


Figure 36. Stream classification results for Lassen Volcanic National Park based on Large Woody Debris metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A–D indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A–D are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

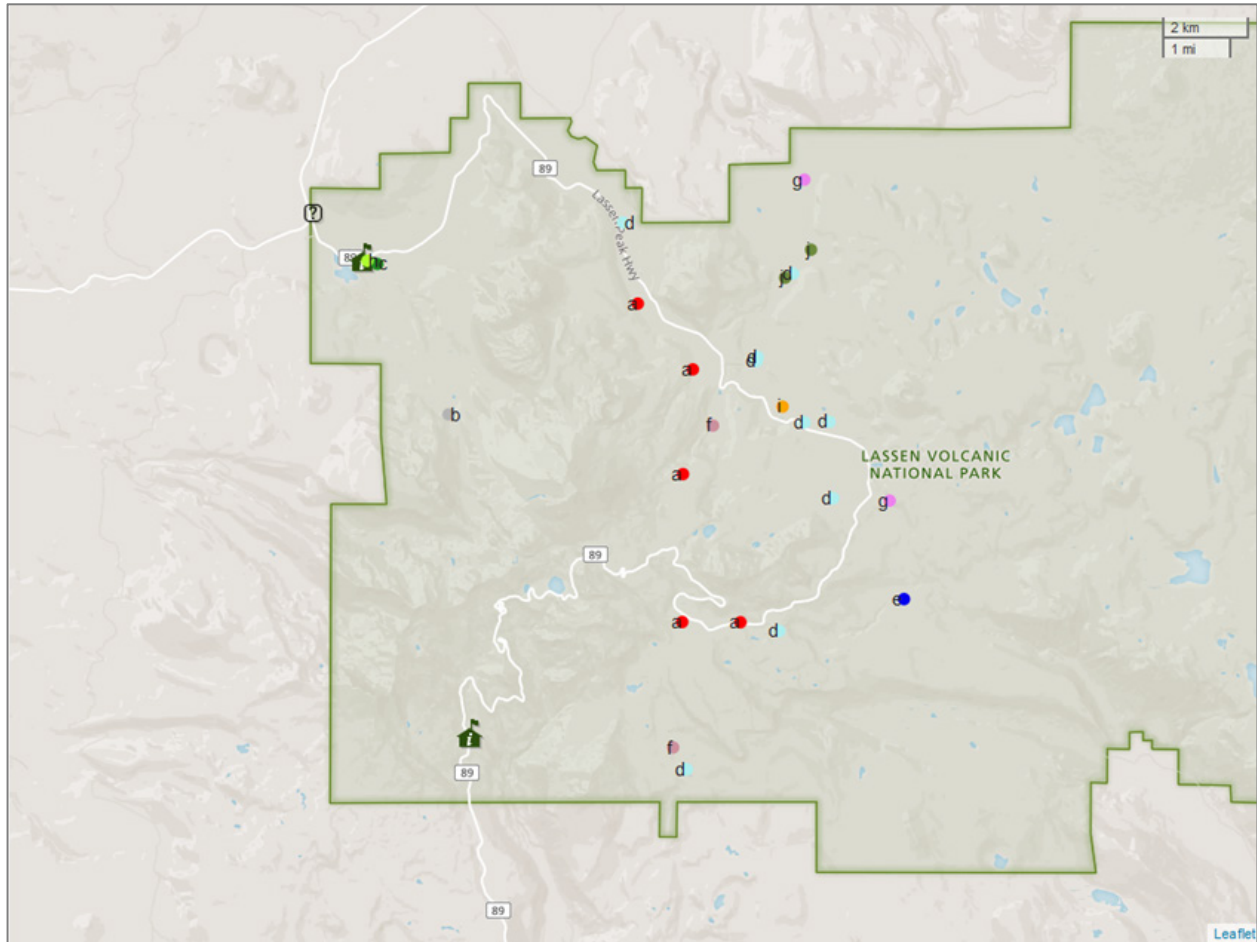


Figure 37. Distribution of stream category groupings based on Large Woody Debris at Lassen Volcanic National Park.

Riparian Characters

- Twelve groups were distinguished, with no group having more than four stream reaches (Figures 38–39)
- Because of variation in groups, plotting in MDS did not always plot coherent groups, showing disparity and a degree of difficulty in interpretation
- However, some sites and groups were associated with high amounts of coniferous canopy, others were more associated with the overall amount of woody cover in all levels, and some had high amounts of ground cover

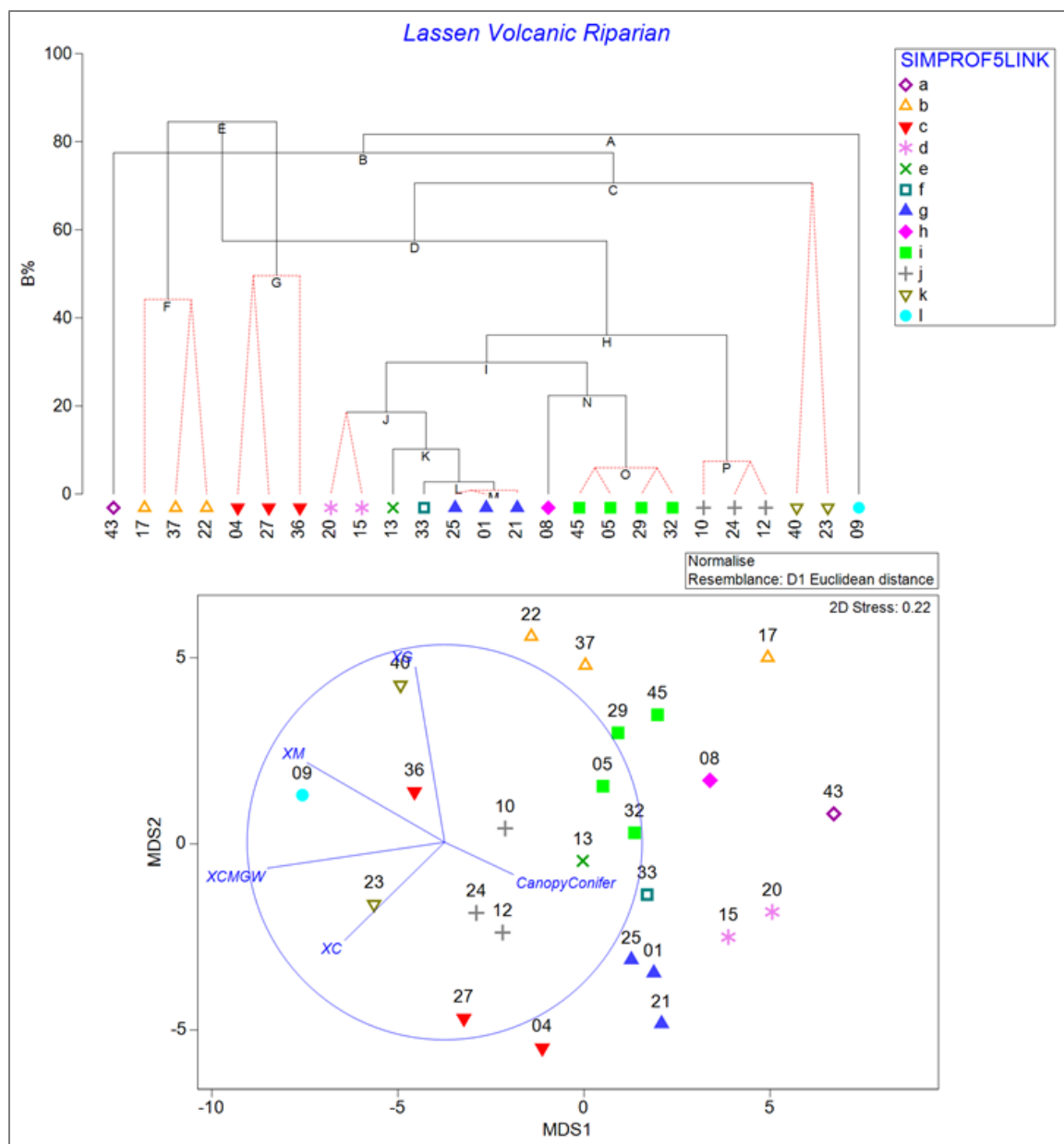


Figure 38. Stream classification results for Lassen Volcanic Park based on Riparian Character metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Vectors represent a further grouping for biological meaning based on correlations of sites to labeled metrics (step F in Figure 3). The outer edge of the circle represents a correlation value of 1; vectors for each parameter are defined by the direction and length, so that this direction in the ordination space is the direction of the parameter increasing. XC = mean cover of all canopy vegetation, XCMGW = mean cover of woody vegetation in canopy, mid-story, and ground cover vegetation, XM = mean cover of the mid-story vegetation, XG = mean of the total ground cover. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

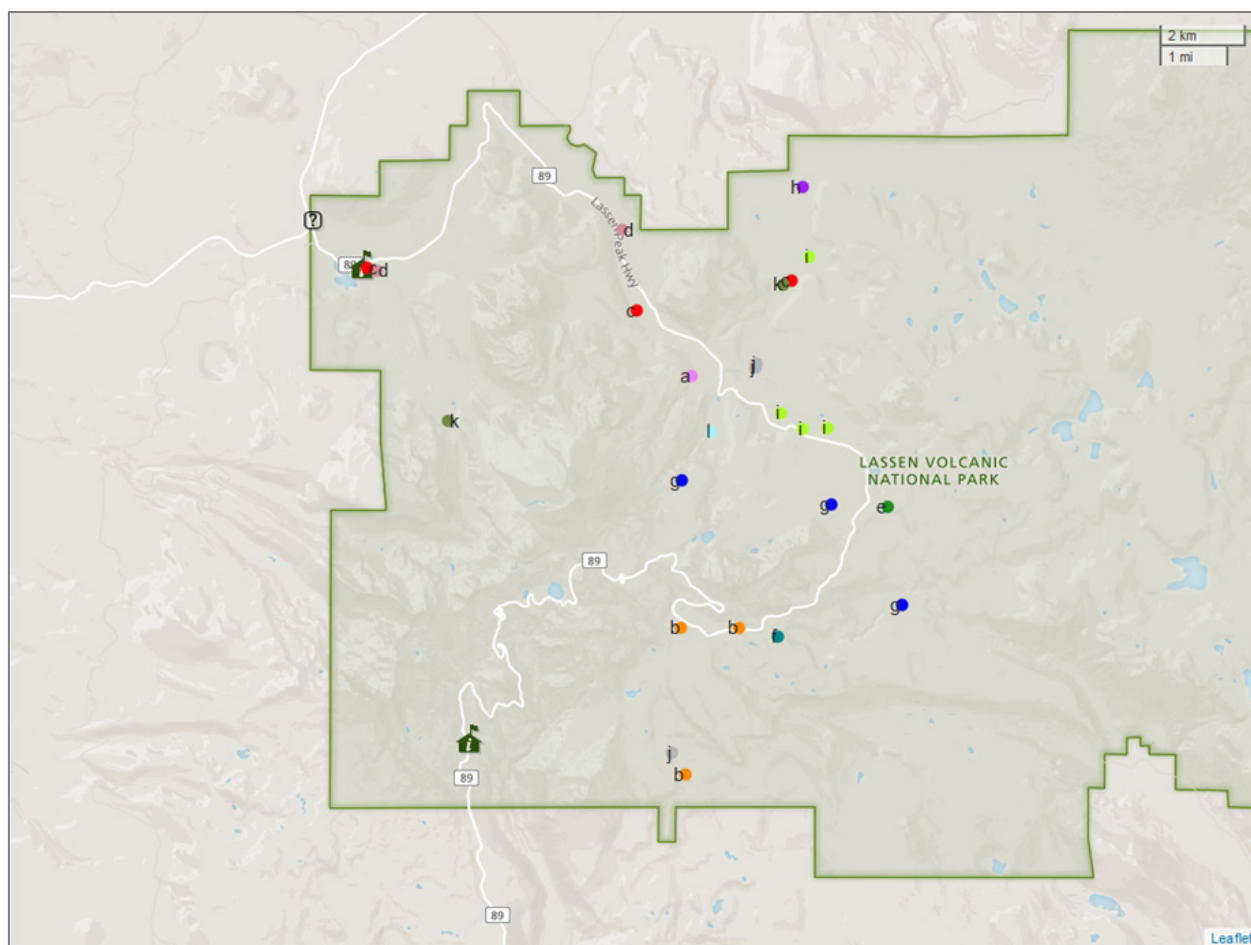


Figure 39. Distribution of stream category groupings at Lassen Volcanic National Park based on Riparian Character metrics.

Slope and Sinuosity

- Two groups were differentiated, with one group being over 4.5% in slope and the rest being under (Figures 40–41)
- Sampled sites in the north and south of the park tended to be in the steeper groups (over 4.5%), while sites in the center had shallower gradients

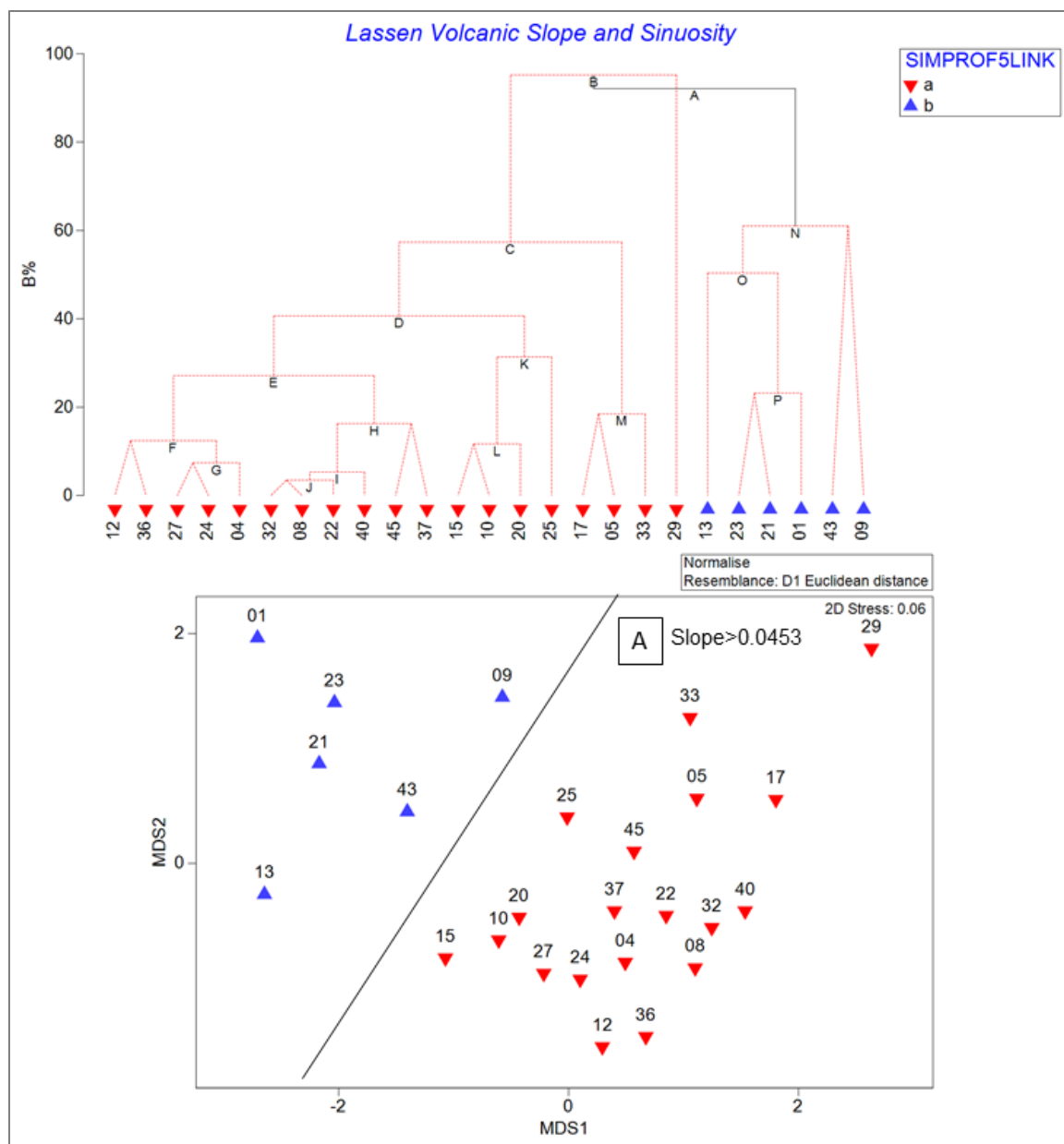


Figure 40. Stream classification results for Lassen Volcanic National Park based on Slope and Sinuosity. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letter A indicates further grouping for biologically meaningful distinctions based on slope (see step F in Figure 3). Letter A is different from SIMPROF5LINK groups and reflects the split in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

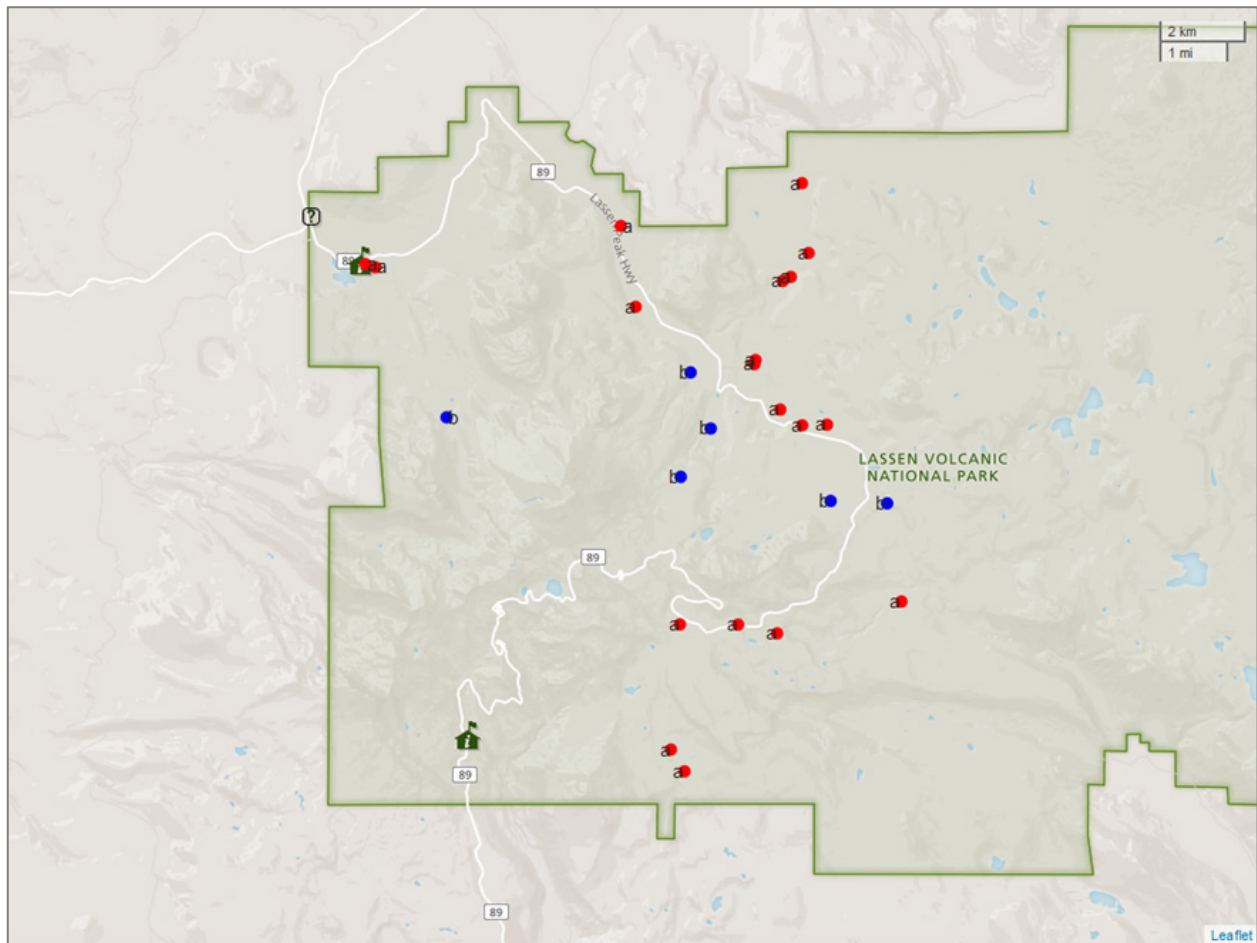


Figure 41. Distribution of stream category groupings at Lassen Volcanic National Park based on Slope and Sinuosity.

Stream Substrate

- Four groups were differentiated, with the main separation based on the amount of substrate larger than coarse gravel (Figures 42–43)
- One group, noted for low amounts of substrate above coarse gravel, included Lost Creek (04) and Kings Creek (33)
- Geographically, some creeks appear to have similar characters (e.g., Most Hat Creek sites in the north of the park were all in the same group)

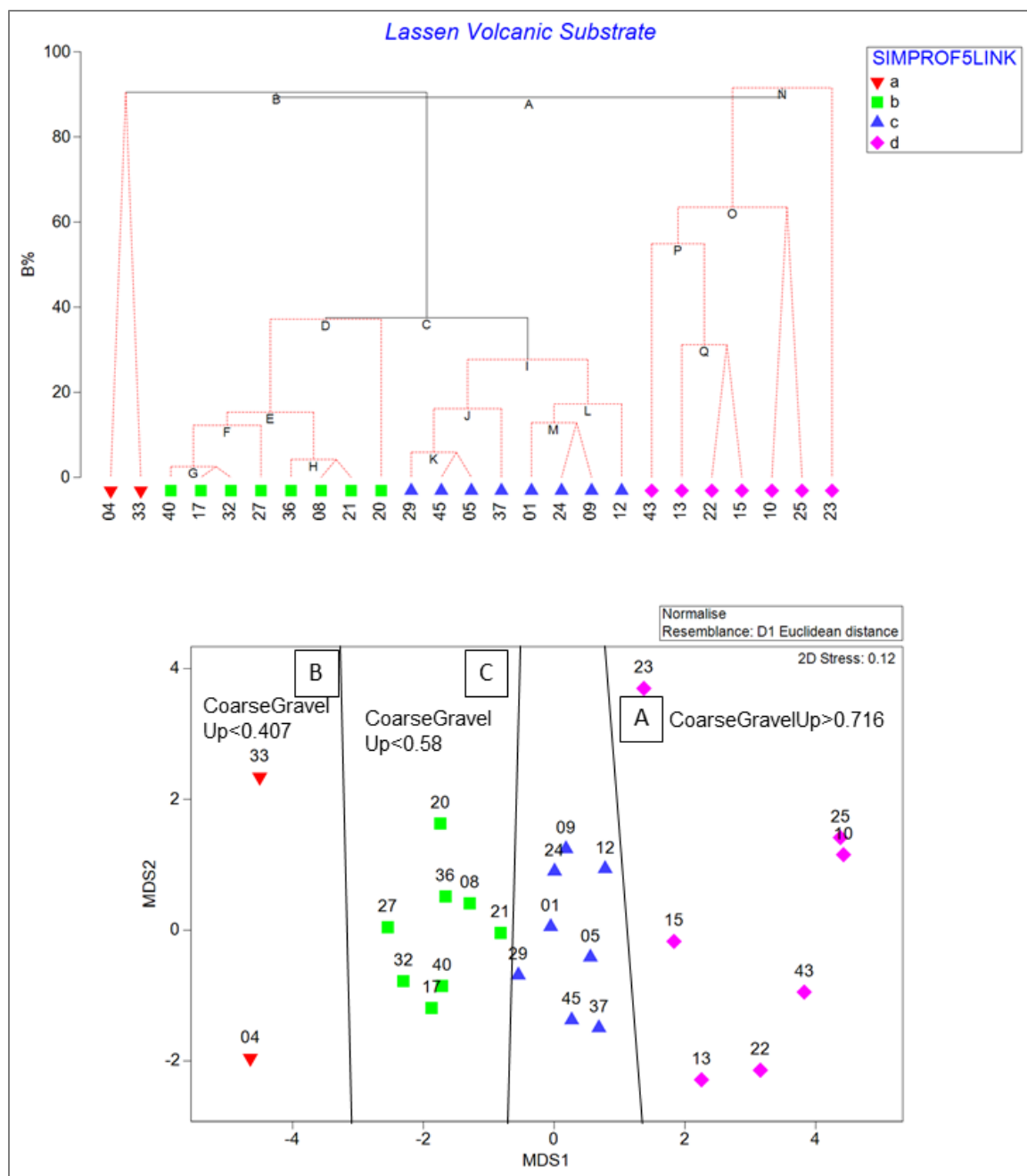


Figure 42. Stream classification results for Lassen Volcanic National Park based on Substrate. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A–C indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A–C are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

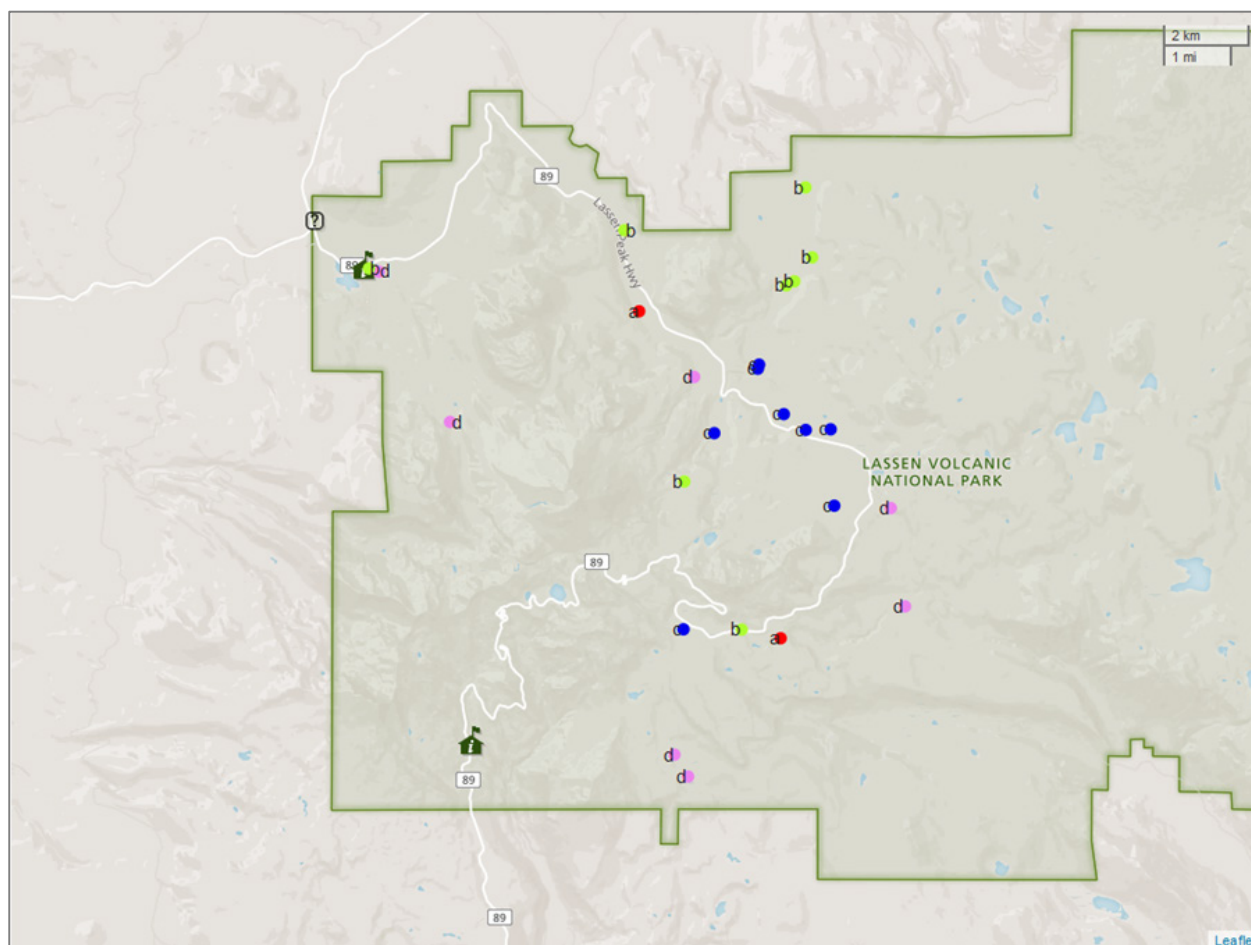


Figure 43. Distribution of stream category groupings at Lassen Volcanic National Park based on Stream Substrate.

Water Chemistry

- Four groups were differentiated, with two of the groups represented by singular sites (Figures 44–45)
- One group, West Fork Hat Creek (09), was noted for being high in Chloride
- One group, Lost Creek (43), was distinguished by having high Nitrogen

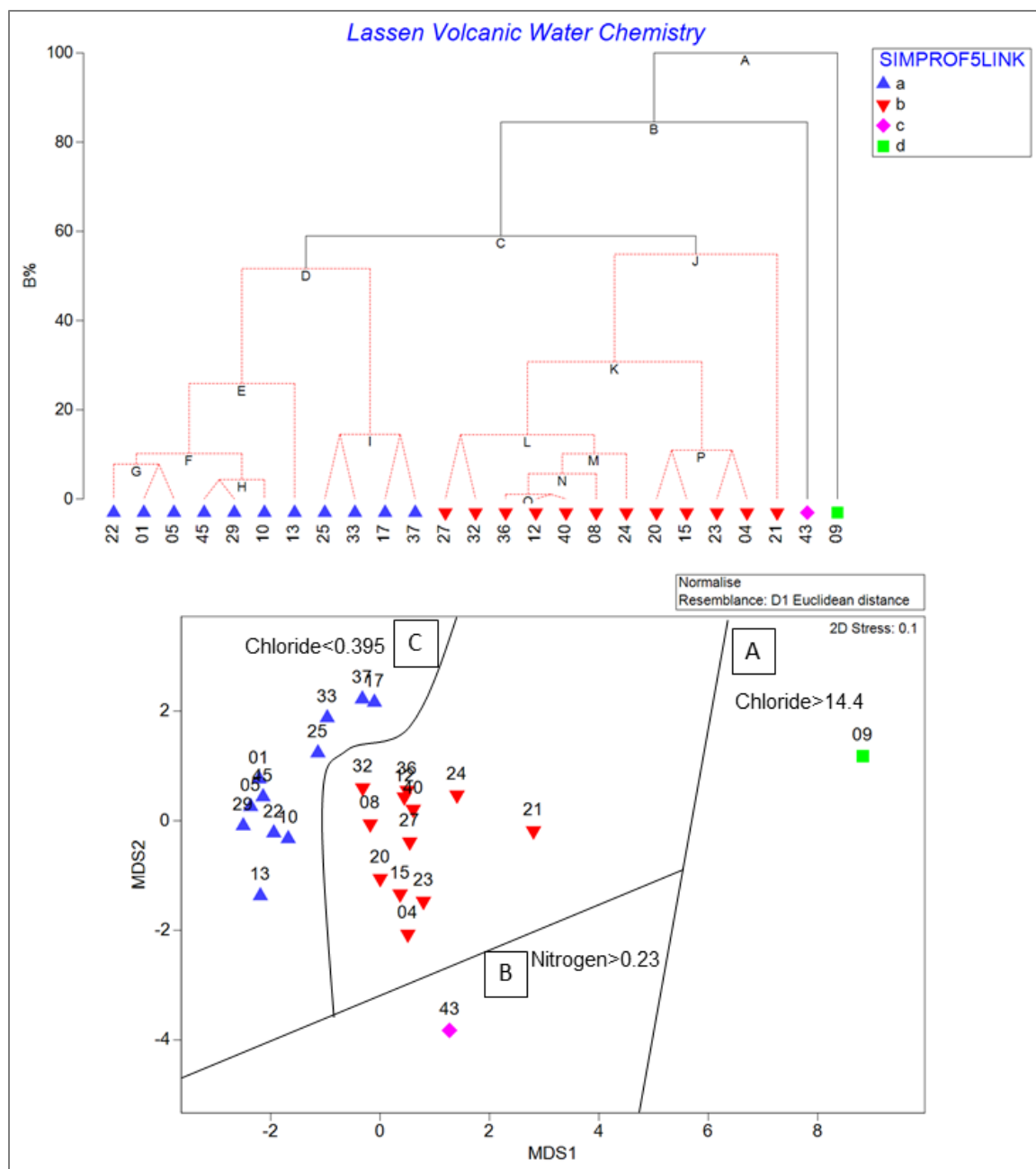


Figure 44. Stream classification results for Lassen Volcanic National Park based on Water Chemistry. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A–C indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A–C are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

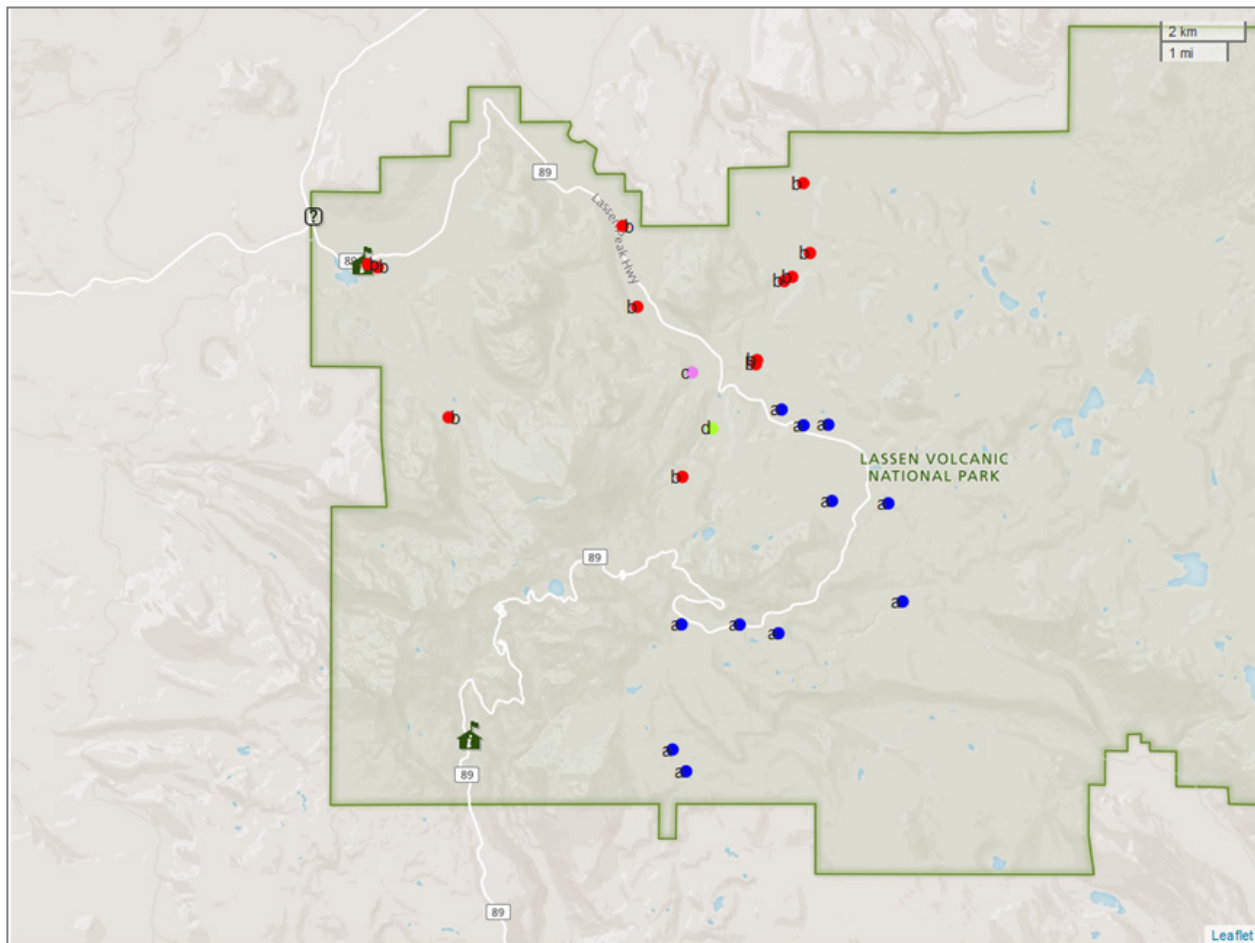


Figure 45. Distribution of stream category groupings at Lassen Volcanic National Park based on Water Chemistry.

Water Quality

- Three groups were differentiated, with most streams of the park belonging to a primary group (Figures 46–47)
- The stream reaches distinguished from most others were North Arm Rice Creek (10) and Summit Creek (13), which were higher in temperature (>9.03 degrees); however, point in time measurements of temperature are unreliable in overall assessment
- One singular group, Kings Creek (37), was higher in Conductivity

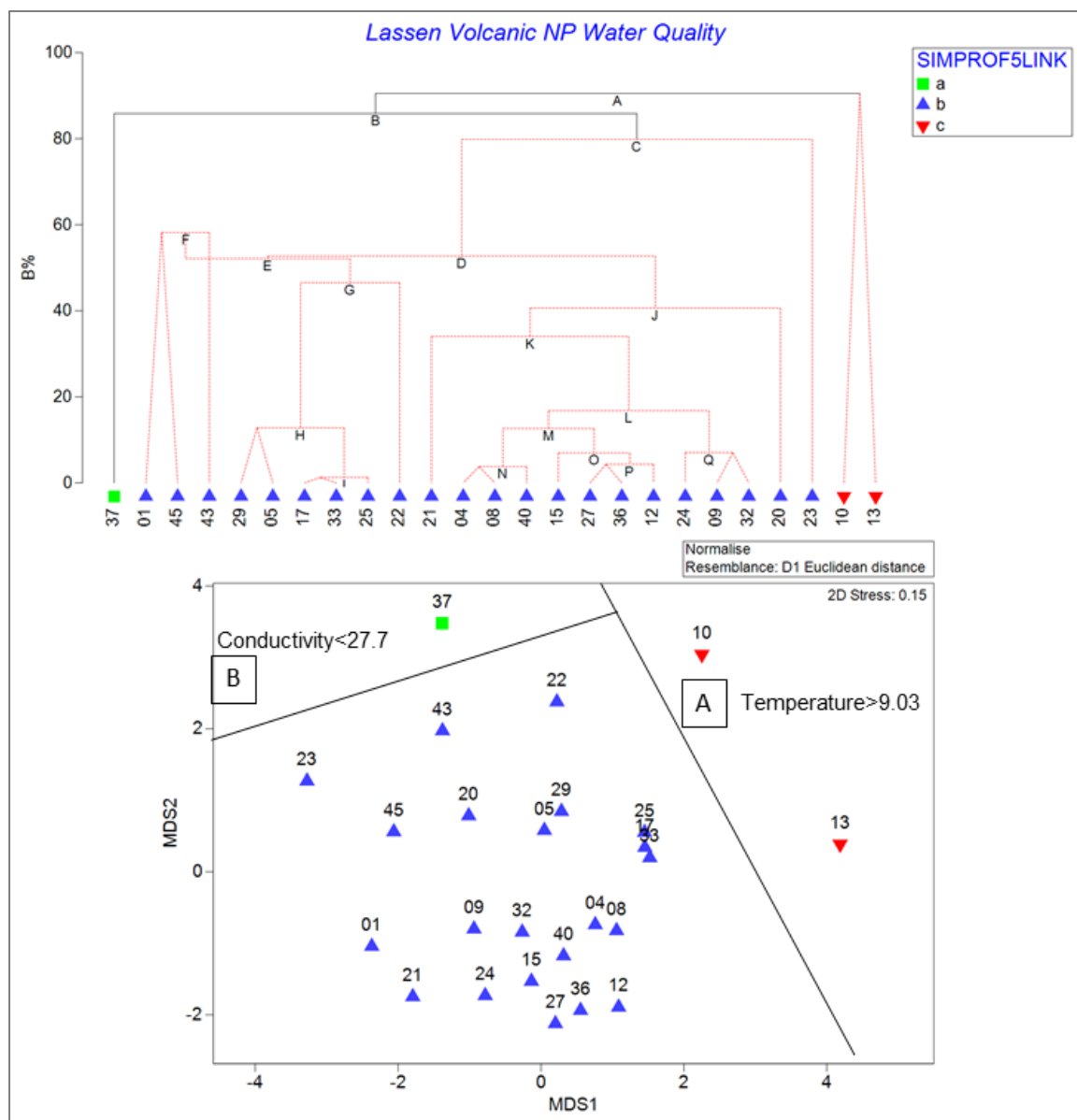


Figure 46. Stream classification results for Lassen Volcanic National Park based on Water Quality. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A–B indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A–B are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

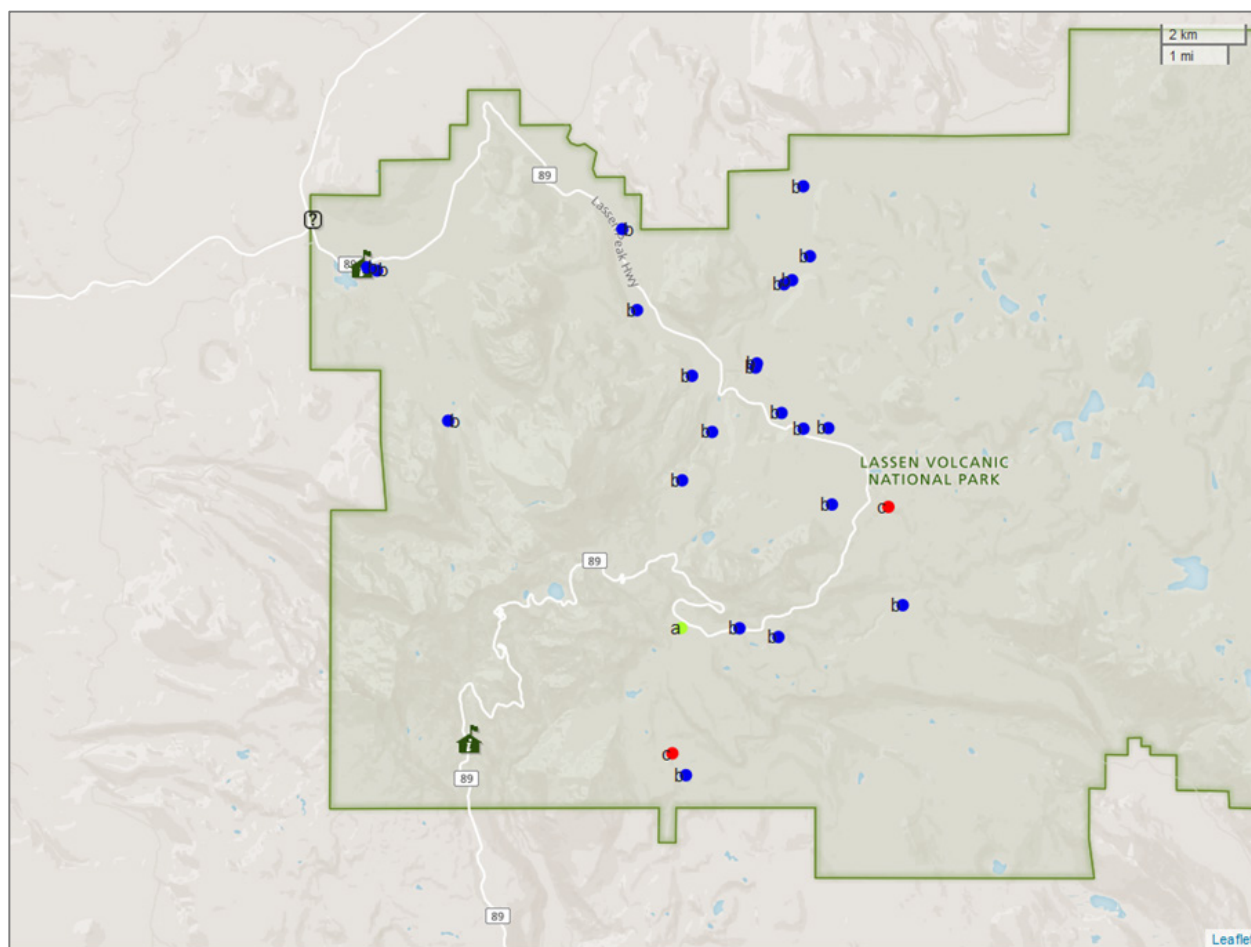


Figure 47. Distribution of stream category groupings at Lassen Volcanic National Park based on Water Quality.

Appendix E. Redwood National and State Parks

This appendix provides analytical figures and brief text summarizing three analyses for the classification of stream groups based on physical and chemical characters. Following a narrative summary of key results, figures for each metric category (e.g., Channel Morphology, Water Quality, Water Chemistry, etc.) are presented that display the cluster analysis, resulting linktree group allocation via simprof, and a metric Multi-Dimensional Scaling (mMDS) ordination. The ordination shows how sites are grouped based on a similarity profile test with 5% significant threshold (SIMPROF5LINK) and is overlaid with lines and lettered groups based on linktree separation characters or a vector biplot, both showing more biologically significant correlations. Lastly, in cases where multiple significant groups occurred (e.g., two or more), a map of the park shows the spatial distribution of groups.

Table 35 shows the name, sampling code, and coordinates of sites sampled.

Table 35. Site and stream names, location coordinates, and years site was sampled for Redwood National and State Parks.

Site Code	Stream Name	Longitude	Latitude	Years Sampled
REDWWQ01	McArthur Creek	-124.068	41.24171	2012, 2015, 2018
REDWWQ02	UT to Brown	-124.009	41.38615	2012, 2015, 2018
REDWWQ03	West Branch Mill Ck	-124.058	41.68514	2012, 2015, 2018
REDWWQ04	Redwood Creek	-124.001	41.20703	2012, 2015, 2018
REDWWQ05	East Fork Mill Creek	-124.089	41.72889	2012, 2015, 2018
REDWWQ06	Lost Man Creek	-124.022	41.32938	2012, 2015, 2018
REDWWQ07	Cedar Creek	-124.073	41.77723	2012, 2015, 2018
REDWWQ08	Bummer Lake Creek	-124.047	41.74156	2012, 2015, 2018
REDWWQ09	Wilson Creek	-124.061	41.67108	2012, 2015, 2018
REDWWQ10	UT to Prairie	-124.046	41.357	2012, 2015, 2018
REDWWQ11	West Branch Mill Ck	-124.092	41.69369	2012, 2015, 2018
REDWWQ12	Little Lost Man Creek	-124.004	41.28674	2012, 2015, 2018
REDWWQ13	Lost Man Creek	-123.977	41.32427	2012, 2015, 2018
REDWWQ14	Rock Creek	-124.008	41.66379	2012, 2015, 2018
REDWWQ15	Mill Creek	-124.114	41.75003	2012, 2015, 2018
REDWWQ16	Redwood Creek	-124.01	41.21897	2012, 2015, 2018
REDWWQ17	Peacock Creek	-124.108	41.82964	2012, 2015, 2018
REDWWQ19	West Branch Mill Ck	-124.109	41.7177	2012, 2015, 2018
REDWWQ20	Redwood Creek	-124.035	41.29679	2012, 2015, 2018
REDWWQ21	Godwood Creek	-124.024	41.36801	2012, 2015, 2018
REDWWQ23	West Branch Mill Ck	-124.108	41.72845	2012, 2015, 2018

Table 35 (continued). Site and stream names, location coordinates, and years site was sampled for Redwood National and State Parks.

Site Code	Stream Name	Longitude	Latitude	Years Sampled
REDWWQ24	Lost Man Creek	-124.002	41.32352	2012, 2015, 2018
REDWWQ25	Redwood Creek	-124.029	41.28875	2012, 2015, 2018
REDWWQ26	Rock Creek	-124.007	41.6643	2015, 2018
REDWWQ28	Godwood Creek	-124.037	41.38173	2015, 2018
REDWWQ29	Bond Creek	-124.021	41.23361	2015, 2018
REDWWQ30	West Branch Mill Ck	-124.109	41.71664	2018

Key Results

(Numbers in this section reference stream site codes from Table 35.)

Channel Morphology

- Nine groups were differentiated, with thalweg depth being a common separator (Figures 48–49)
- Two groups, both with two stream sites each, were characterized by being deeper than most other streams of Redwood National and State Parks, and all four stream sites were on Redwood Creek

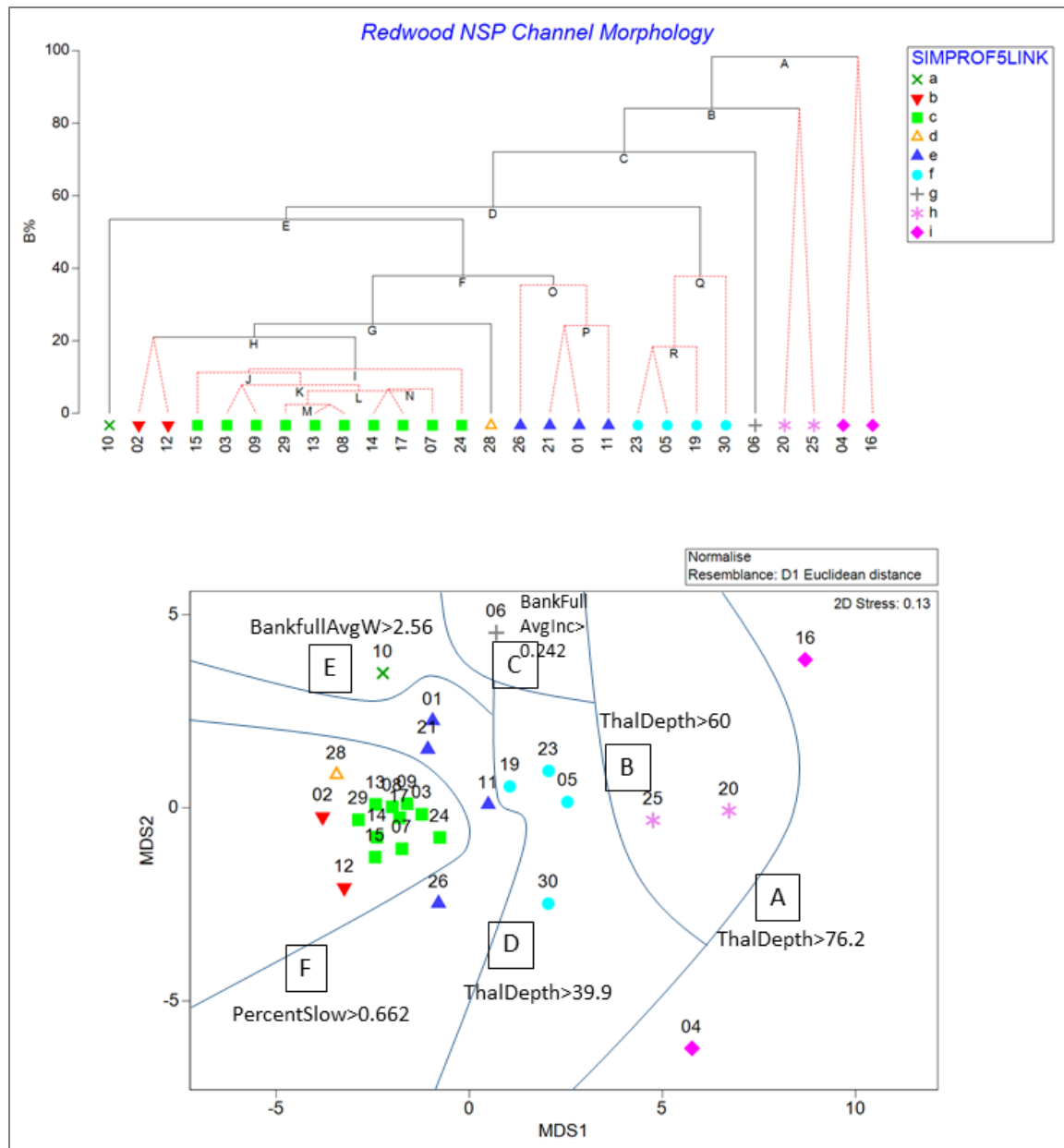


Figure 48. Stream classification results for Redwood National and State Parks based on Channel Morphology metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A–F indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A–F are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

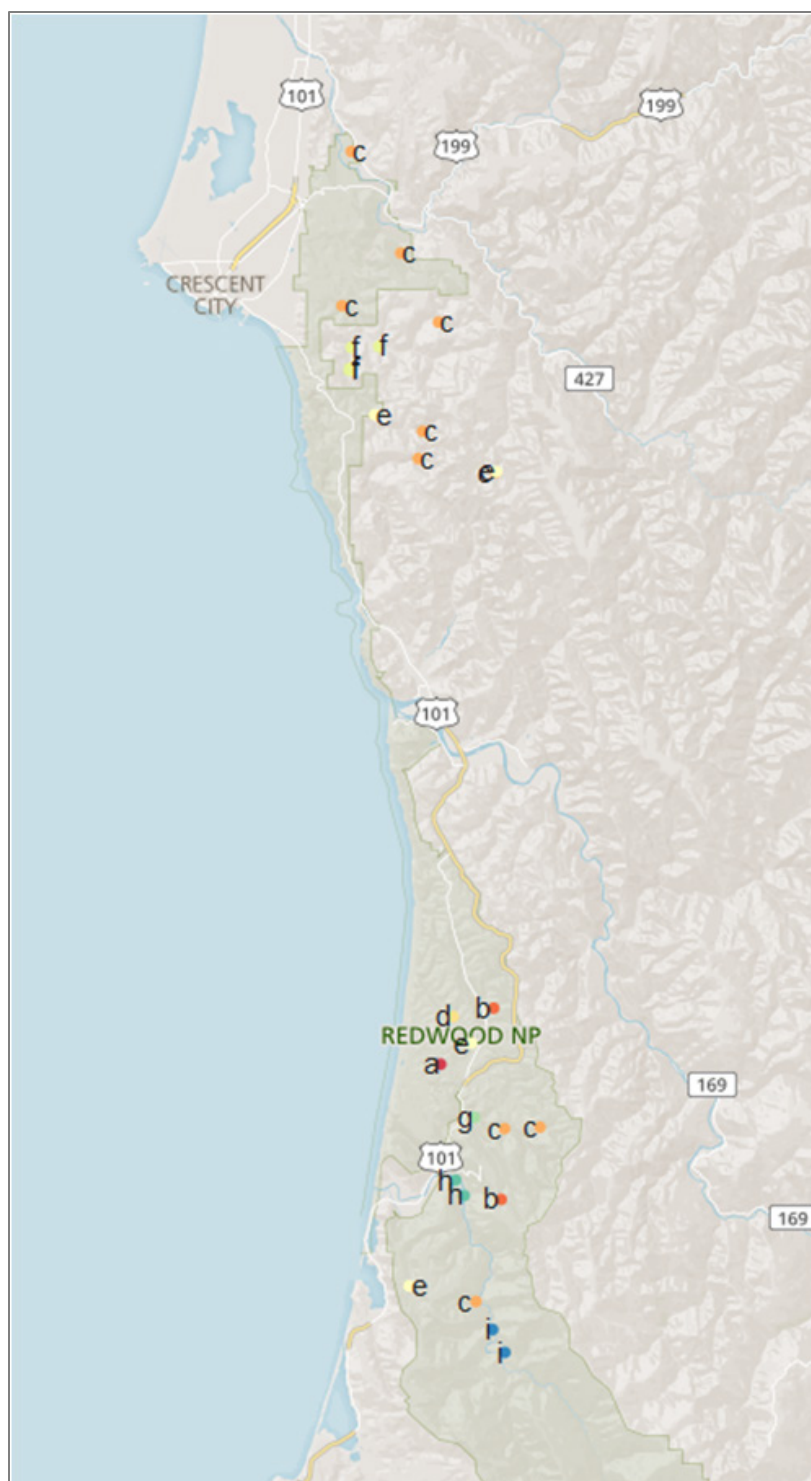


Figure 49. Distribution of stream category groupings at Redwood National and State Parks based on Channel Morphology.

Habitat Complexity

- Seven groups were differentiated, with basic separation based on low to high amounts of complexity (Figures 50–51)
- Redwood Creek sites were in the lower complexity groups, but were not exclusive to these groups (i.e., other stream were also characterized by low complexity, for example West Branch Mill Creek [30])
- No geographical pattern was apparent

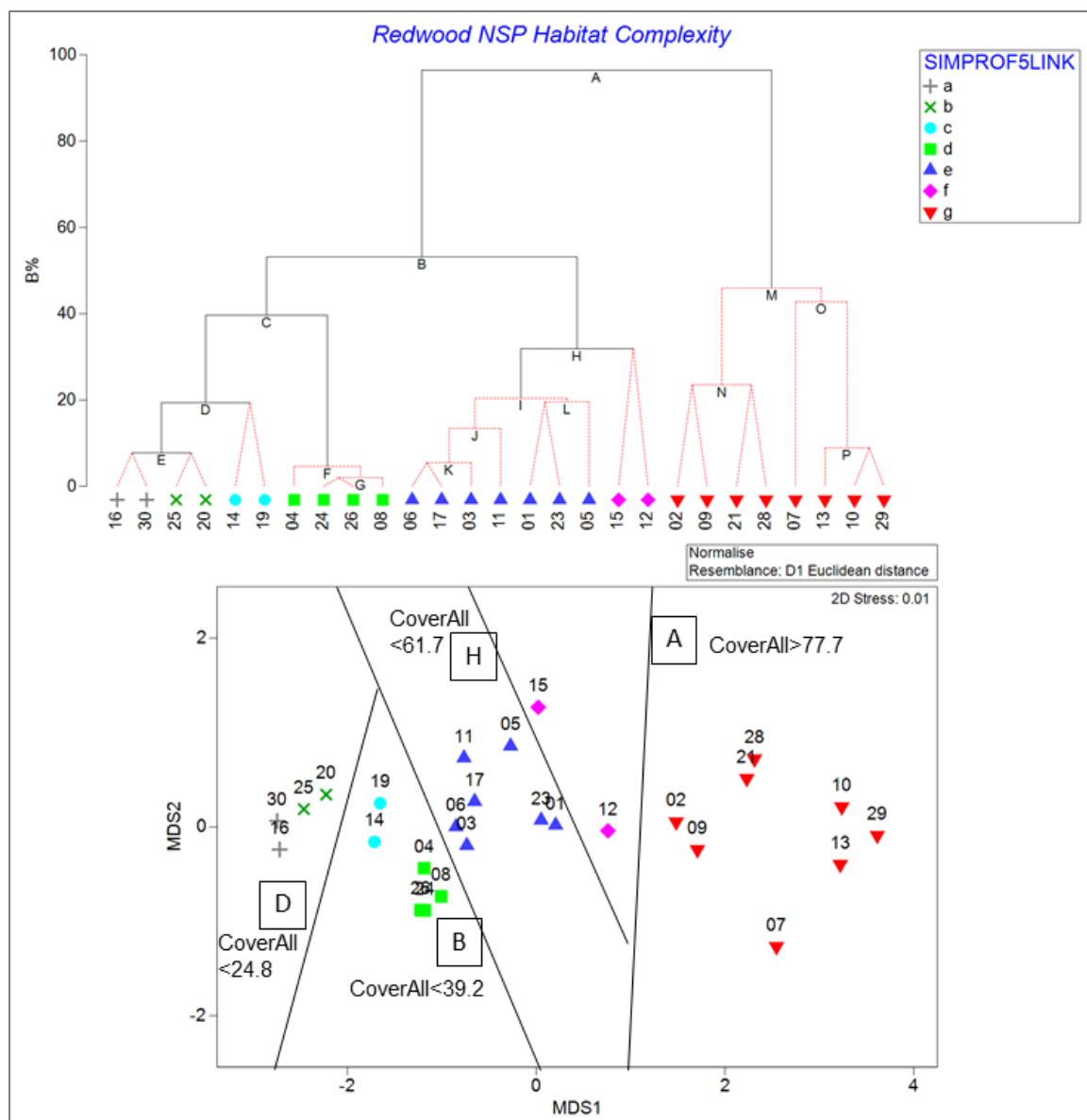


Figure 50. Stream classification results for Redwood National and State Parks based on Habitat Complexity metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A, B, D, and H indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A, B, D, and H are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

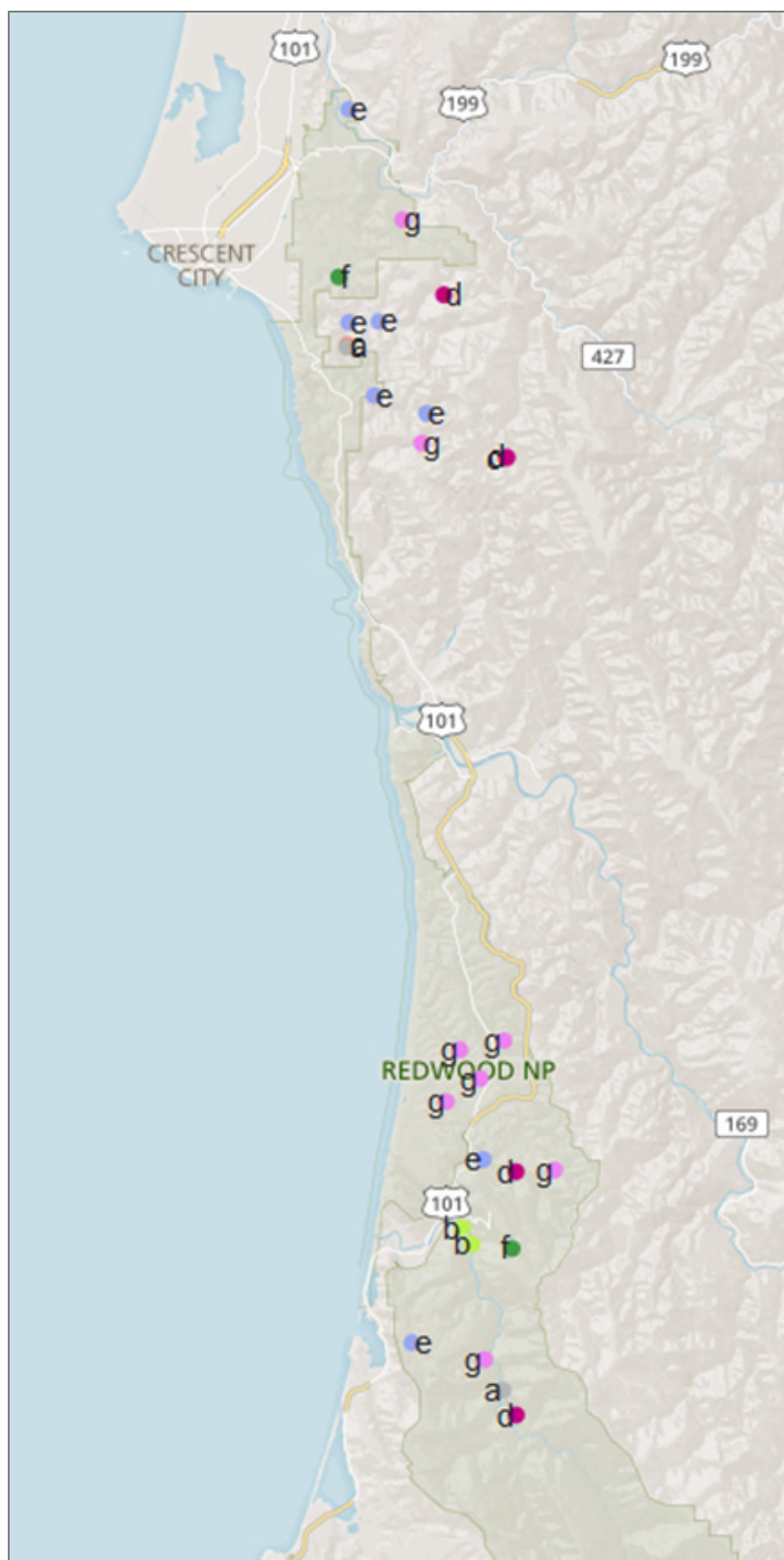


Figure 51. Distribution of stream category groupings at Redwood National and State Parks based on Habitat Complexity.

Large Woody Debris

- Eight groups were differentiated, with most sites characterized together on the relatively low end for large woody debris (note that sites with “low” woody debris in Redwood National and State Parks may still have substantial amounts of woody debris because the data are normalized) (Figures 52–53)
- One site in a singular group was noted as having the highest amount of Large Woody Debris—Bond Creek (29)

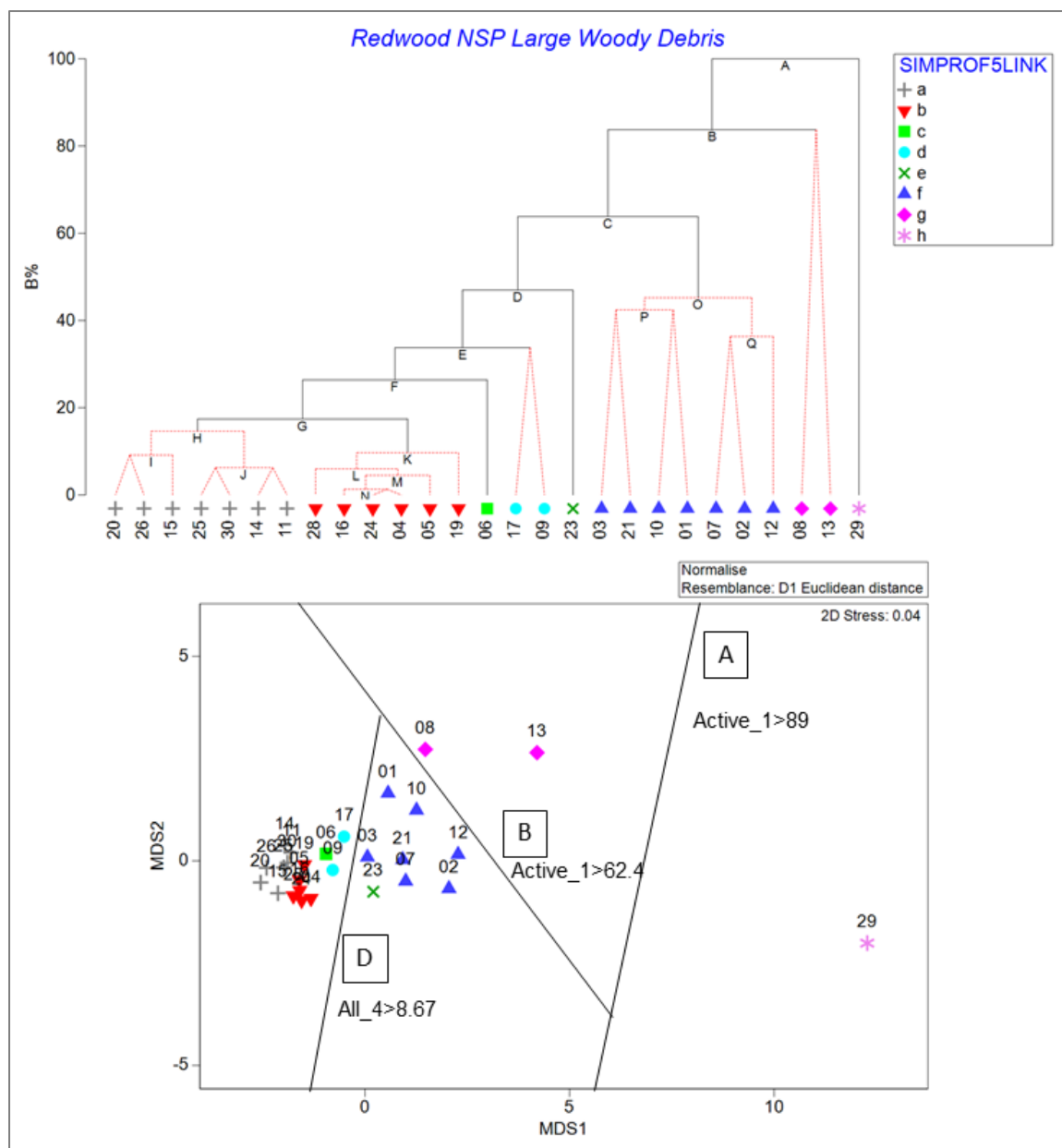


Figure 52. Stream classification results for Redwood National and State Parks based on Large Woody Debris metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A, B, and D indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A, B, and D are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

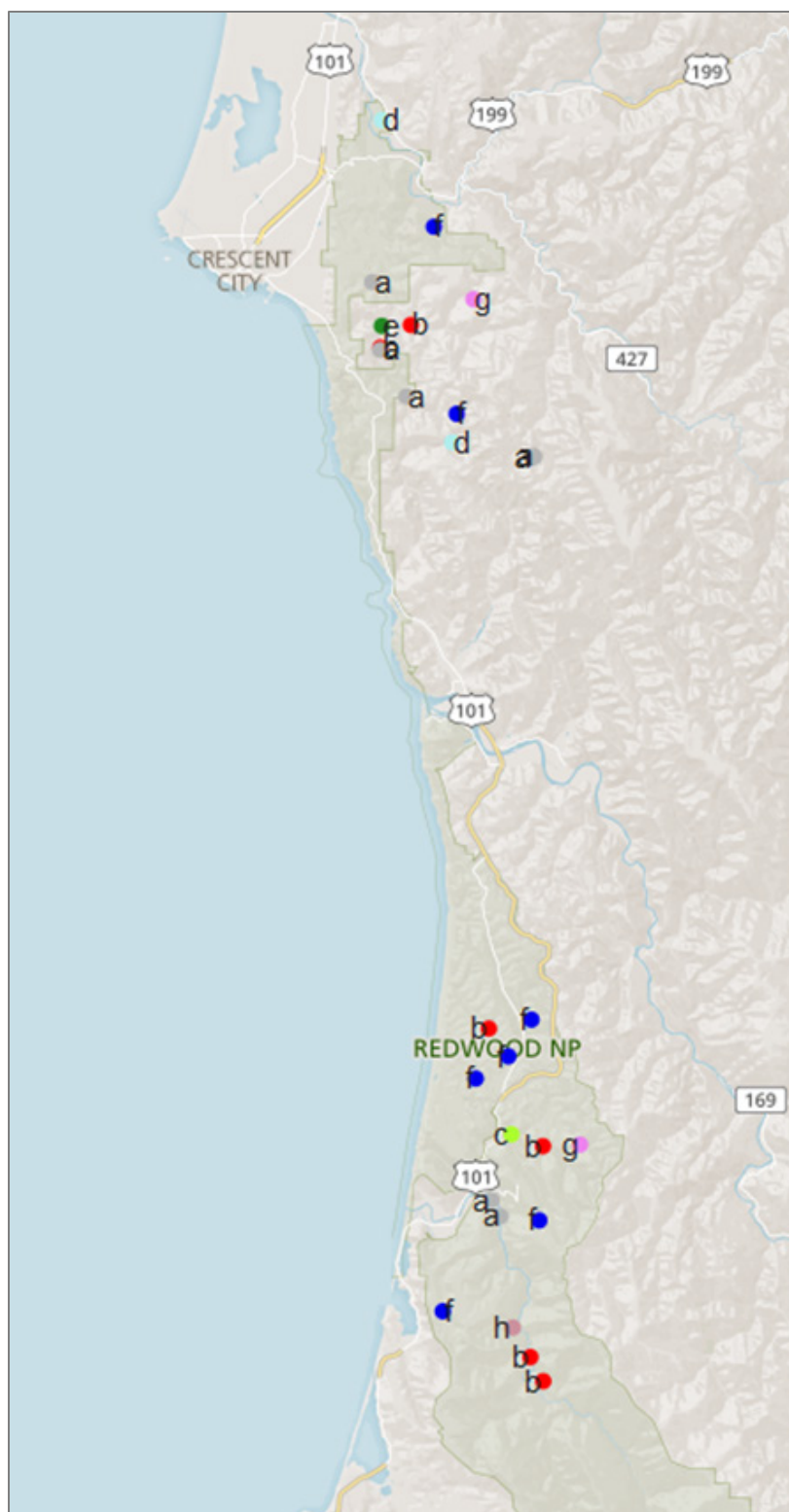


Figure 53. Distribution of stream category groupings at Redwood National and State Parks based on Large Woody Debris.

Riparian Characters

- Ten groups were differentiated (Figures 54–55). No clear pattern was apparent, although Redwood Creek sites appeared to be associated with low amount of ground cover.
- Other variables providing correlative separation of groups and stream sites were the amount of mean woody cover in the mid-story, the amount of understory deciduous cover, and the mean amount of ground cover.

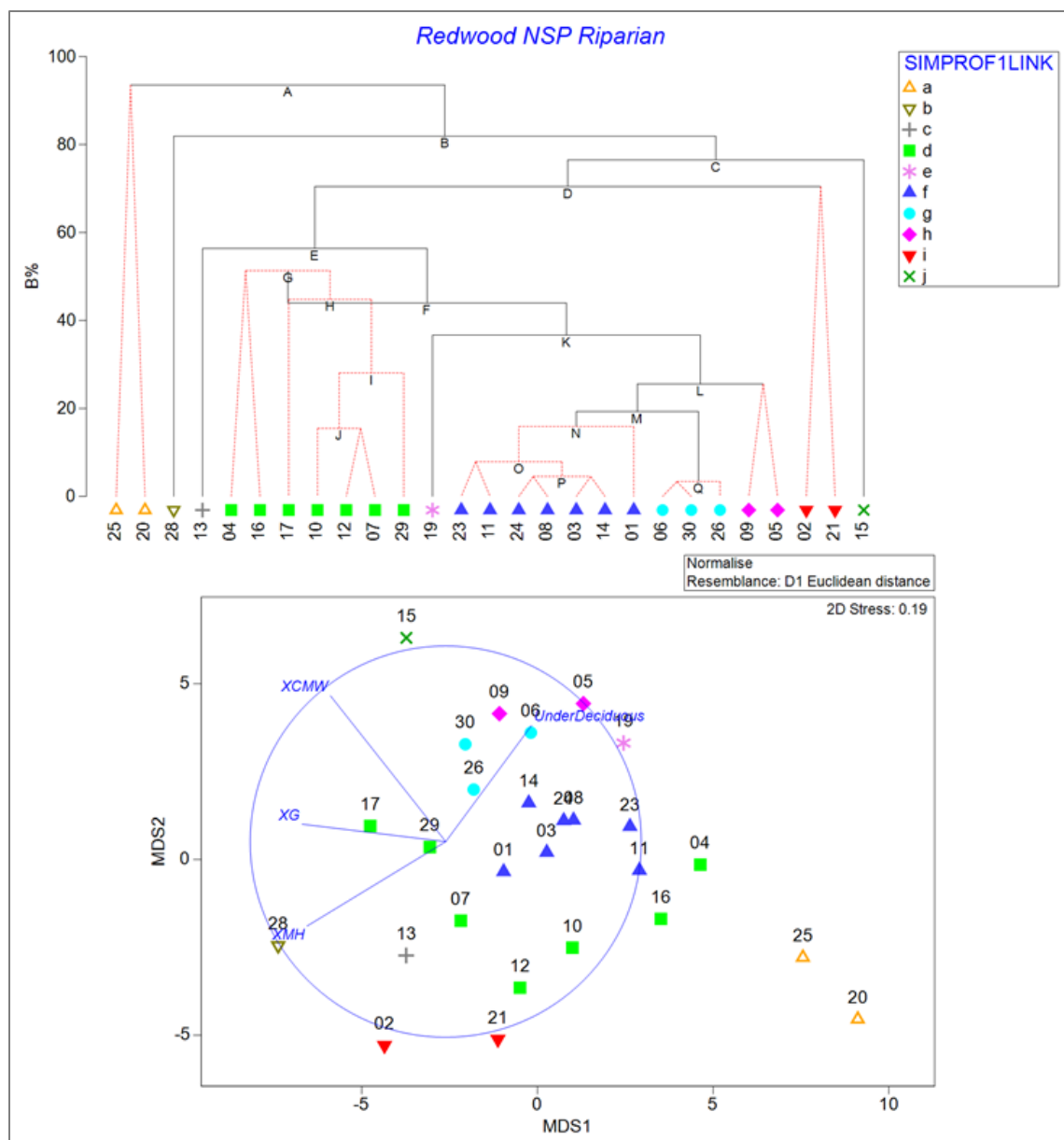


Figure 54. Stream classification results for Redwood National and State Parks based on Riparian metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Vectors represent a further grouping for biological meaning based on correlations of sites to labeled metrics (step F in Figure 3). The outer edge of the circle represents a correlation value of 1; vectors for each parameter are defined by the direction and length, so that this direction in the ordination space is the direction of the parameter increasing. XCMW = mean cover in the canopy and mid-story of woody vegetation, XMH = mean of mid-story herbaceous vegetation, XG = mean of the total ground cover, UnderDeciduous = percent of deciduous vegetation in the understory. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

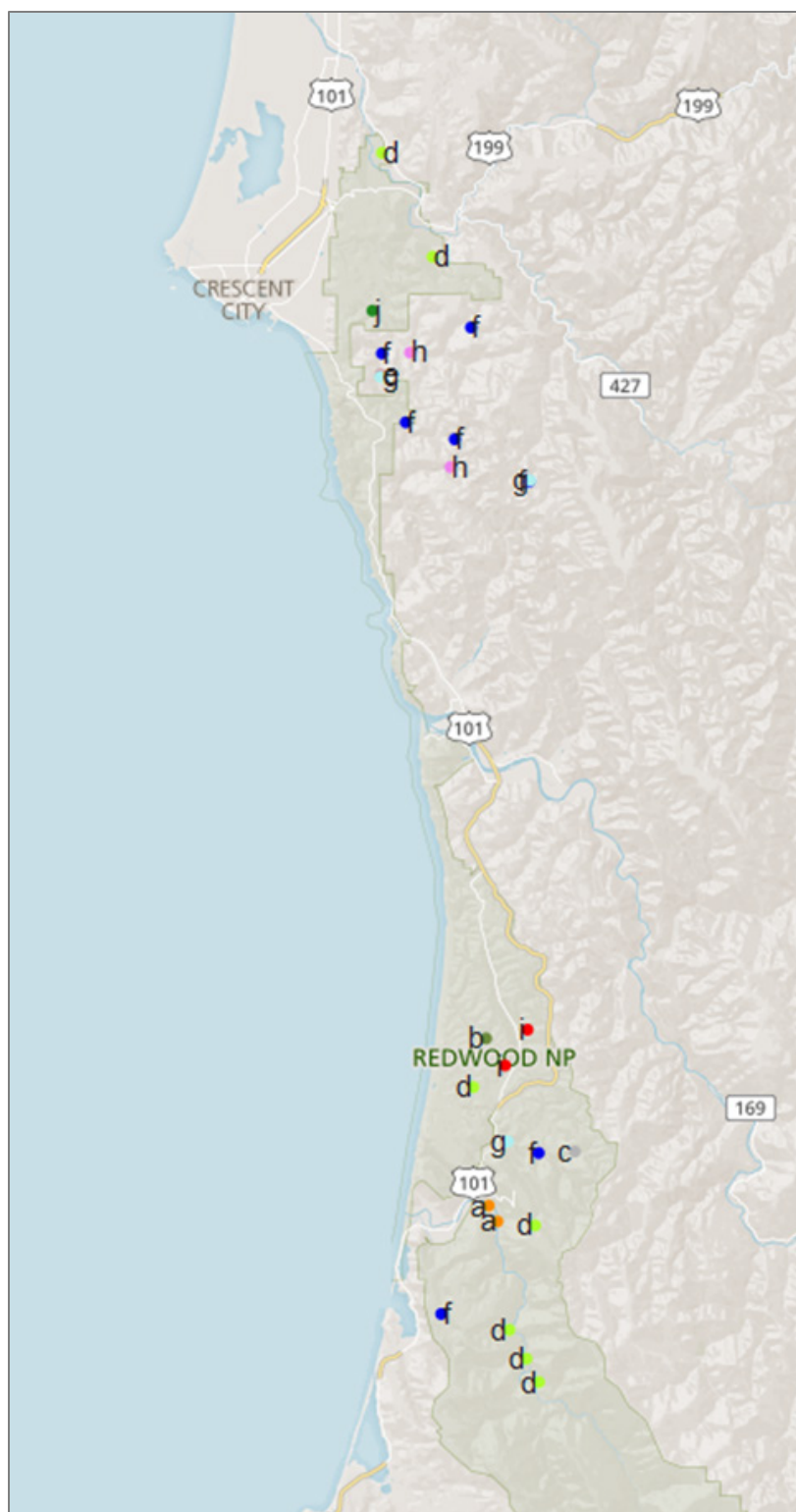


Figure 55. Distribution of stream category groupings at Redwood National and State Parks based on Riparian Character metrics.

Slope and Sinuosity

- Seven groups were differentiated (Figures 56–57).
- No clear pattern was discernible, but four sites in two groups were associated with higher slopes. These were Bond Creek (29), Bummer Lake Creek (08), Unnamed tributary to Brown (02), and Lost Man Creek (13).

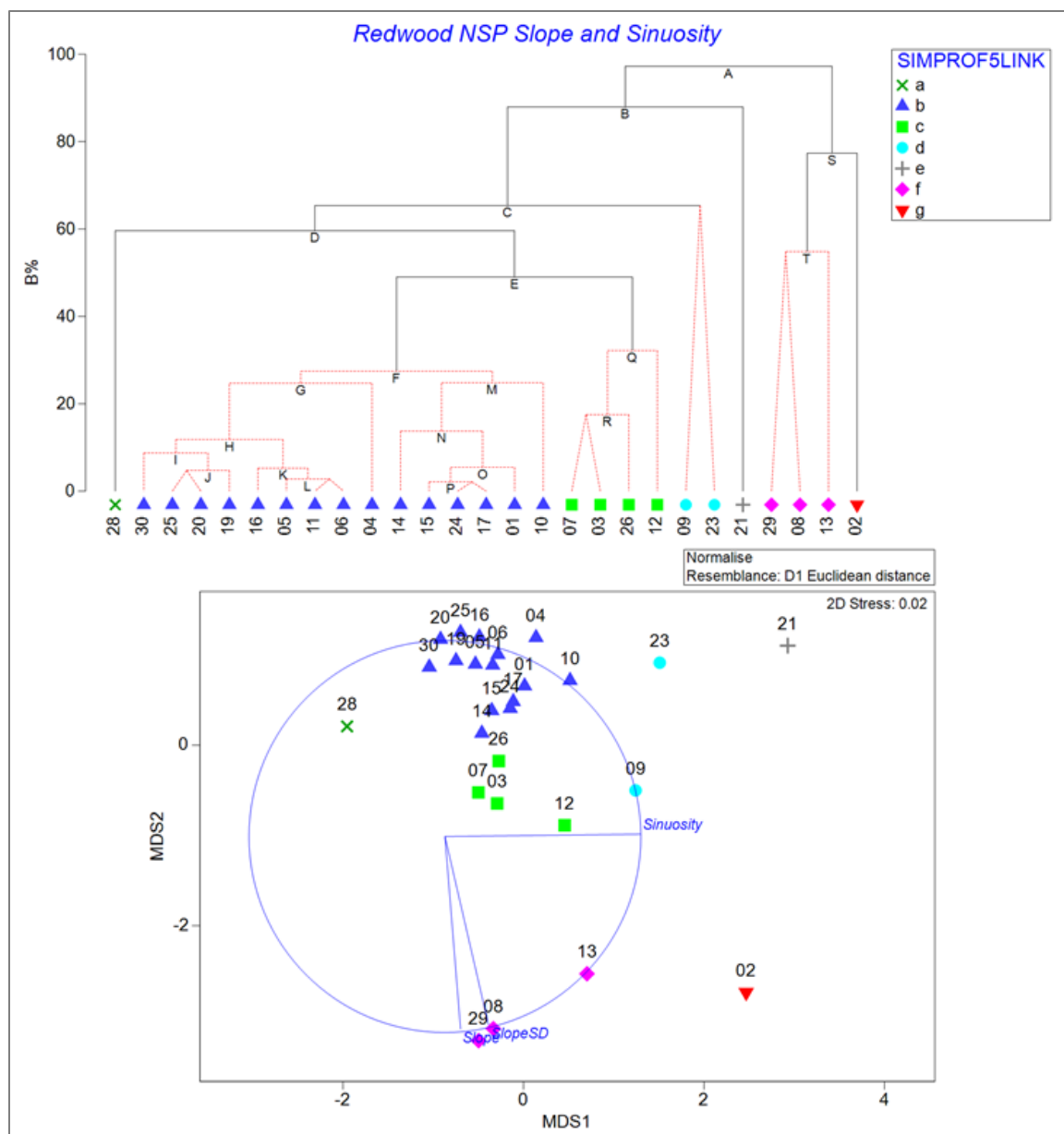


Figure 56. Stream classification results for Redwood National and State Parks based on Slope and Sinuosity. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Vectors represent a further grouping for biological meaning based on correlations of sites to labeled metrics (step F in Figure 3). The outer edge of the circle represents a correlation value of 1; vectors for each parameter are defined by the direction and length, so that this direction in the ordination space is the direction of the parameter increasing. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

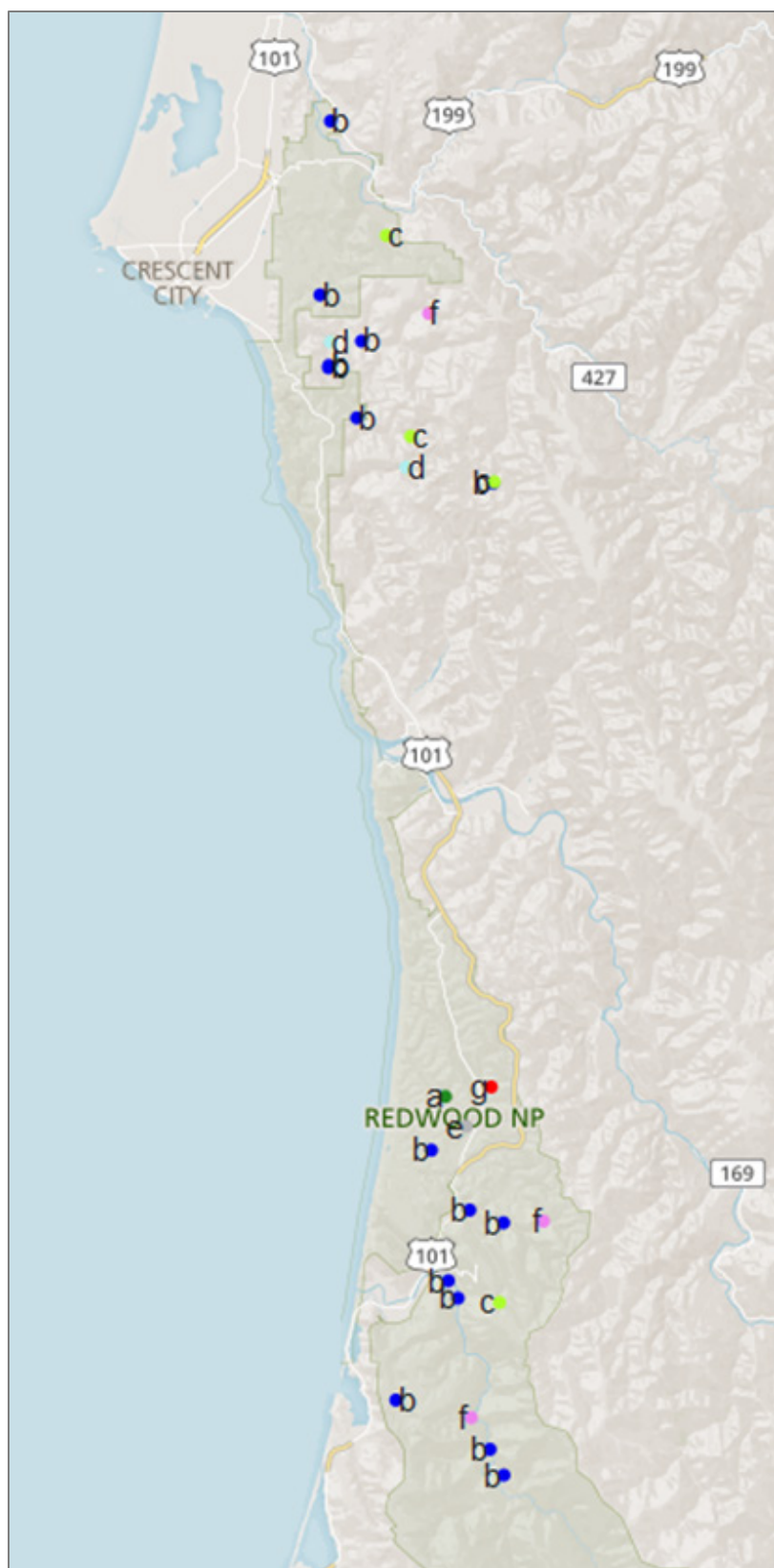


Figure 57. Distribution of stream category groupings at Redwood National and State Parks based on Slope and Sinuosity.

Stream Substrate

- Six groups were differentiated (Figures 58–59)
- One group of note was McArthur Creek (01), characterized by high amounts of fine sediments
- No other discernible pattern was apparent

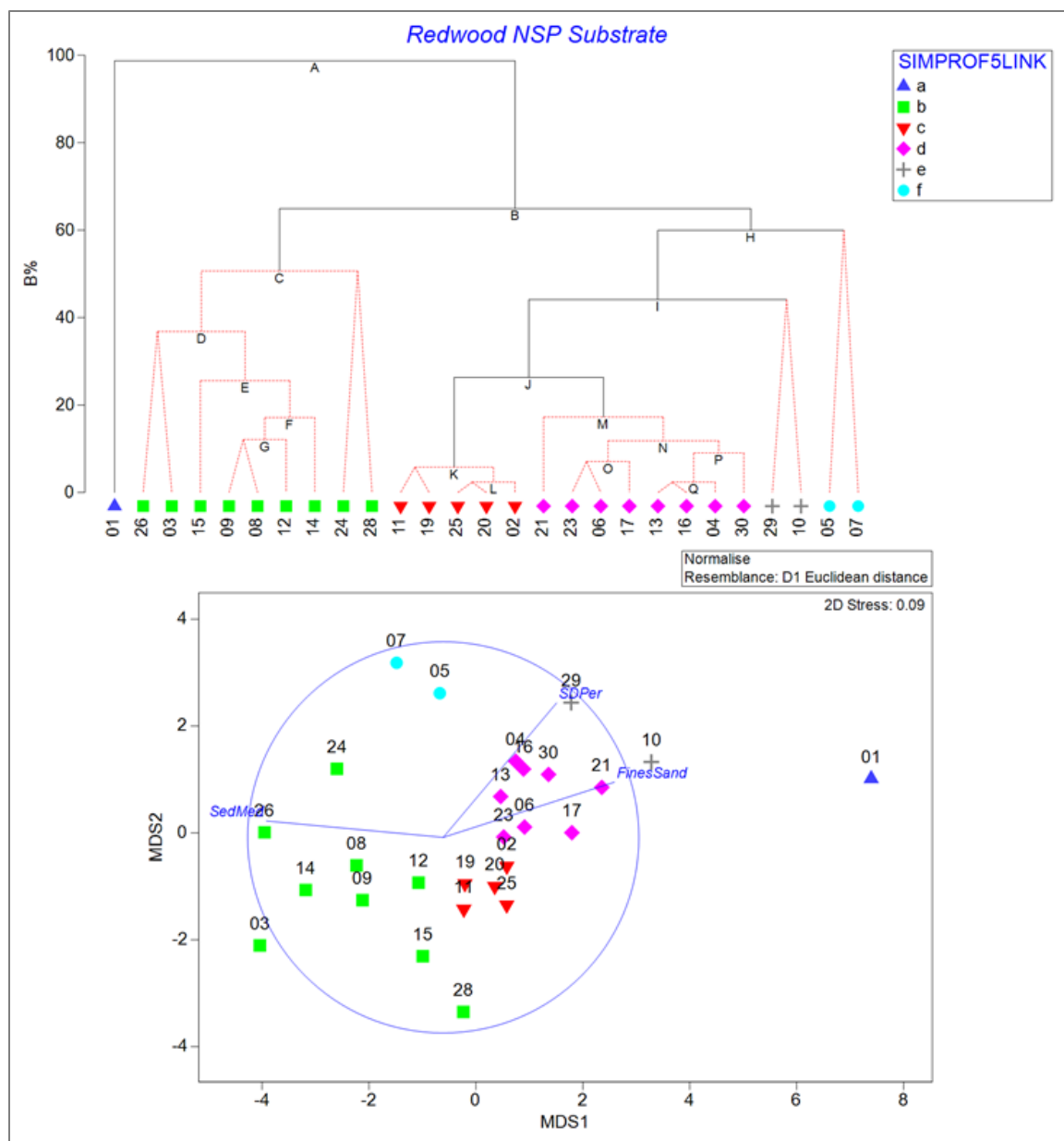


Figure 58. Stream classification results for Redwood National and State Parks based on Substrate. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Vectors represent a further grouping for biological meaning based on correlations of sites to labeled metrics (step F in Figure 3). The outer edge of the circle represents a correlation value of 1; vectors for each parameter are defined by the direction and length, so that this direction in the ordination space is the direction of the parameter increasing. SDPer = standard deviation of percent embeddedness, FinesSand = percent of substrate in the sand and smaller, SedMed = median sediment size. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

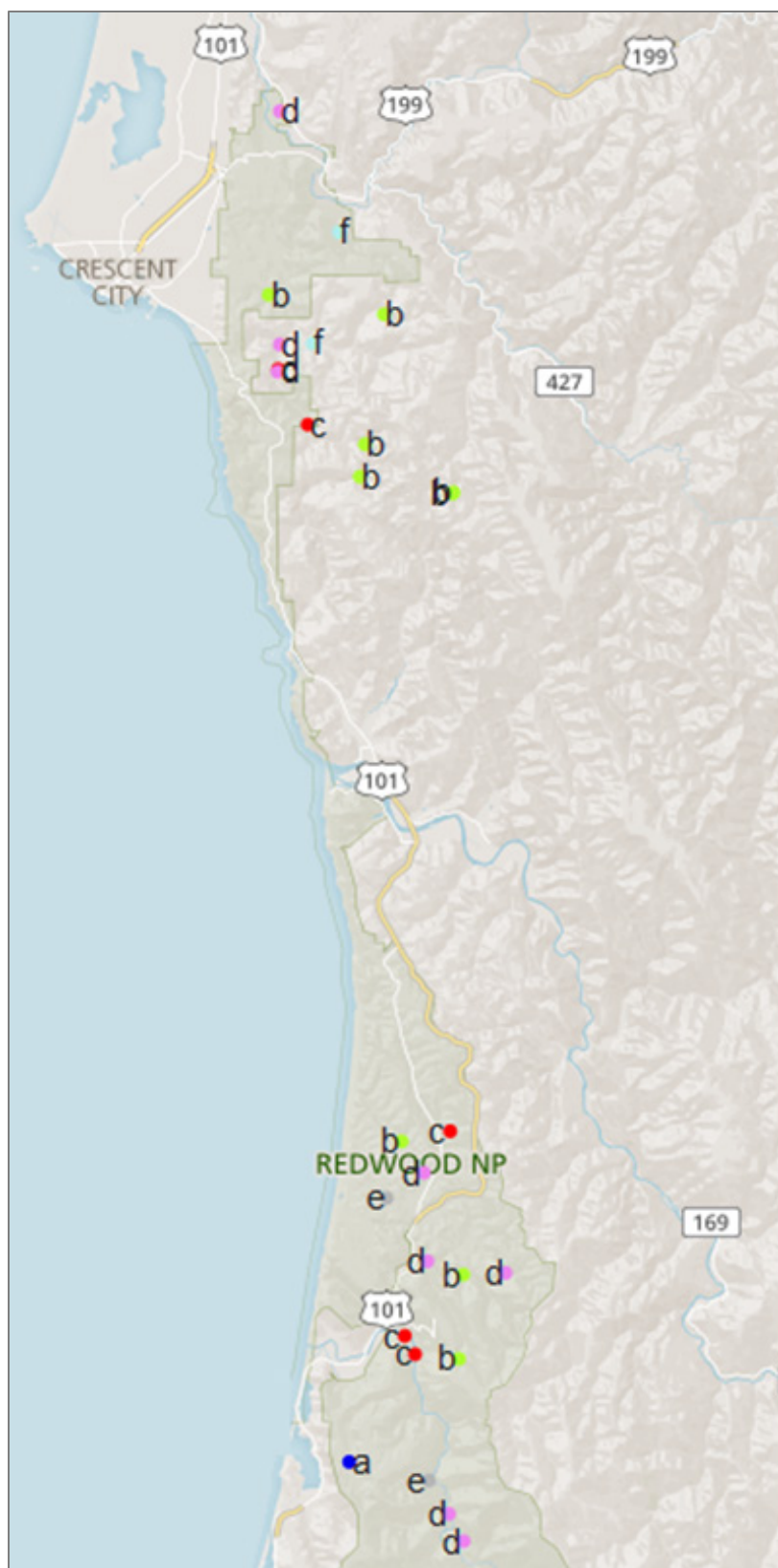


Figure 59. Distribution of stream category groupings at Redwood National and State Parks based on Stream Substrate.

Water Chemistry

- Five groups were differentiated (Figures 60–61).
- Two extremes were apparent. One group, Redwood Creek sites (04, 16, 20, 25), was noted as having high sulfate. One group (McArthur Creek [01], Unnamed Tributary to Prairie Creek [10], and Godwood Creek [21, 28]) was noted to have higher amounts of Chloride.

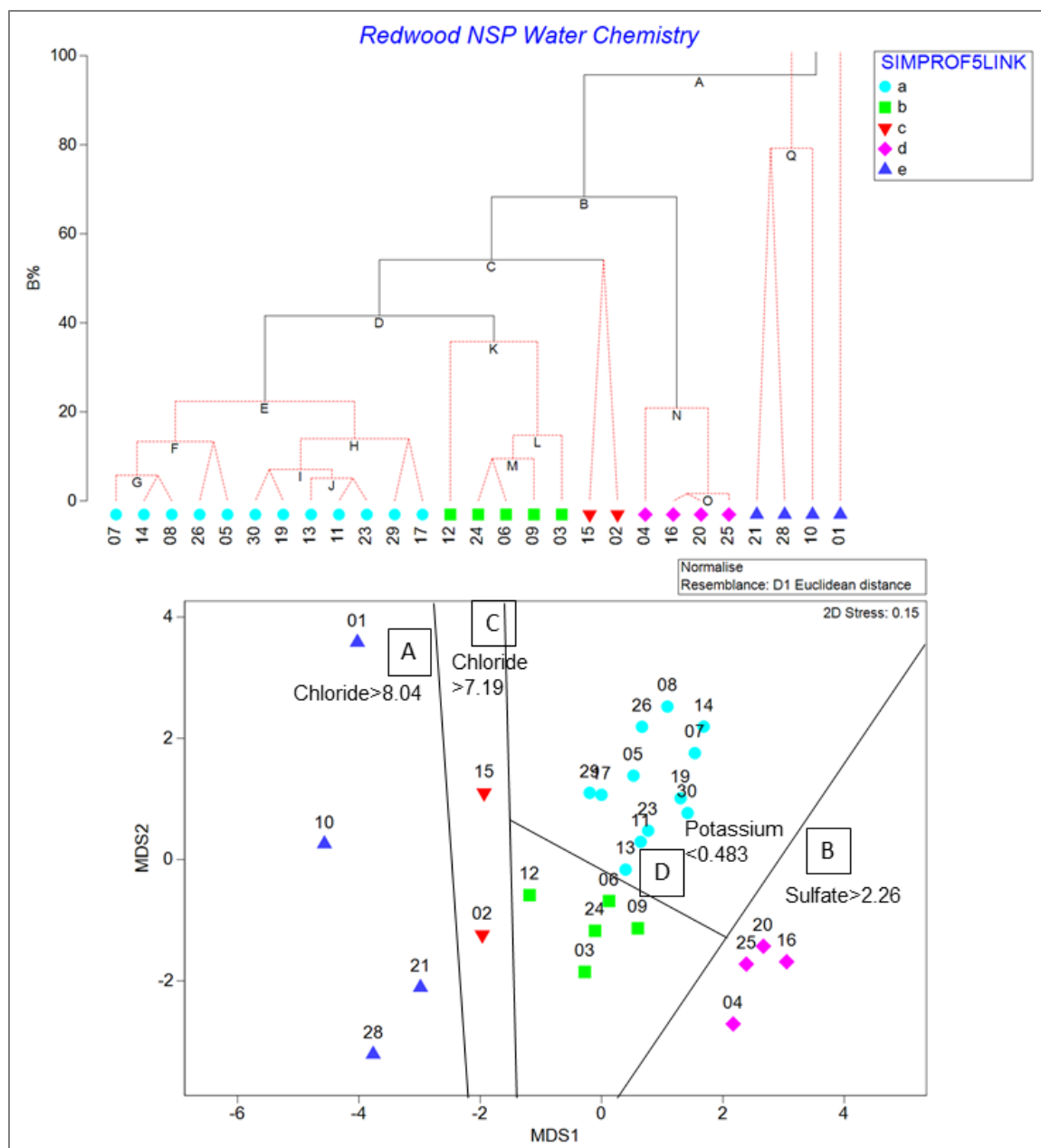


Figure 60. Stream classification results for Redwood National and State Parks based on Water Chemistry. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A–D indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A–D are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

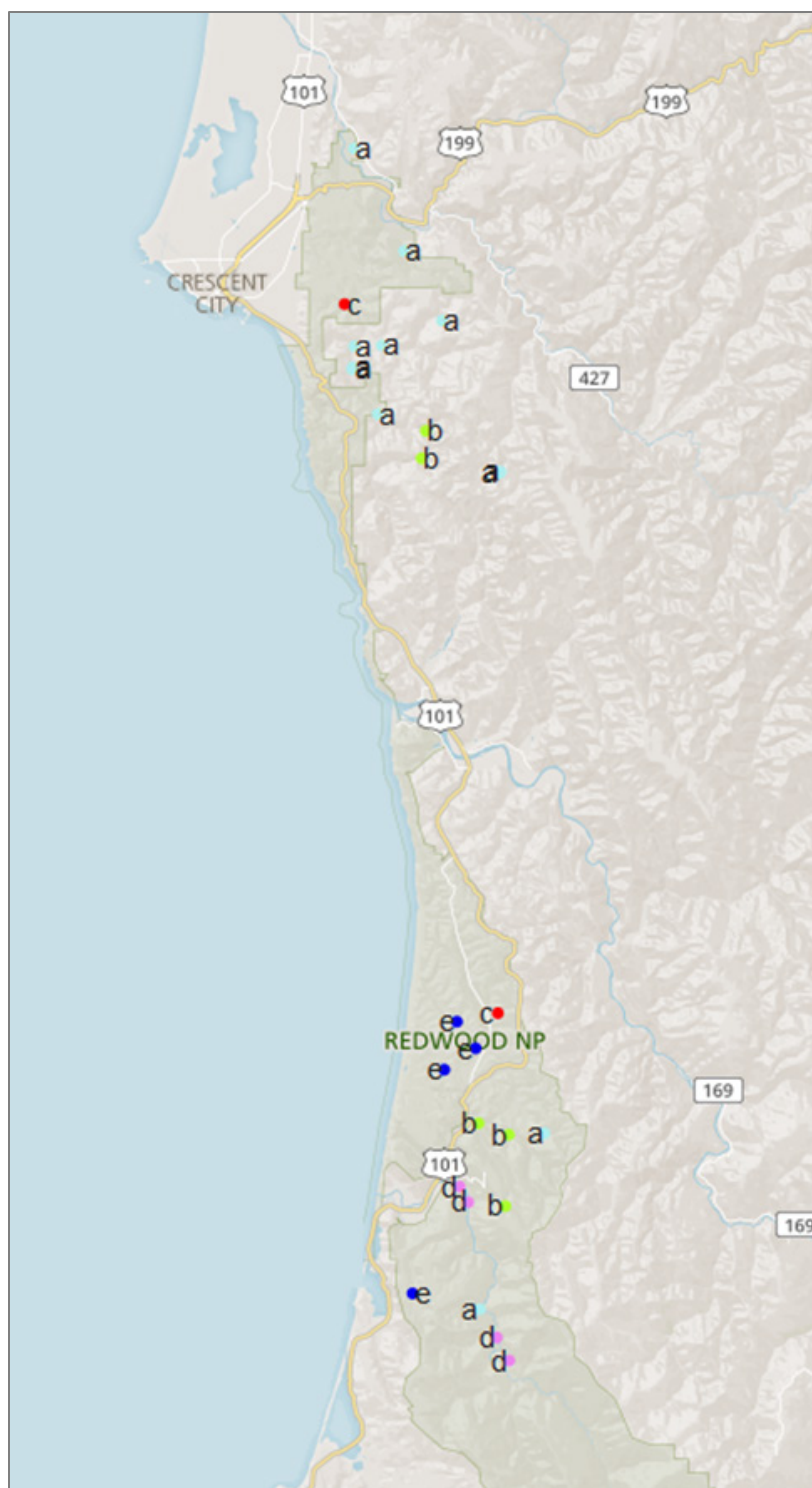


Figure 61. Distribution of stream category groupings at Redwood National and State Parks based on Water Chemistry.

Water Quality

- Five groups were differentiated (Figures 62–63)
- Of these, Cedar Creek (07) stood out as a singular group with high turbidity (>28.6 NTU)
- Secondly, Redwood Creek sites (04, 16, 20, 25) all formed a distinct group with higher temperatures than the other streams (>17 °C)
- An additional group showing coherence to a geographical area of the park and high pH values was composed of an Unnamed Tributary to Brown (02), Peacock Creek (17), and Godwood Creek (21, 28)

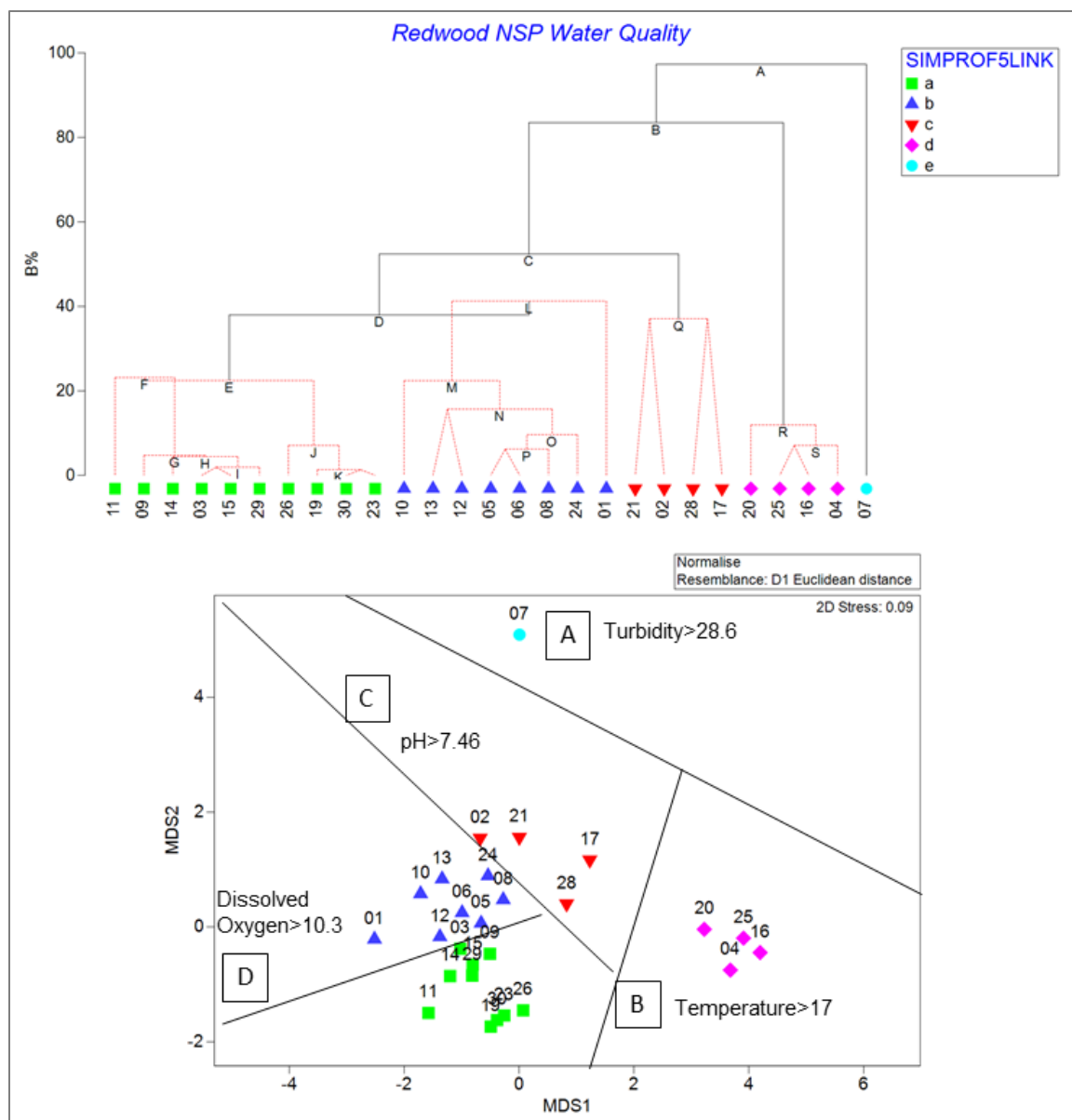


Figure 62. Stream classification results for Redwood National and State Parks based on Water Quality. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A–D indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A–D are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

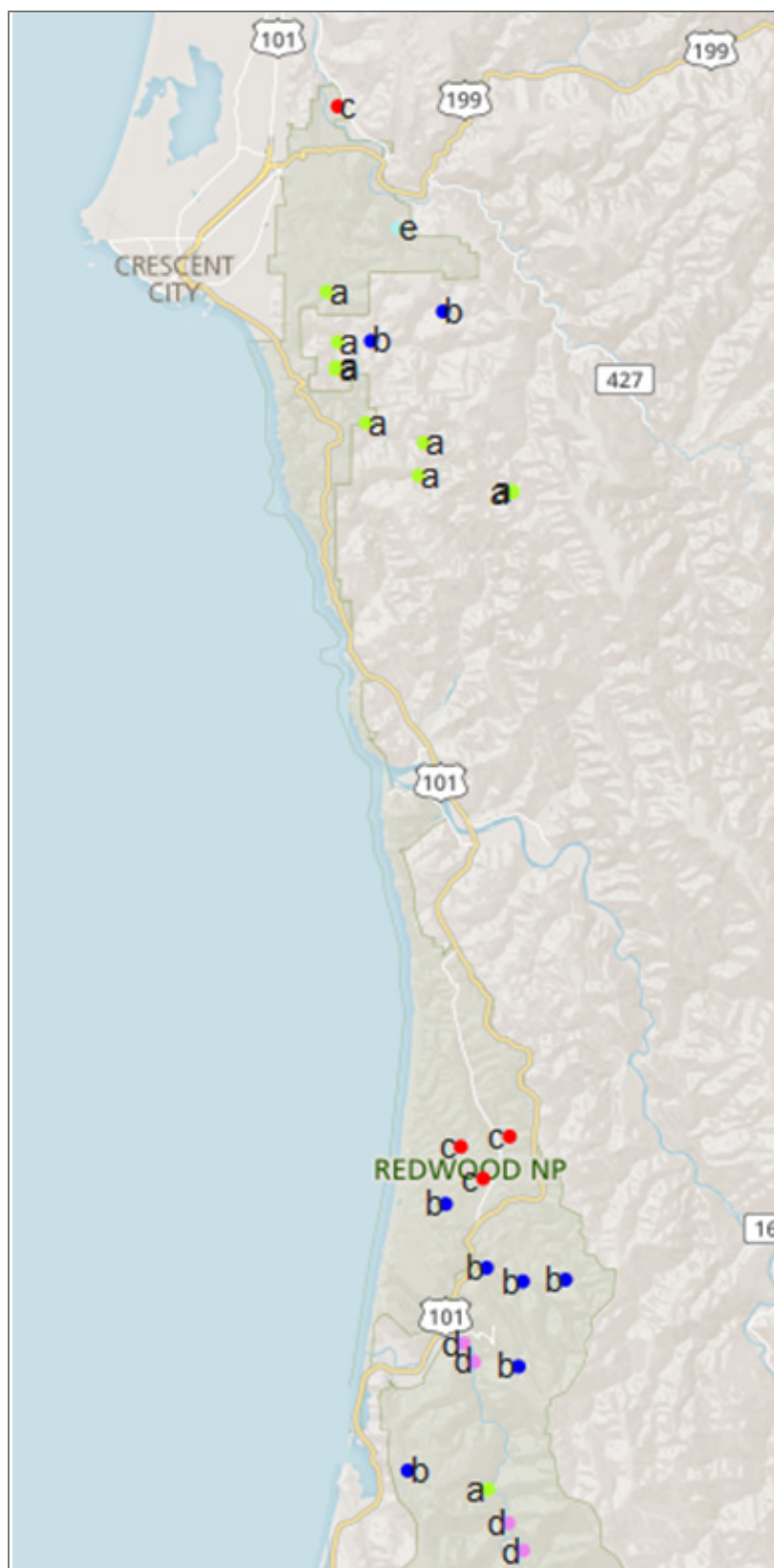


Figure 63. Distribution of stream category groupings at Redwood National and State Parks based on Water Quality.

Appendix F. Whiskeytown National Recreation Area

This appendix provides analytical figures and brief text summarizing three analyses for the classification of stream groups based on physical and chemical characters. Following a narrative summary of key results, figures for each metric category (e.g., Channel Morphology, Water Quality, Water Chemistry, etc.) are presented that display the cluster analysis, resulting linktree group allocation via simprof, and a metric Multi-Dimensional Scaling (mMDS) ordination. The ordination shows how sites are grouped based on a similarity profile test with 5% significant threshold (SIMPROF5LINK) and is overlaid with lines and lettered groups based on linktree separation characters or a vector biplot, both showing more biologically significant correlations. Lastly, in cases where multiple significant groups occurred (e.g., two or more), a map of the park shows the spatial distribution of groups.

Table 36 shows the name, sampling site code, and coordinates of sites sampled.

Table 36. Site and stream names, location coordinates, and years site was sampled for Whiskeytown National Recreation Area.

Site Code	Stream Name	Longitude	Latitude	Years Sampled
WHISWQ01	Willow Creek	-122.650667	40.67120138	2011, 2014, 2017
WHISWQ02	Boulder creek	-122.601209	40.6354694	2011, 2014, 2017
WHISWQ03	UT to Crystal Creek 1	-122.682228	40.6314629	2011, 2014, 2017
WHISWQ05	Boulder creek	-122.630445	40.62347487	2011, 2014, 2017
WHISWQ06	Grizzly Gulch	-122.599424	40.65966298	2011, 2014, 2017
WHISWQ08	Paige Boulder Creek	-122.56467	40.58097227	2011, 2014, 2017
WHISWQ09	Mill creek	-122.650885	40.64598322	2011, 2014, 2017
WHISWQ12	Brandy creek	-122.603557	40.59582173	2011, 2014, 2017
WHISWQ14	UT to Brandy Creek	-122.597756	40.60085552	2011
WHISWQ15	Crystal creek	-122.667601	40.65198875	2011, 2014, 2017
WHISWQ17	Boulder creek	-122.627778	40.62736935	2011, 2014, 2017
WHISWQ18	Brandy creek	-122.57721	40.60956249	2011, 2014, 2017
WHISWQ21	Willow Creek	-122.640026	40.66618167	2011, 2014, 2017
WHISWQ22	UT to Boulder Creek	-122.615429	40.62843641	2011, 2014, 2017
WHISWQ23	Crystal creek	-122.676907	40.63409337	2011, 2014, 2017
WHISWQ24	UT to Brandy Creek	-122.60187	40.59043355	2011, 2014, 2017
WHISWQ25	Clear creek	-122.633901	40.66507603	2011, 2014, 2017
WHISWQ26	Whiskey creek	-122.55965	40.65652626	2011, 2014
WHISWQ28	UT to Paige Boulder Creek	-122.581754	40.57739072	2011, 2014, 2017
WHISWQ33	Boulder creek	-122.621275	40.63213142	2011, 2014, 2017
WHISWQ34	Brandy creek	-122.576568	40.61101384	2011, 2014, 2017
WHISWQ35	UT to Crystal Creek	-122.689204	40.62969678	2011, 2014, 2017

Key Results

(Numbers in this section reference stream site codes from Table 36.)

Channel Morphology

- Two groups were differentiated, suggesting that the sample streams of Whiskeytown are all physically similar, with the exception of one outlier—Clear Creek (25) (Figures 64–65). Clear Creek was in a singular group characterized by deep depth (thalweg > 55 cm).

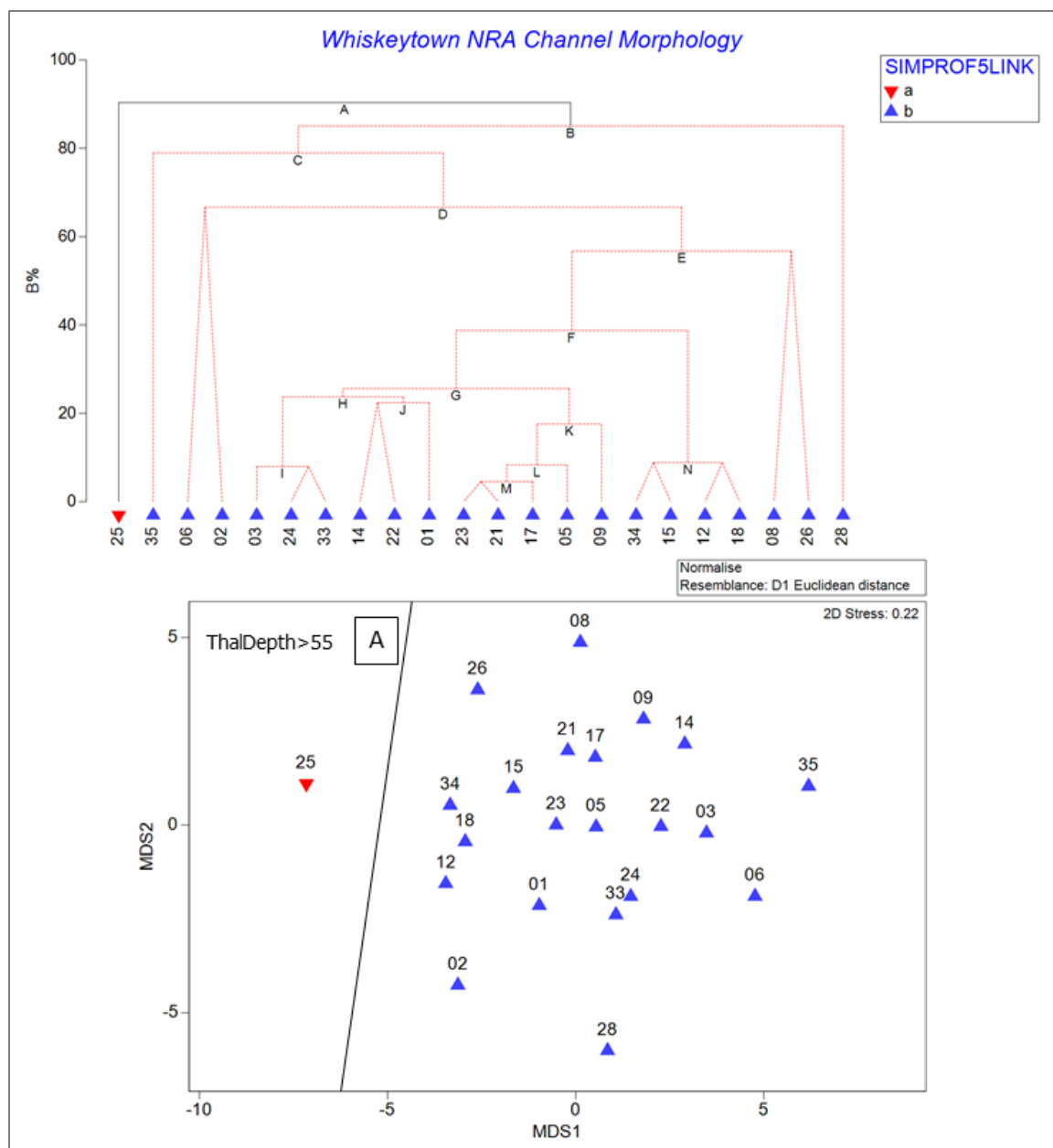


Figure 64. Stream classification results for Whiskeytown National Recreation Area based on Channel Morphology metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letter A indicates further grouping for biologically meaningful distinctions that are described by the metric threshold inside the group (step F in Figure 3). Letter A is different from SIMPROF5LINK groups and reflects a split in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

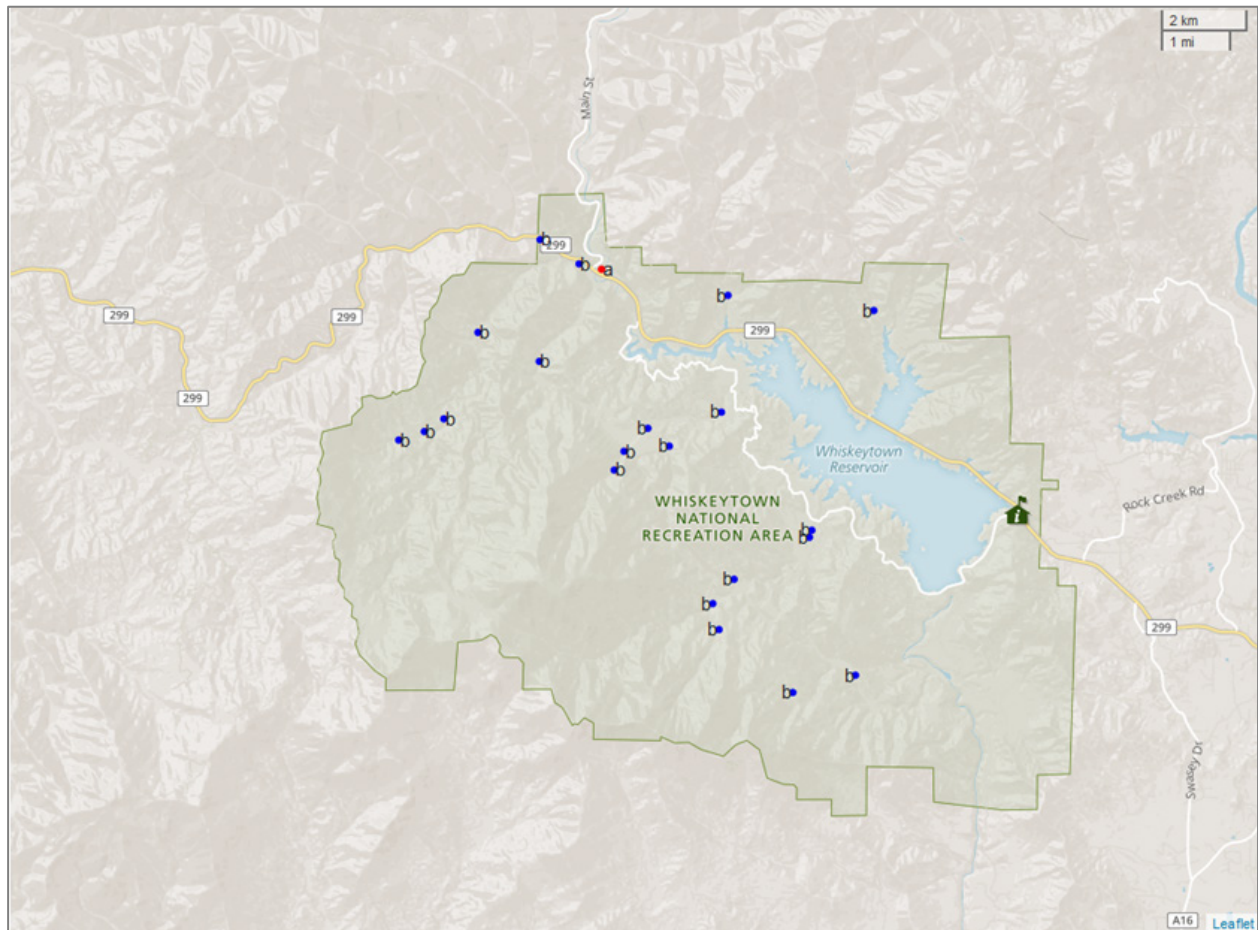


Figure 65. Distribution of stream category groupings at Whiskeytown National Recreation Area based on Channel Morphology.

Habitat Complexity

- Six groups were differentiated (Figures 66–67)
- Groups generally follow a linear gradient from higher to lower cover (Unnamed Tributary to Brandy Creek [14]) was the highest in a singular group)
- Three streams (Clear Creek [25], Willow Creek [21], and Whiskey Creek [26]) formed a group with the lowest amount of habitat complexity

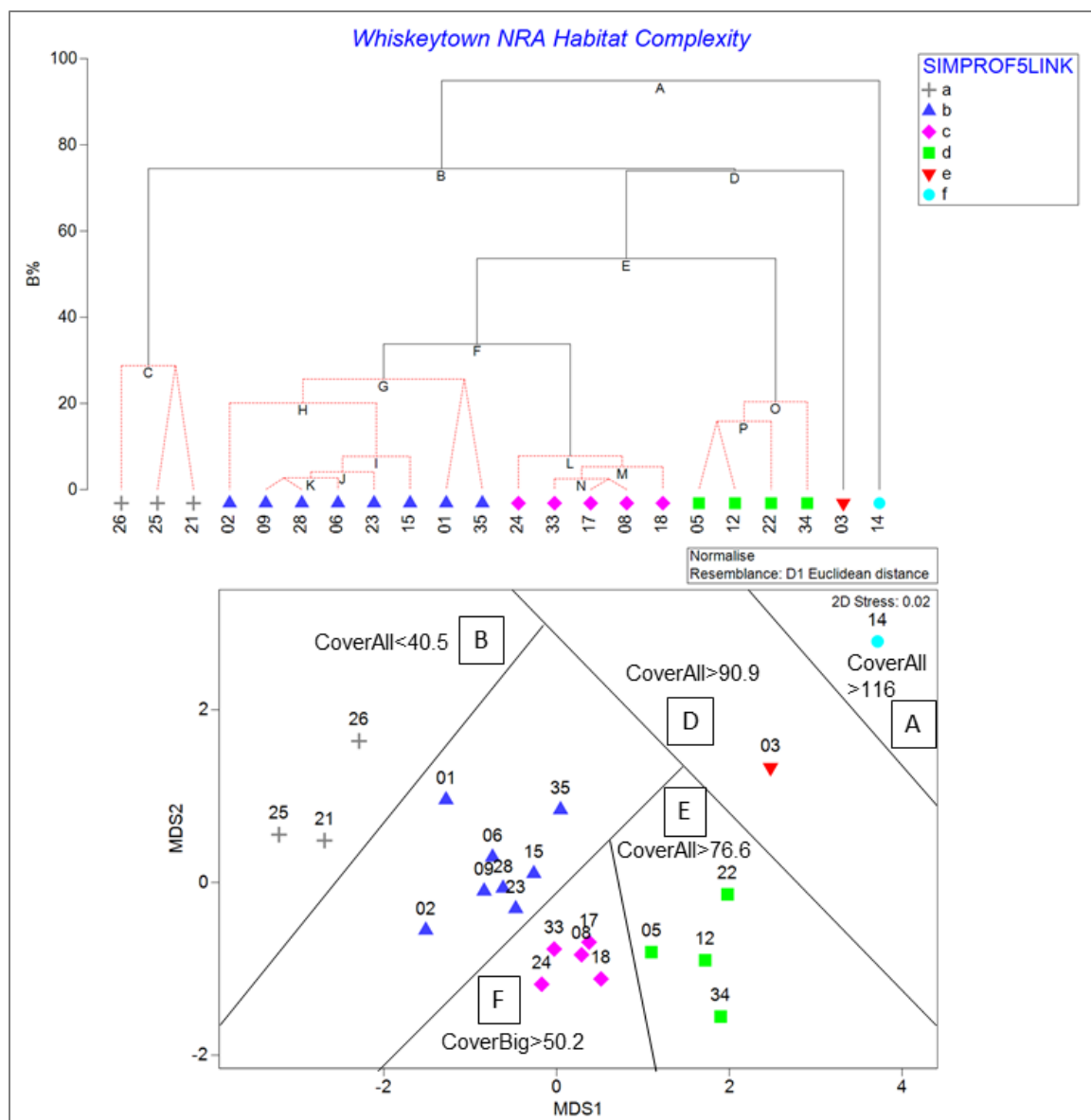


Figure 66. Stream classification results for Whiskeytown National Recreation Area based on Habitat Complexity metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups. Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A, B, D, E and F indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A, B, D, and F are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

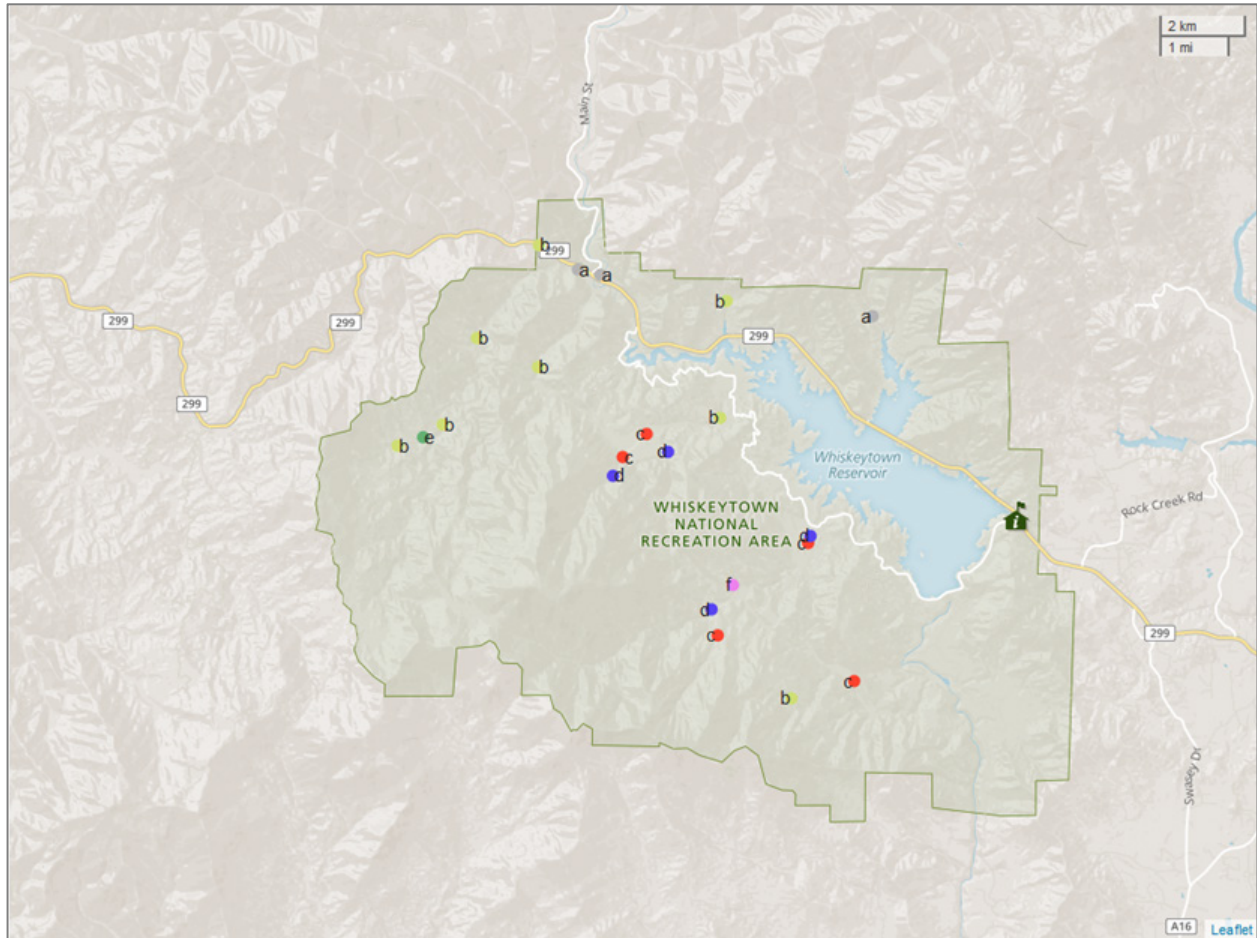


Figure 67. Distribution of stream category groupings at Whiskeytown National Recreation Area based on Habitat Complexity.

Large Woody Debris

- Seven groups were differentiated (Figures 68–69)
- Several groups were at the low end of the amount of relative large woody debris, and tightly clustered indicating subtle differences
- Two groups of streams were characterized by higher amounts of large woody debris than the rest of the park:
 - One group composed of Unnamed Tributary to Brandy Creek (14) and Boulder Creek (17) had the highest amounts of woody debris
 - One group composed of two Unnamed Tributaries to Crystal Creek (3, 35) had the second largest amount of woody debris

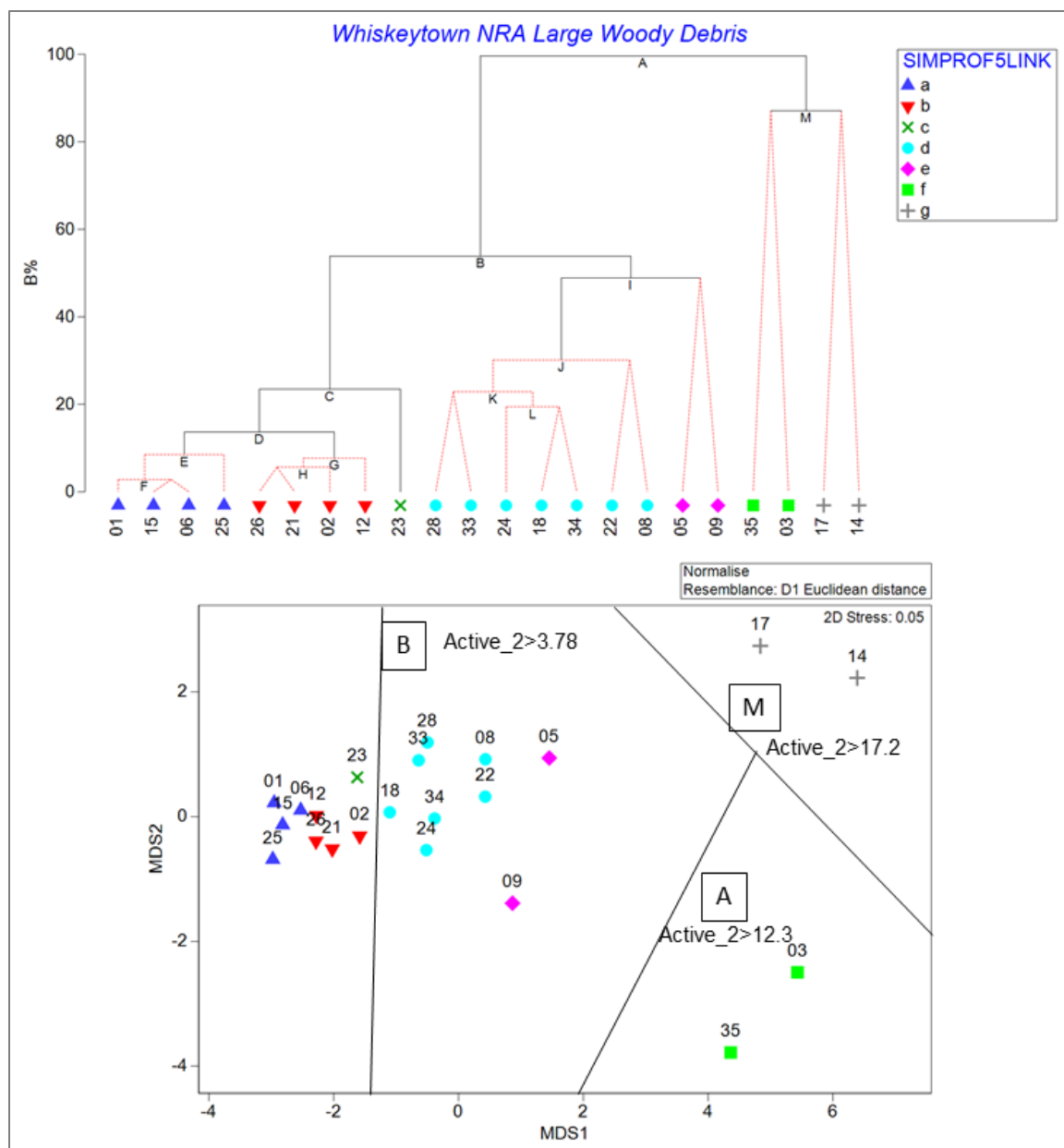


Figure 68. Stream classification results for Whiskeytown National Recreation Area based on Large Woody Debris metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Different letters A, B, and M indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Active_2 = amount of large woody debris in the active channel. Letters A, B, and M are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

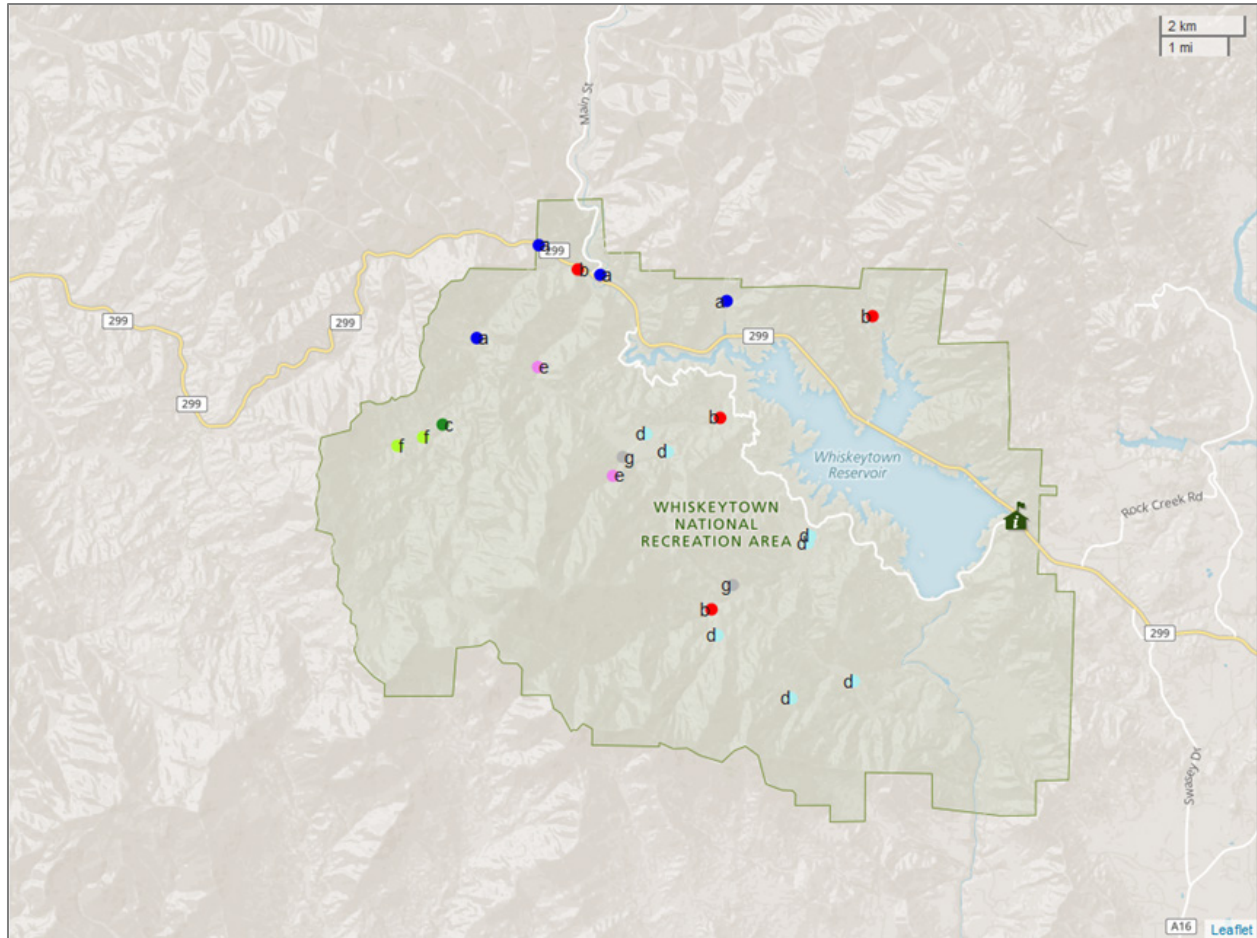


Figure 69. Distribution of stream category groupings at Whiskeytown National Recreation Area based on Large Woody Debris.

Riparian Characters

- Nine groups were differentiated (Figures 70–71).
- Most groups were characterized by higher amounts of riparian cover at all three layers (ground cover, mid-story, and canopy) as well as understory deciduous vegetation. One singular group was characterized by higher amounts of herbaceous ground cover (Clear Creek [25]).
- A group with two streams, Unnamed Tributary to Brandy Creek (14) and Boulder Creek (17), was characterized by lower amounts of riparian cover.

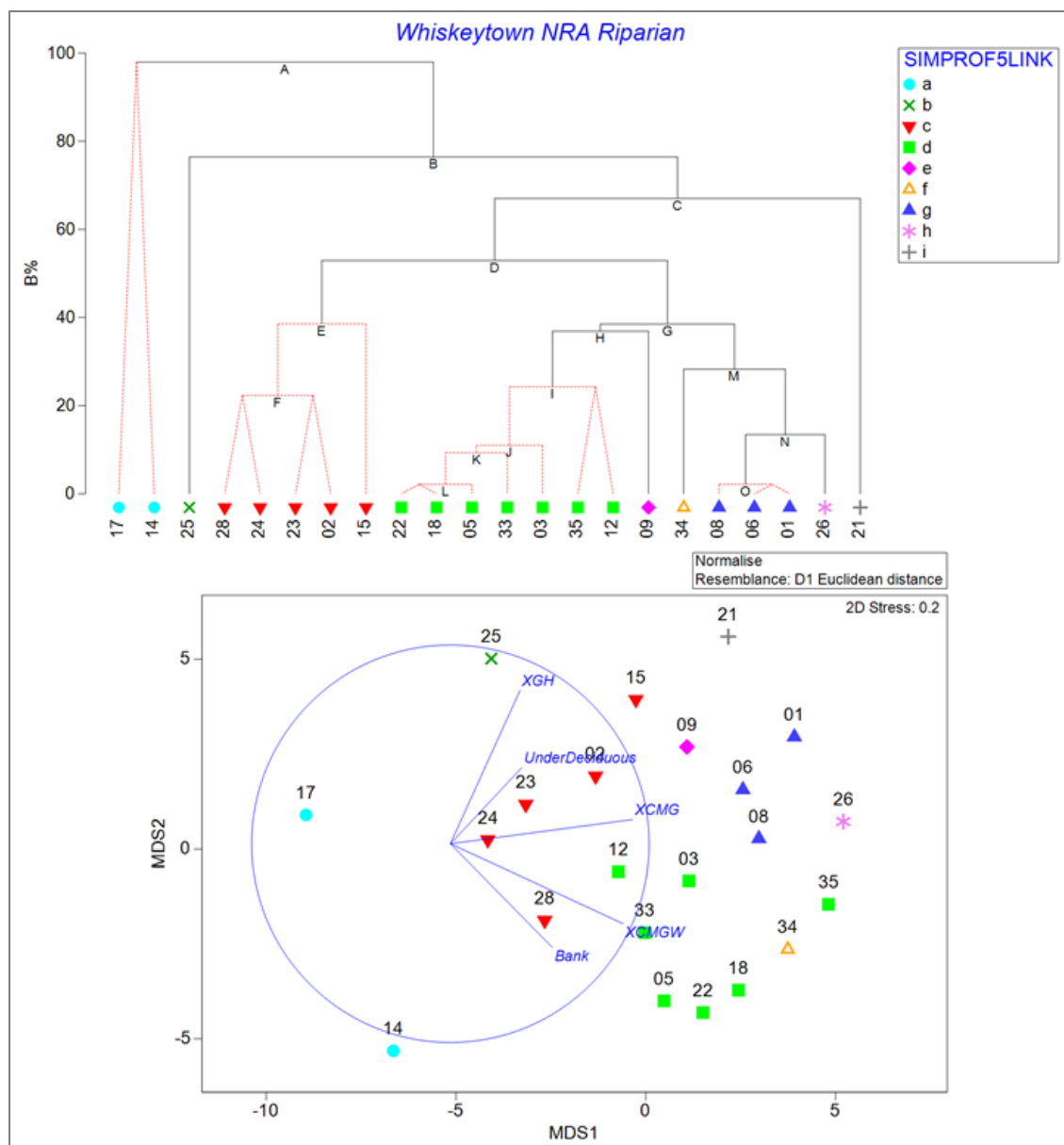


Figure 70. Stream classification results for Whiskeytown National Recreation Area based on Riparian Character metrics. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Vectors represent a further grouping for biological meaning based on correlations of sites to labeled metrics (step F in Figure 3). The outer edge of the circle represents a correlation value of 1; vectors for each parameter are defined by the direction and length, so that this direction in the ordination space is the direction of the parameter increasing. XGH = mean cover of herbaceous groundcover, UnderDeciduous = percent understory deciduous vegetation, XCMG = mean cover of ground, mid-story, and canopy vegetation, XCMGW = mean cover of ground, mid-story, and canopy woody vegetation, Bank = mean shading of stream banks. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

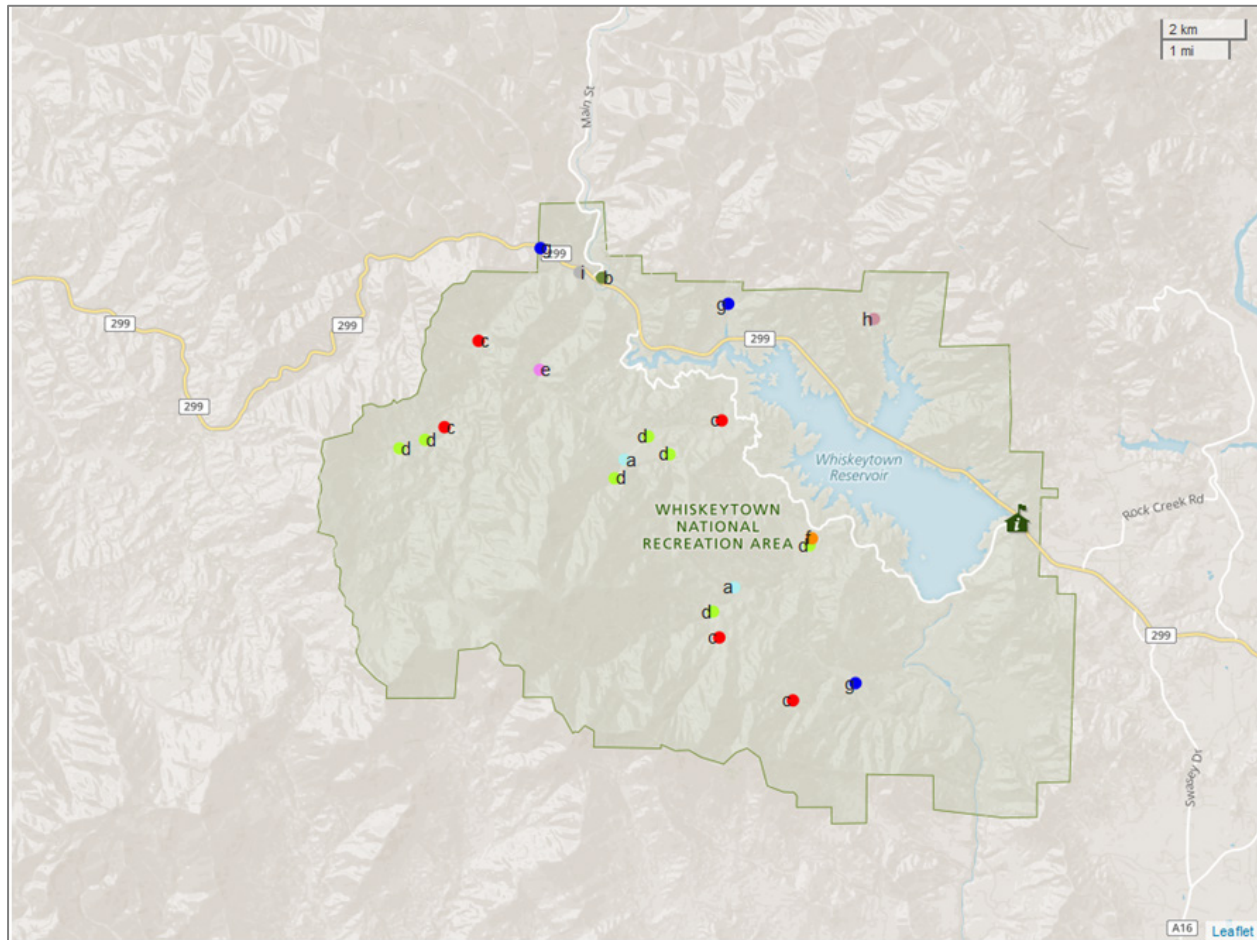


Figure 71. Distribution of stream category groupings at Whiskeytown National Recreation Area based on Riparian Character metrics.

Slope and Sinuosity

- Three groups were differentiated (Figures 72–73)
- Most streams fell into one larger variable group
- One singular group, with Boulder Creek (05), was distinct for higher slopes than the rest of the streams (>12.4%)
- Both an Unnamed tributary to Brandy Creek (24) and Whiskey Creek (26) were different for having substantially higher sinuosity than other sampled streams of the park

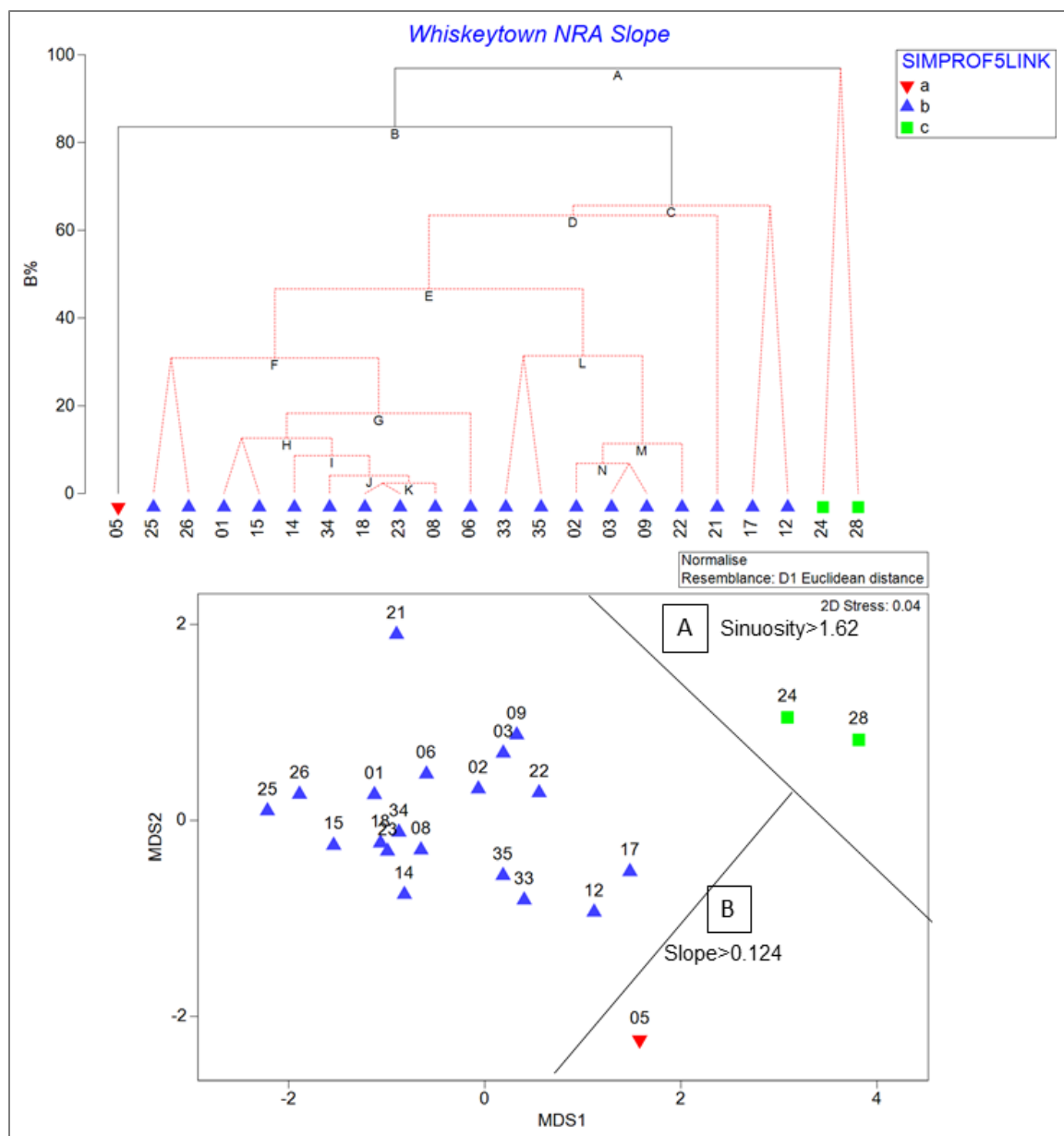


Figure 72. Stream classification results for Whiskeytown National Recreation Area based on Slope and Sinuosity. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Letters A–B indicate further grouping for biologically meaningful distinctions that are described by the metric thresholds inside each group (step F in Figure 3). Letters A–B are different from SIMPROF5LINK groups and reflect splits in the cluster analysis at the top part of this figure. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

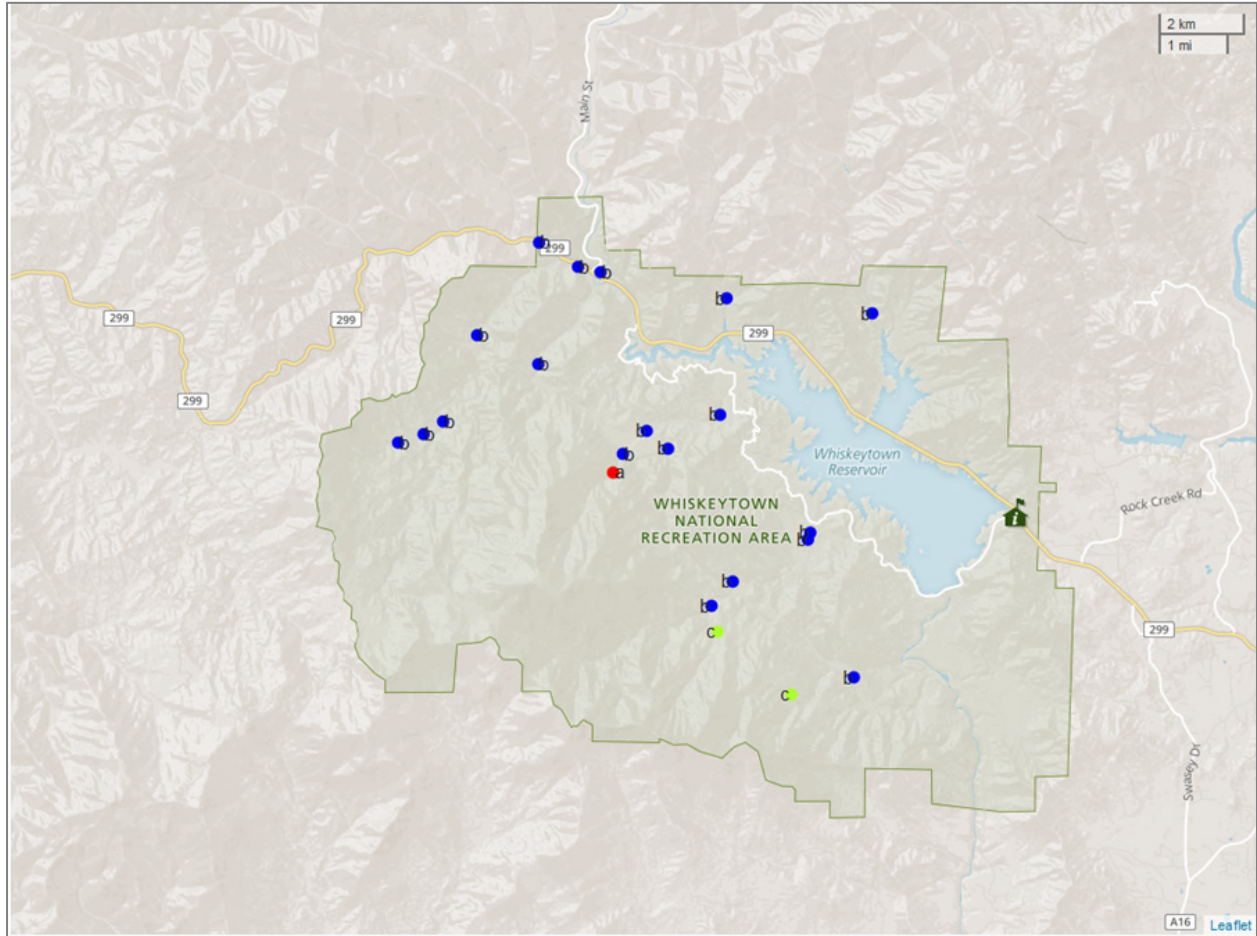


Figure 73. Distribution of stream category groupings at Whiskeytown National Recreation Area based on Slope and Sinuosity.

Stream Substrate

- Seven groups were differentiated (Figures 74–75).
- Willow Creek (21) formed a singular group characterized by relatively high proportions of fine gravel and smaller sediments. A second group, Unnamed Tributary to Crystal Creek (3, 35) and Willow Creek (1), was also associated with smaller sediments.
- The remaining groups were all associated with higher amounts of larger substrates (cobble, boulders, etc.).

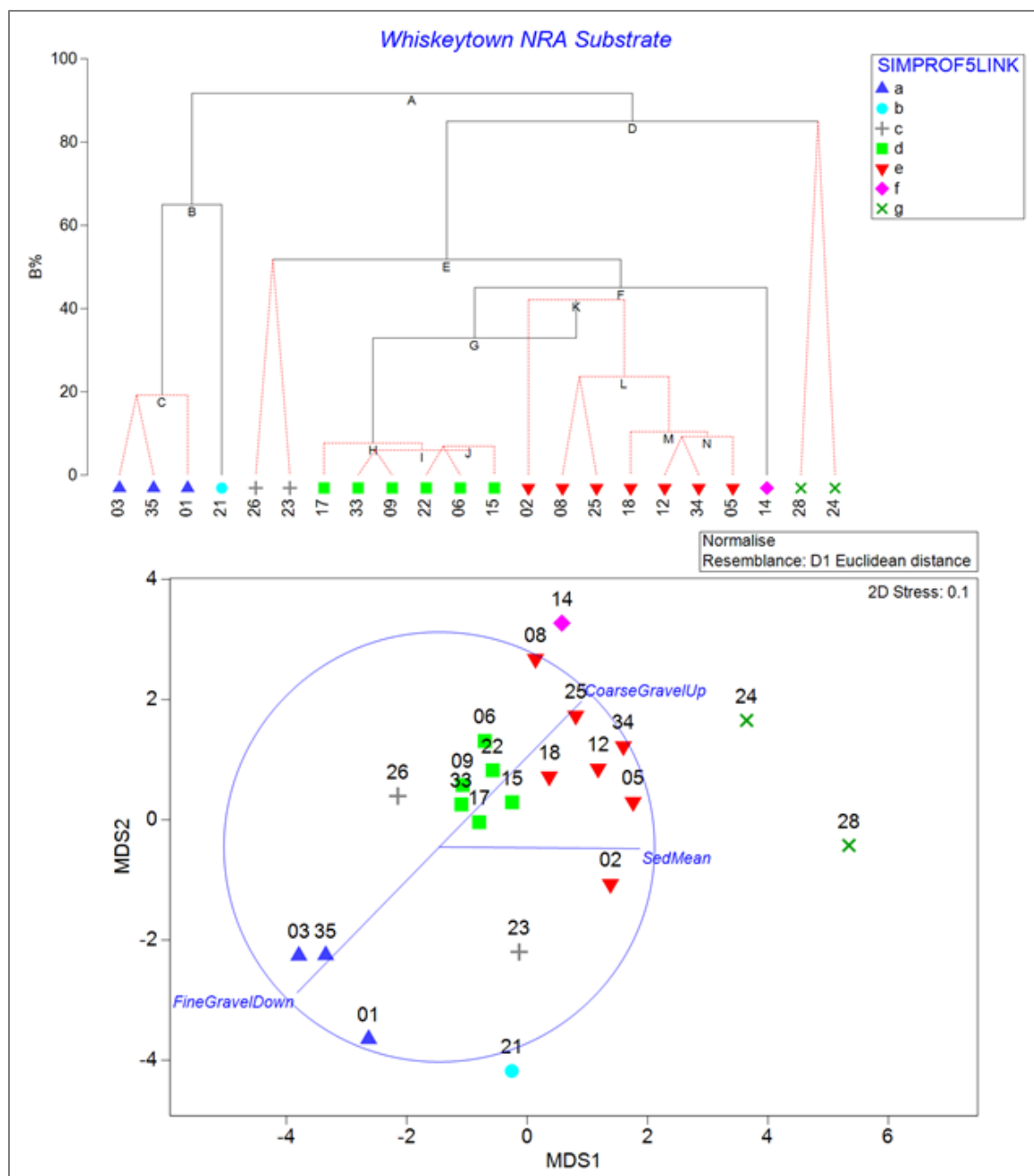


Figure 74. Stream classification results for Whiskeytown National Recreation Area based on Stream Substrate. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Vectors represent a further grouping for biological meaning based on correlations of sites to labeled metrics (step F in Figure 3). The outer edge of the circle represents a correlation value of 1; vectors for each parameter are defined by the direction and length, so that this direction in the ordination space is the direction of the parameter increasing. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

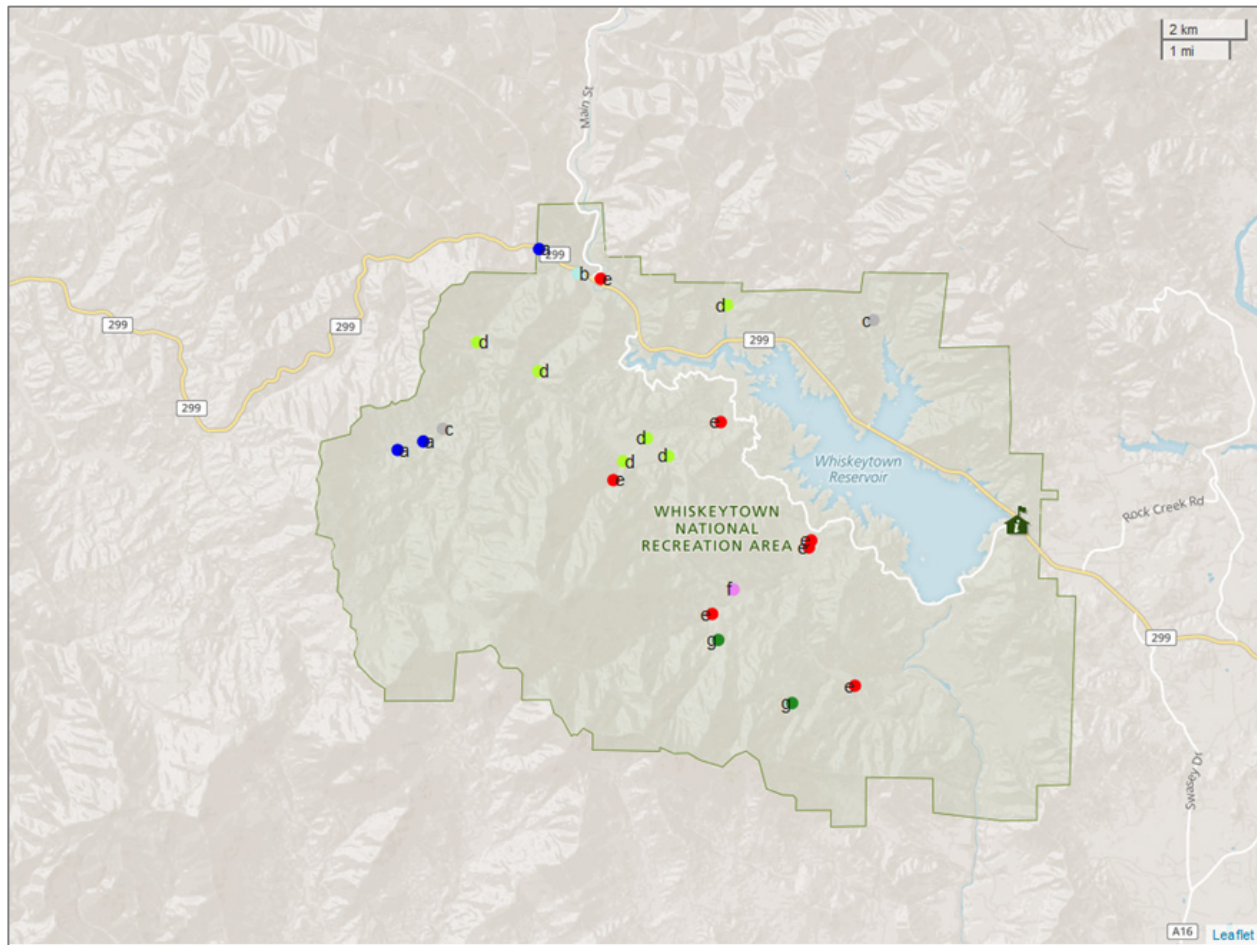


Figure 75. Distribution of stream category groupings at Whiskeytown National Recreation Area based on Stream Substrate.

Water Chemistry

- Six groups were differentiated (Figures 76–77).
- Most groups were characterized by relatively low levels of Nitrogen, Phosphorous, and salts (anions and cations).
- One group was associated with higher levels of both nutrients and salts. Both sites are on Willow Creek (1, 21).

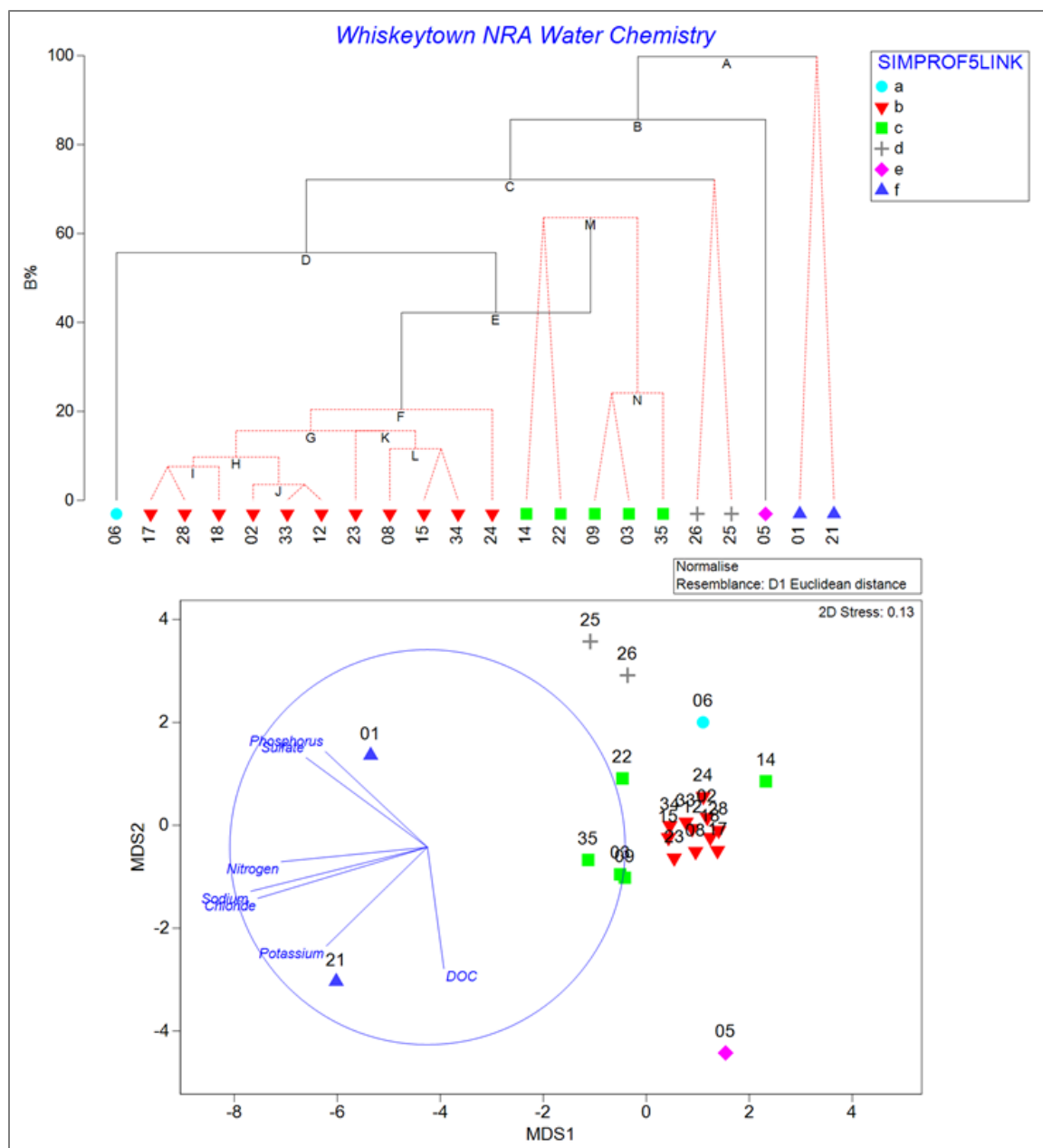


Figure 76. Stream classification results for Whiskeytown National Recreation Area based on Water Chemistry. Top—cluster and group significance (red dotted lines indicate no significant separation, black solid lines show significant groups). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination shows the relationship of groups and sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. SIMPROF5LINK refers to the group output of the similarity profile test with 5% significance threshold. Vectors represent a further grouping for biological meaning based on correlations of sites to labeled metrics (step F in Figure 3). The outer edge of the circle represents a correlation value of 1; vectors for each parameter are defined by the direction and length, so that this direction in the ordination space is the direction of the parameter increasing. DOC = dissolved organic carbon. Taken together, analyses provide insight into the number of different groups, how big the groups are, and what makes the groups different.

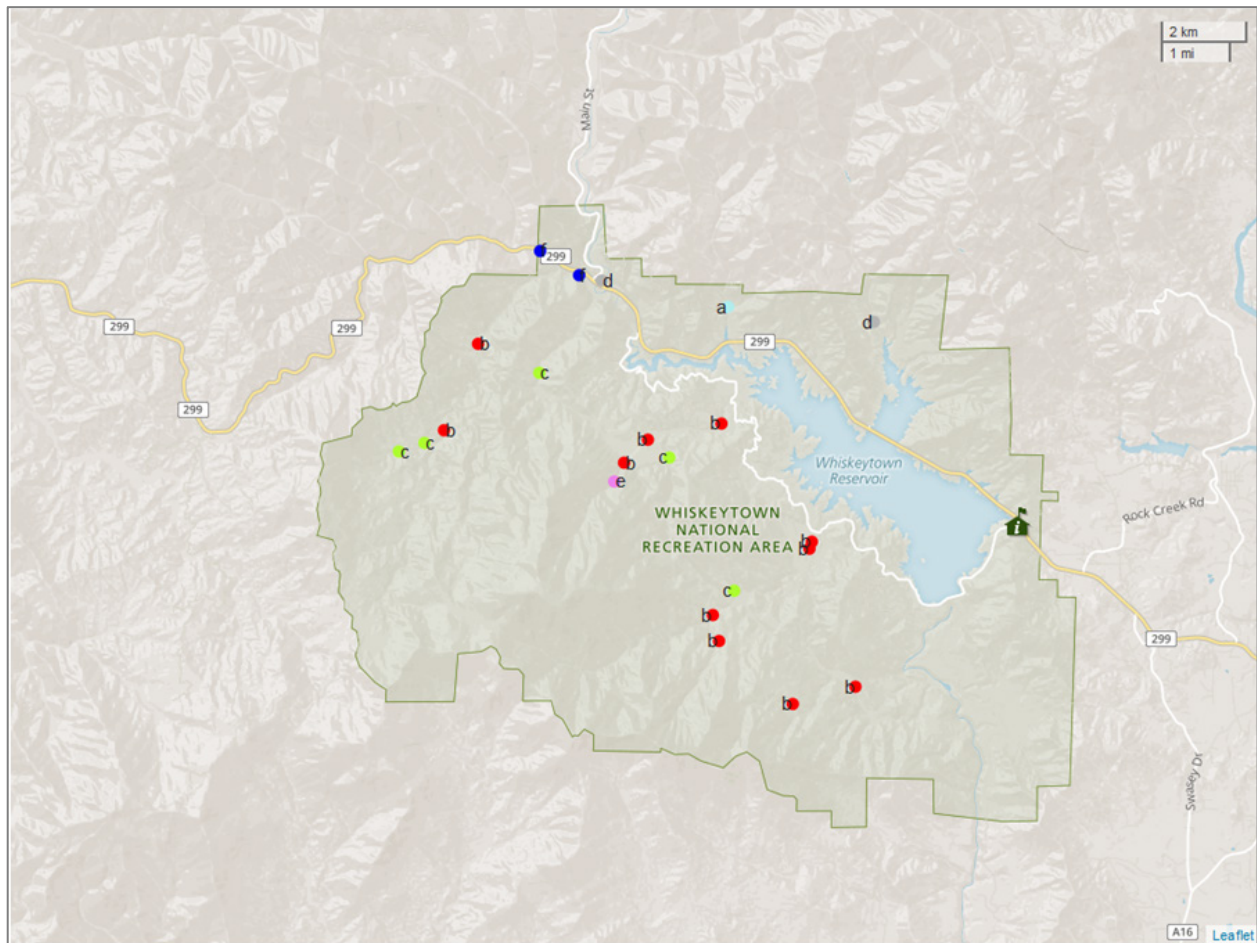


Figure 77. Distribution of stream category groupings at Whiskeytown National Recreation Area based on Water Chemistry.

Water Quality

- Only a single group was detected, with no clear interpretation (Figure 78)

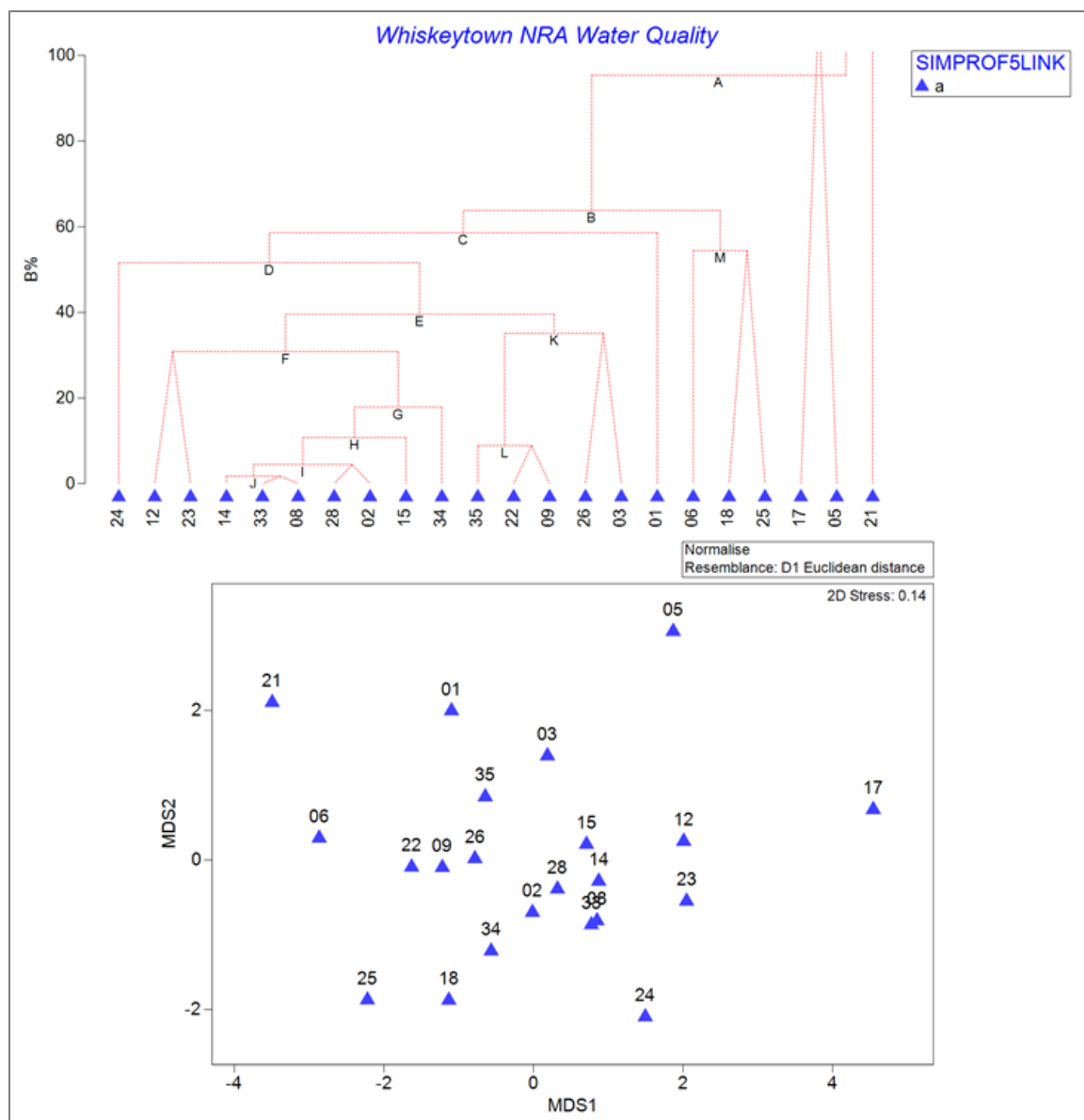


Figure 78. Stream classification results for Whiskeytown National Recreation Area based on Water Quality. Top—cluster and group significance (red dotted lines indicate no significant separation). Numbers are site codes (see table in this appendix). Bottom—metric MDS ordination showing the relationship of sites to one another. Close spacing indicates similar site characters, and far spacing indicates sites with differing characters. Since there is only one group, no map is provided.

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Natural Resource Stewardship and Science

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