TRINITY RIVER RESTORATION PROGRAM
P.O. BOX 1300
WEAVERVILLE, CA
PHONE: 530-623-1800
www.trrp.net

A First Year of Periphyton Monitoring in the Trinity River, California

Technical Report: TRRP-2022-2

Prepared by:

Eric B. Peterson
ORC ID: 0000-0001-9501-3872
U.S. Bureau of Reclamation, Trinity River Restoration Program
Weaverville, California

April 5, 2022

Suggested Citation:
Peterson, E. B. 2022. A first year of periphyton monitoring in the Trinity River, California. Technical Report TRRP-2022-2. U.S. Bureau of Reclamation, Trinity River Restoration Program, Weaverville, CA.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

cfs = cubic feet per second (a measure of flow rate). 1 cms ≅ 35.3147 cfs.

cm = centimeters

cms = cubic meters per second (a measure of flow rate). 1 cms ≅ 35.3147 cfs.

km = kilometers

m = meters

ml = milliliters

rkm = river kilometers

TRRP = Trinity River Restoration Program

ABSTRACT

Early in the summer of 2018, algae seemed to proliferate in the Trinity River below Lewison Dam more than anyone could remember. Limited local scientific knowledge of algae in the Trinity led to this present study to ascertain general patterns of periphyton in the river. The study design is intended to provide an overview of spatial and temporal patterns of growth, and to document periphyton community composition. Thus, the investigation includes two elements: (1) photographic monitoring (photomonitoring) of periphyton growth (a score of abundance) on approximately 2-month intervals and (2) sampling of biodiversity (taxonomic richness) in winter and summer. Monitoring occurs at multiple mainstem sites and within major tributaries along the 64 km restoration focal reach for the TRRP, plus several locations above Trinity Lake. Multiple years of monitoring will be necessary to understand temporal patterns of periphyton growth in relation to varying river flows as disturbance events. This report covers only the first year of monitoring, yet is sufficient to establish baseline knowledge of periphyton presence, diversity, and to test two hypotheses: one on the prevalence of the diatom *Didymosphenia geminata* and another on the prevalence of cyanobacteria in general.

Photomonitoring results showed that periphyton cover scores within the mainstem river were generally high immediately below Lewiston Dam and that some sites had the greatest cover scores in the cooler months. Tributaries were spatially variable in cover scores and timing of peak periphyton cover score. A possible correspondence to tributary geology is noted for future study.

Biodiversity samples identified a total of 35 taxa across sites (gamma diversity; 1 bryophyte, 12 filamentous algae, 15 diatoms, and 5 cyanobacteria) and an additional 72 morphotypes. *Cladophora* was observed at many sites but was lacking immediately below Lewiston Dam where *Spirogyra* accounts for most of the filamentous algae. *Didymosphenia geminata* was found at up to 10 sites, primarily within the mainstem Trinity River. Cyanobacteria were also widespread, but generally noted as low in abundance.

While the single year of data are too limited to develop a full understanding of periphyton patterns within the Trinity River, the data are adequate to establish several hypotheses for future testing:

Reservoir-Nutrient Hypothesis: *Trinity and Lewiston Reservoirs impound nutrients in a way that elevates nutrient concentrations in the river immediately below the dams.*

Dam-Temperature Hypothesis: *The lack of* Cladophora *immediately below Lewiston Dam is caused by stable, cold, water temperatures favoring* Spirogyra*.*

Dam-Scour Hypothesis (alternative): *The lack of* Cladorphora *immediately below Lewiston Dam is caused by a lack of disturbance by scour of mobile sediments.*

Dam-Herbivore Hypothesis: *Due to the lack of* Cladophora *in the river immediately below Lewiston Dam, herbivorous macroinvertebrates are less abundant and thus less autochthonous prey are available for juvenile salmonids than downstream where* Cladophora *becomes more common.*

Tributary Geology Hypothesis: *Periphyton abundance in tributaries is dependent on the geology of the tributary watershed.*

INTRODUCTION

Early in the summer of 2018, algae seemed to proliferate in the 64 kilometers of the Trinity River below Lewison Dam more than anyone could remember (either program scientists or public). This “bloom” of filamentous green algae covered much of the river bed throughout the 64 km restoration focal reach. While algae concerns have been intermittently raised in the past, particularly for downstream reaches where filamentous algae affect tribal fisheries, the 2018 bloom intensified these concerns resulting in numerous inquiries to the Trinity River Restoration Program (TRRP). However, TRRP had never monitored algae. Some agencies, such as the Hoopa Valley Tribal Environmental Protection Agency and the California State Water Resources Control Board conduct water quality testing for the presence of cyanotoxins in the Trinity River (HVTEPA 2021; CSWRCB 2021). Cyanotoxins are a human health hazard produced by photoautotrophic cyanobacteria, not filamentous green algae, though these can grow intermixed. Otherwise, the available literature on algae specific to the Trinity River consists of a brief memo from the California Department of Fish and Game describing algae dislodging below Lewiston in 1964 as the Lewiston Dam release increased from 4.25 cubic meters per second (cms; 150 cubic feet per second, cfs) to 5.66 cms (200 cfs; Healey 1964), a report from the U.S. Forest Service investigating the presence of *Didymosphenia geminata* (Fleitz 2018), and brief mentions in two recent studies of macroinvertebrate drift (Starkey-Owens 2020; Willamshen 2021). The absence of information specific to Trinity River algae, particularly with regard to riverine ecology, made it difficult to clearly answer questions except by referring to general research on other rivers. Awareness of this lack of local scientific knowledge led to this present study to ascertain the patterns of periphyton in the Trinity River.

Periphyton Biology and Ecology

The “algae” of concern on the Trinity River are a mix of true plants with microscopic characters, plus cyanobacteria. Within the river channel, these photoautotrophs grow over the surface of rocks or other substrates in the benthic zone, and are collectively known as periphyton. Periphyton tend to dominate the primary production in oligotrophic and mesotrophic rivers like the Trinity (Hill & Webster 1982), while planktonic (floating) algae do not accumulate in large quantities within unpolluted flowing rivers. Within the Trinity, periphyton are primarily filamentous green algae, a variety of diatoms, and cyanobacteria, either directly attached to the substrate (mostly rock), or living among those that are attached. Some diatoms adhere to green algal filaments, thus existing primarily as epiphytes. Additionally, bryophytes, vascular plants, *Vaucheria* (Xanthophyceae, or yellow-green algae), and the lichenized fungus *Verrucaria* (Lecanoromycetes) occur in the benthos of the Trinity River (personal observation). While these are taxonomically varied, they collectively form a spatially distinct component of the riverine ecosystem and provide the autotrophic base of the within-river foodweb. Understanding patterns in periphyton growth is therefore valuable to understanding the foundation of salmonid river ecology.

Periphyton communities are well known to harbor high biodiversity (Pfiester et al. 1979). Yet little is known about natural periphyton community composition or the possibility of invasion by exotic species. Perhaps best studied is the diatom *Didymosphenia geminata* (also known as “didymo” or “rock snot”). Long thought to be invasive, *D. geminata* is now considered to be native to much of the Northern Hemisphere (Taylor & Bothwell 2014), including the Trinity River (S. Spaulding personal communication, email 2009-11-02). Yet *D. geminata* remains a concern in many North American rivers where it can form nuisance blooms (Kumar et al. 2009). Two reasons have been hypothesized for these blooms: [1] water temperatures kept artificially cold by stratified reservoirs (Spaulding & Elwell 2007) and [2] reduced levels of phosphorus resulting in lower competition with other periphyton (Bothwell et al. 2014).

Periphyton can have negative impacts to river ecology. Heavy growths of periphyton can lead to oxygen depletion as they decompose (see Carpenter 2003; Assarian & Kann 2006). The common filamentous green alga *Cladophora* is known to develop nuisance blooms with such impacts (Dodds et al. 1997; Banish 2017). In the Trinity River below Lewiston Dam, reliable flows with substantial mixing should prevent oxygen depletion within the channel, but such impacts may occur in alcoves and other locations with weak flow due to isolation from the thalweg. Where water warms sufficiently, cyanobacteria can become problematic as some species can produce toxins, putting public health at risk (CSWRCB 2021). Cyanotoxins are an increasing problem on the Eel River (Power et al. 2015), a regular problem in the Klamath River (Genzoli 2019), and an occasionally problem in the lower Trinity River (Trinity Journal 2021).

However, periphyton also have beneficial ecological roles. Riverine food webs derive from allochthonous sources (living or dead organic matter from outside the wetted channel) and autochthonous sources (within the river). Periphyton are the primary producers of autochthonous organic matter in natural river systems like the Trinity (Hill & Webster 1982). While the research studies on periphyton in the Trinity are extremely scant, the nearby Eel River has been a site of multiple ecological studies that have shown how disturbance by sediment transport can initiate periphyton growth cycles and influence availability of food for salmonids (Power et al. 2008a; Vadeboncoeur & Power 2017). Where water temperatures are cool to moderate, *Cladophora* can be quite abundant, though is not itself a highly nutritious basis of the food web. With time, a variety of epiphytic diatoms colonize the *Cladophora*. These diatoms are more nutritious than the *Cladophora*, particularly those in the genus *Epithemia*, which have nitrogen-fixing endosymbionts. This nitrogen source makes them valuable food for benthic macroinvertebrates, which then feed salmon and steelhead. When channels mobilize, disturbance of the benthos resets the periphyton community to varying degrees, and the timing and magnitude of this disturbance influences the availability of food for juvenile salmonids (Vadeboncoeur & Power 2017).

River restoration recognizes that geomorphic processes of sediment transport (scour and deposition) are fundamental to building a healthy river ecosystem with productive habitat for young fish (Trush et al. 2000). But how does sediment transport lead to fish production? There are numerous complex processes that occur between the movement of rock and a young fish becoming safe, healthy, and well fed. These include both incorporation of food sources from above the water surface (Grunblatt et al. 2019) and development of food webs within the aquatic system (Vadeboncoeur and Power 2017).

Currently, dam regulation has shifted geomorphic flood events on the Trinity River to be temporally disjunct from natural patterns (Buxton 2021, Thomas Gast & Associates 2021). Most naturally occurring floods within the region include sharp, geomorphically active peaks during winter and early spring. On the Trinity River below Lewiston Dam floods are mostly limited to late spring flow releases and are capped at significantly lower rates than natural floods due to water management policy (USDI 2000). Sufficient tributary flows accrete to dam releases such that flows in the river are regarded as mostly natural after the confluence with the North Fork Trinity River, 64 km downstream of Lewiston Dem. Temperature of water below the Dam is also known to have an unnatural pattern (Thomas Gast &

Associates 2021), which may also lead to unusual patterns in periphyton growth or composition (Kazanjian et al. 2018).

A Beginning for Periphyton Monitoring on the Trinity River

This monitoring effort was established to address concerns over algal growth and lay foundations for understanding the role of periphyton in Trinity River productivity. The study design is intended to provide an overview of spatial and temporal patterns of growth (where and when, relative to tributaries and seasonal weather), and to document periphyton community composition. Thus, the investigation includes two elements: (1) photographic monitoring (hereafter 'photomonitoring') of periphyton growth (scored abundance) on approximately 2-month intervals and (2) sampling of biodiversity (taxonomic richness) in winter and summer. Monitoring occurs at multiple mainstem sites and within major tributaries along the 64 km restoration focal reach for the TRRP, plus several locations above Trinity Lake. Inclusion of tributaries and sites above the lake will increase the potential for explaining changes to periphyton patterns along the mainstem as a function of distance from dam versus a function of tributary input. It will also provide comparison of periphyton in the regulated river relative to its unregulated tributaries.

Given the relevance of geomorphic flooding to periphyton succession, properly understanding temporal patterns of periphyton growth in the Trinity will require sampling across multiple years with varying river flows that provide disturbance events. The present report covers only the first year of monitoring and therefore will defer detailed analyses for a subsequent multi-year report. The present intent is to acknowledge the baseline information available from a single year of monitoring. This baseline is sufficient for testing the following simple informational hypotheses:

- **Didymo Hypothesis:** Since *Didymosphenia geminata* is native, it will be widespread in the Trinity watershed.
- **Cyano Hypothesis:** Cyanobacteria are commonly present at sub-dominant levels within the periphyton in the study reach of the mainstem Trinity River.

However, one year is insufficient for testing other hypotheses of spatial or temporal patterns, or hypotheses of ecological function. Rather, the data presented here will be used to develop or refine such hypotheses for future testing.

METHODS

Monitoring Sites

Twenty-four sites were sampled (Figure 1; Table 1; Appendix A). These primarily follow an alternating sequence along the river with one sampling point in each major tributary and one point within the mainstem between each sampled tributary. Each mainstem site is sufficiently below tributary confluences for tributary waters to mixed with mainstem waters. Four sites were chosen on the largest tributaries to the reservoirs formed by Lewiston and Trinity Dams, one of which was the mainstem of the Trinity River above the reservoir. Three supplemental sites were included: one immediately below Lewiston Dam and two at recent channel restoration sites. Sites were chosen to accommodate similar water depths and velocities across a range of river flow rates as best as could be estimated from site visits during low water conditions. At all sites, monitoring was restricted to areas with gravel or cobble bed, with water flowing downstream so as to prevent accumulation of dislodged algae, yet with insufficient force to dislodge local algal growth. Such locations tended to be runs or mild riffles with water depths of 10-40 cm. Preliminary sampling confirmed that robust filamentous green algae and diatom communities can develop within these parameters. Flow velocity is known to affect periphyton community so future community analyses may need to focus on changes within sites over time or, when spatial patterns are analyzed, then on patterns that are consistent across groups of sites. Given that flow levels will change by season, perhaps with rapid changes during winter, no effort was made to ensure velocities remain within a specific range.

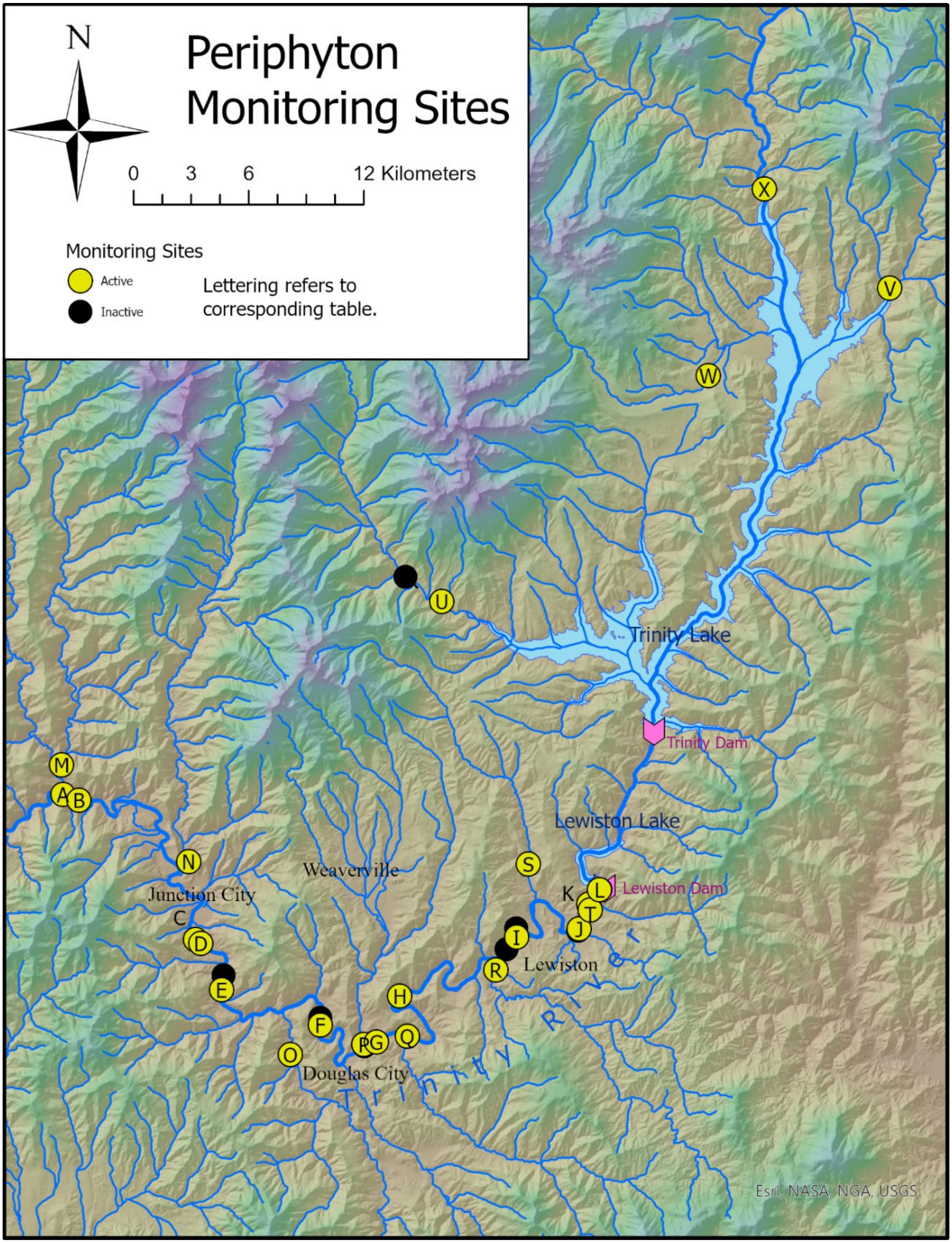


Figure 1: Photographic monitoring sites.
Gold circles indicate current monitoring sites; black dots indicate previously used locations for the nearest current site.

Table 1: Periphyton Monitoring Sites.
Map Label refers to the lettering on the map in Figure 1. Strike-through font indicates a site that has been moved (see Appendix A).

Map Label	Site Name	Type	Latitude	Longitude	Active Monitoring	Ocean Distance	Mainstem Distance
A	Pigeon Point	River	40.7685	-123.1278	Yes	189.4	0
B	Pear Tree Gulch	River	40.7660	-123.1177	Yes	190.6	0
C	Deep Gulch	River	40.7011	-123.0448	Yes	206.4	0
D	Chapman	River	40.6994	-123.0415	Yes	206.7	0
E	Evans Bar	River	40.6777	-123.0284	Yes	210.1	0
F	~~Lorenz Gulch~~	River	40.6650	-122.9671	No	218.2	0
F	Lorenz Gulch	River	40.6616	-122.9673	Yes	218.5	0
G	Above Weaver	River	40.6540	-122.9326	Yes	225.5	0
H	Steelbridge	River	40.6756	-122.9184	Yes	233.0	0
I	~~Bucktail~~	River	40.7080	-122.8472	No	243.8	0
I	Bucktail	River	40.7038	-122.8468	Yes	243.3	0
J	~~Lewiston~~	River	40.7071	-122.8088	No	243.2	0
J	Lewiston	River	40.7081	-122.8082	Yes	251.0	0
K	Weir Pool	River	40.7197	-122.8025	Yes	252.6	0
L	~~Lewiston Dam~~	River	40.7265	-122.7953	No	254.2	0
L	~~Lewiston Dam~~	River	40.7269	-122.7952	No	254.2	0
L	Lewiston Dam	River	40.7266	-122.7958	Yes	254.2	0
M	North Fork	Trib.	40.7825	-123.1288	Yes	189.7	1.78
N	Canyon Creek	Trib.	40.7377	-123.0496	Yes	200.9	1.34
O	Browns Creek	Trib.	40.6477	-122.9856	Yes	214.9	2.73
P	Weaver Creek	Trib.	40.6530	-122.9401	Yes	224.8	0.18
Q	Indian Creek	Trib.	40.6568	-122.9135	Yes	227.4	0.18
R	~~Grass Valley Creek~~	Trib.	40.6888	-122.8592	No	241.6	0.60
R	Grass Valley Creek	Trib.	40.6885	-122.8594	Yes	241.6	0.64
S	Rush Creek	Trib.	40.7383	-122.8399	Yes	247.3	2.13
T	Deadwood Creek	Trib.	40.7170	-122.8015	Yes	252.3	0.16
U	~~Stewart’s Fork~~	Trib.	40.8726	-122.9175	No	268.6	16.00
U	Stewart’s Fork	Trib.	40.8613	-122.8949	Yes	268.6	13.30
V	East Fork	Trib.	41.0101	-122.6193	Yes	288.8	6.70
W	Swift Creek	Trib.	40.9684	-122.7314	Yes	290.9	5.30
X	Carrville	River	41.0562	-122.6977	Yes	298.9	0

Photomonitoring

Growth monitoring, of the periphyton community as a whole, was performed via photomonitoring (Hall 2002) in even numbered months, with an additional sampling to capture data for

July, the warmest month of the year. A diagram of photographic positions for each site is provided in Figure 2. Three underwater photographs were taken obliquely across the waterway bed, at approximately 30 degree angles from each other with the middle angle approximately perpendicular to the thalweg. Two additional photos were taken above water for context: one below the sampled site looking upstream and one above the sampled site looking downstream. A third above-water photo was often taken from the bank adjacent to the sampled site looking across the stream/river.

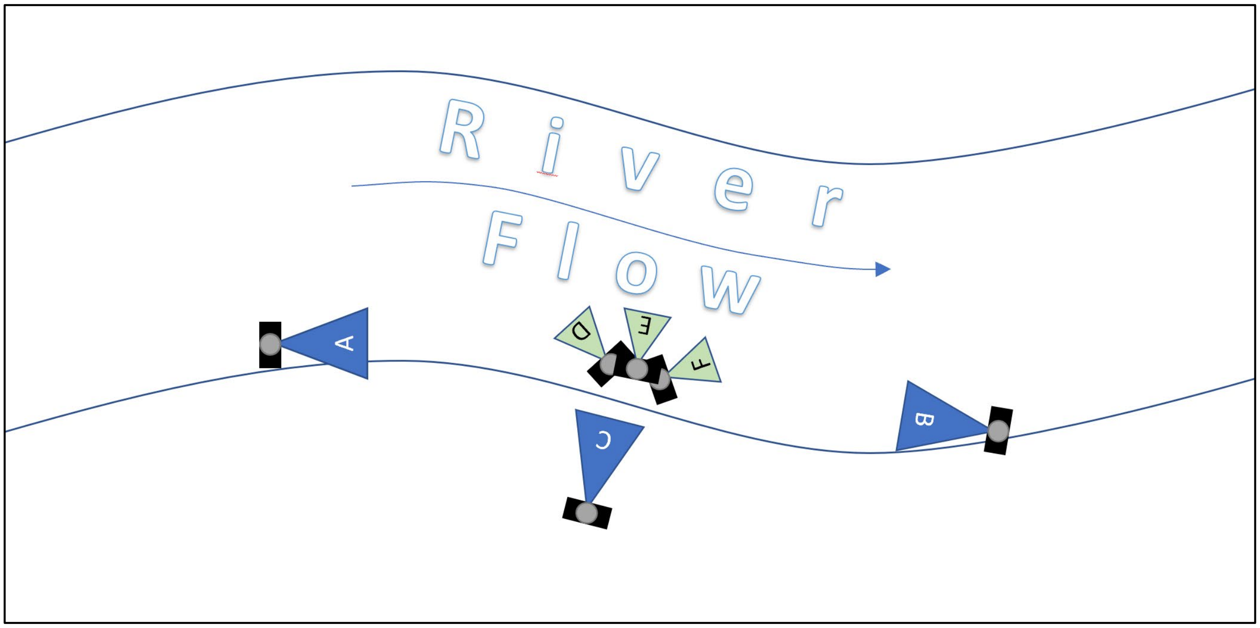


Figure 2: Illustration of photography for a photomonitoring site.
Above water photos are represented by the large blue triangles and were taken for site reference; below water photos taken for photomonitoring are represented by the small green triangles; river flow is from left to right with wavy lines to represent the banks.

Precise locations were not marked for exact repetition, as flow levels can force changes to exact placements due to water depths, velocities, and changes to eddy patterns. However, placement of photographs always faced toward deeper waters and always were in sufficient depth to avoid areas that appeared to be freshly inundated. The three underwater photographs were scored according to Table 2 and Figure 3 with the highest scoring among the photographs used to represent the site.

Biodiversity Sampling

Biodiversity (the richness of periphyton taxa) was sampled at each site twice per year, during February and August photomonitoring. Sampling was adapted from (Ode et al. 2016) to involve selection of two rocks per sampling site that could be readily lifted to shore, then three circular areas of periphyton colonized rock surface (one from one rock, two from the other), each 1.0 cm in radius, were sampled with a PVC delimiting ring by scrubbing and washing the rock within the ring into a storage bag. Bags were maintained in a cooler with ice or in a refrigerator for no more than 1.5 weeks. For the present study, no preservatives were used. Periphyton was allowed to settle to a corner of the bag then approximately 4 drops were extracted by eyedropper and placed on glass slides for identification of periphyton taxa with a compound microscope capable of 1000x magnification under oil immersion (clumping of algae and debris makes it impossible to guarantee a reliably uniform 4 drops). Identification was primarily to genus, following Bellinger and Sigee (2015) and Diatoms of North America (2021). No attempt was made to assess abundance of individual taxa. Therefore biodiversity discussion will focus on richness of taxa within sites (alpha diversity) and across the study area (gamma diversity) as per Whittaker (1972).

Analysis

Since the present report is to acknowledge observation data from the first year of monitoring, only graphical data descriptors (heatmaps, bar graphs), plus basic summary statistics (including box plots) will be provided. No statistical analyses will be performed until at least three years of data have been collected.

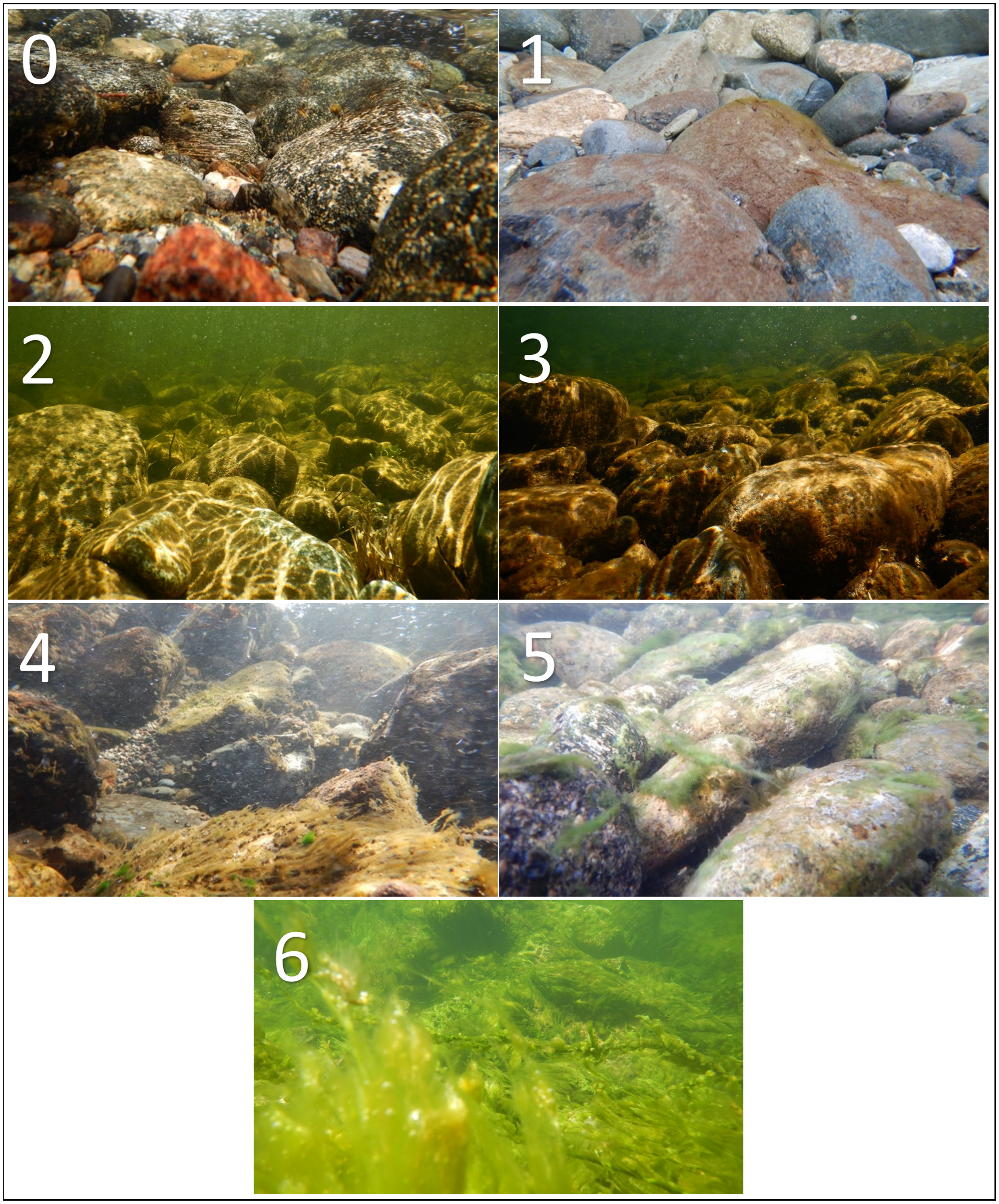


Figure 3: Scoring of periphyton cover in underwater images.
0 = Not Detectable; 1 = Film; 2 = Felt; 3 = Shag; 4 = Tufted; 5 = Pendulous; 6 = Obscuring.

Table 2: Scoring of periphyton growth.
Scores were assigned to represent the majority of large gravel within the image (a single pendulous *Cladorphora* colony in an otherwise felted image would be scored as #2, Felt). A single anomalously large colony across the three images was ignored. If two or more larger colonies are present yet not representative of the algal situation, then 0.5 was added to the score. Thus, if a second pendulous *Cladophora* colony was visible in the otherwise felted situation described above, then the score would total 2.5. If more than 10 such larger colonies are present, then they were considered the representative cover.

Rank	Category	Description
0	Not Detectable	Rocks appear clean as if recently mobilized and scoured.
1	Film	Rock are coated with a very thin brownish, yellowish, or greenish layer but the general color and pattern of the rock material remains evident.
2	Felt	Rocks are coated in a layer of a few mm thickness, color and pattern of rock material no longer clear where coated.
3	Shag	Rocks are covered in a layer more than a few mm thick, up to about 1 cm thick, wavering in current is evident.
4	Tufted	Clumps of periphyton 1-3 cm thick/long.
5	Pendulous	Clumps of periphyton > 3 dm in length.
6	Obscuring	Nearly complete cover of periphyton > 3 dm in length such that even the shapes of the rock beneath are becoming obscured.

RESULTS

MONITORING SITES

Photographic monitoring data include some data-gaps, particularly as the project was initiated. The initial test of the photomonitoring sampling scheme and scoring process was in February of 2020 and collected data from only 15 of the 24 sites currently monitored. Additionally, the sites sampled above the dams at that time were visually scored in the field, thus these lack reference photographs. The April 2020 sampling covered 18 of the 24 current sites. In June of 2020, all sites were sampled except for Lewiston Dam. The full set of 24 sites was monitored as of July 2020. Missing data after that include the lack of water at the Weaver Creek site in October of 2020 and a lack of observations at Chapman and Deep Gulch channel restoration sites for the same monitoring period. All changes to monitoring locations are detailed in Appendix A. The data reported here actually span slightly more than a single year, with

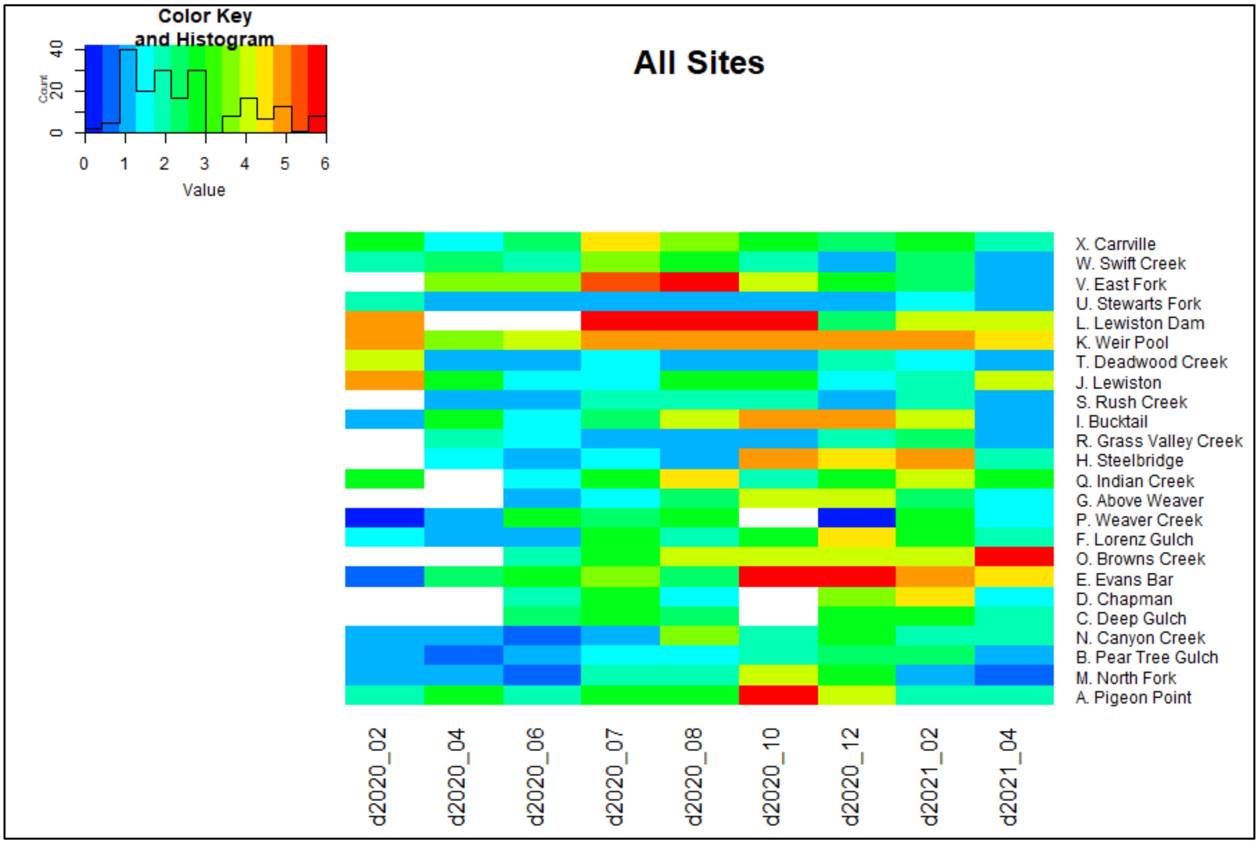


Figure 4: Heatmap of periphyton scores across all sites (vertical) and time (horizontal). Locations are provided with the Map Label for convenient reference to Figure 1 and Table 1. Dates are given preceded by the letter ‘d’, followed by the year, an underscore, and the month.

February and April being sampled twice; reporting was delayed since the sampling lacked several sites during the first two sampling events.

PHOTOGRAPHIC MONITORING

Periphyton cover scores from photomonitoring are presented as heatmaps and bar graphs, then summarized as box plots. Figure 4 provides a heatmap of scores from all sites in order from the highest in the watershed (Carrville) to the lowest (Pigeon Point). While there may be some visual indication of patterns with high scores both longitudinally and temporally, mixing of mainstem and tributary data resulted in a very noisy heatmap with only vague suggestions of patterns.

Figure 5 splits mainstem and tributary data into separate heatmaps (all sites above the dams are included as tributaries). Within the mainstem of the Trinity River, there appeared to be more scores of 5

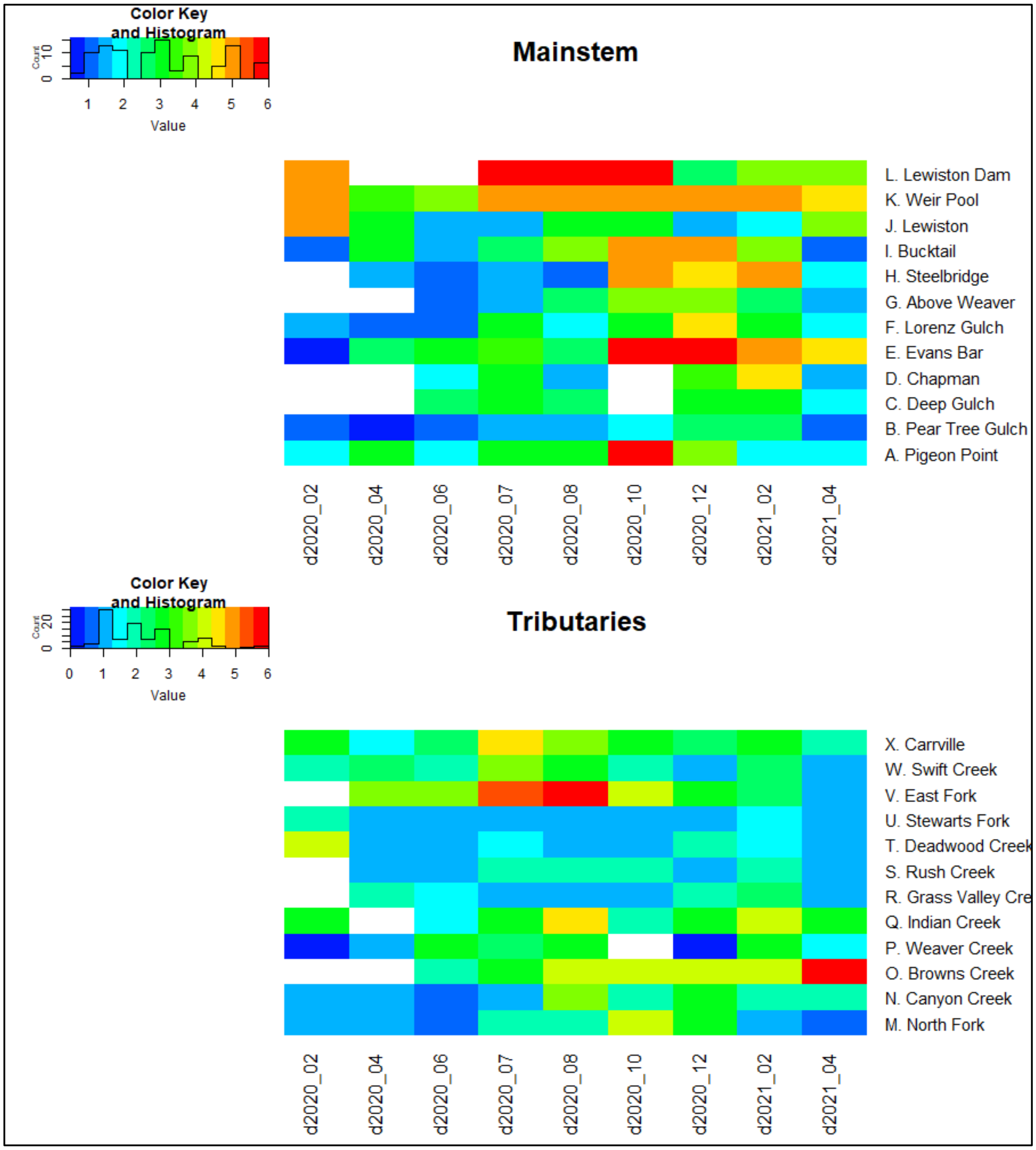


Figure 5: Heatmaps of periphyton scores, separated for Mainstem and Tributaries, across sites (vertical) and time (horizontal).
Locations are provided with the Map Label for convenient reference to Figure 1 and Table 1. Dates are given preceded by the letter ‘d’, followed by the year, underscore, and the month.

or above recorded at the upper-river sites (approximately Steelbridge and above) versus lower river sites. A number of locations had their highest scores recorded during the cooler months of the year (October through February). Tributaries appeared much more variable with no visually clear patterns either longitudinally or with aspect (northerly versus southerly watershed flow). Most tributaries did appear to

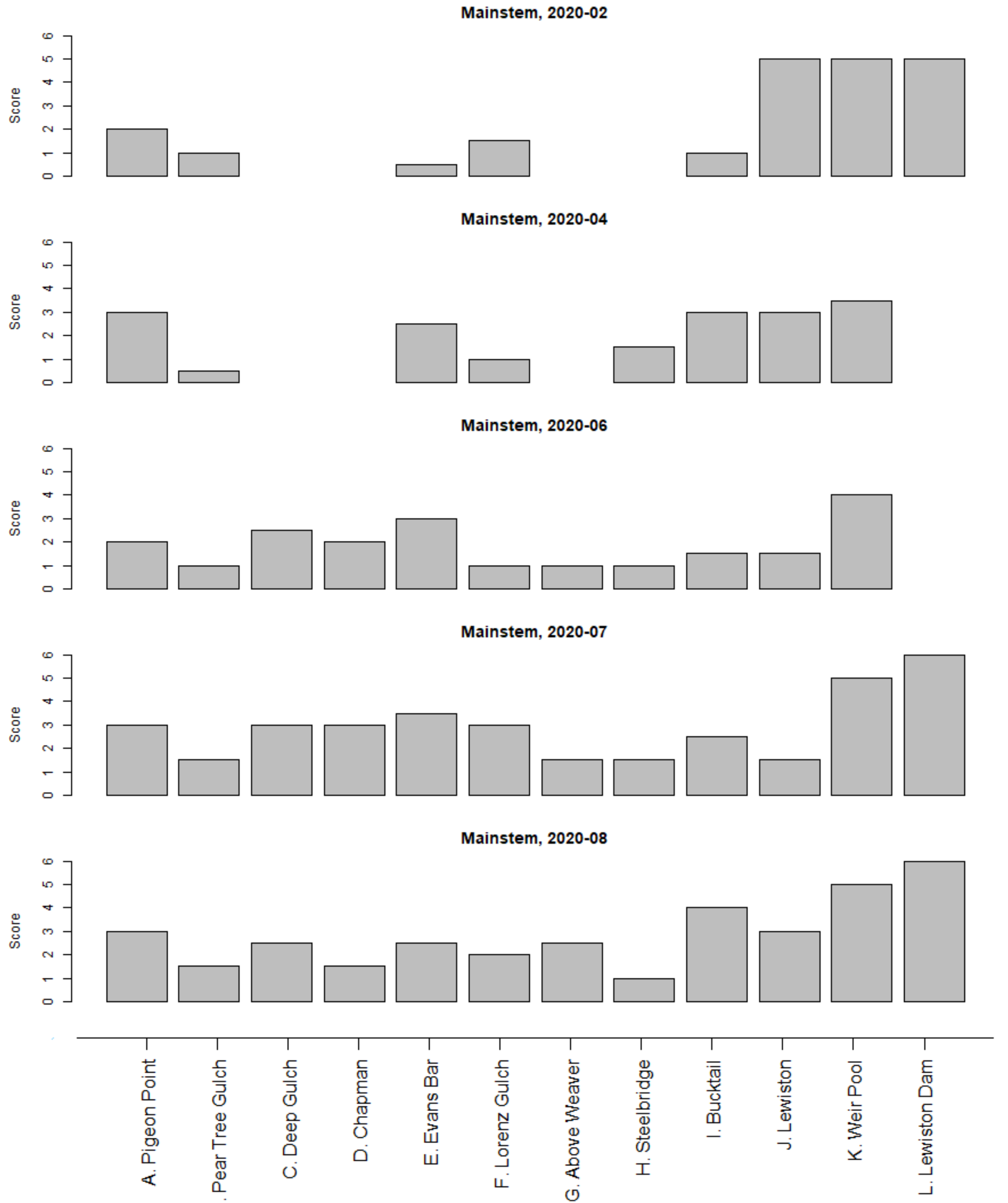
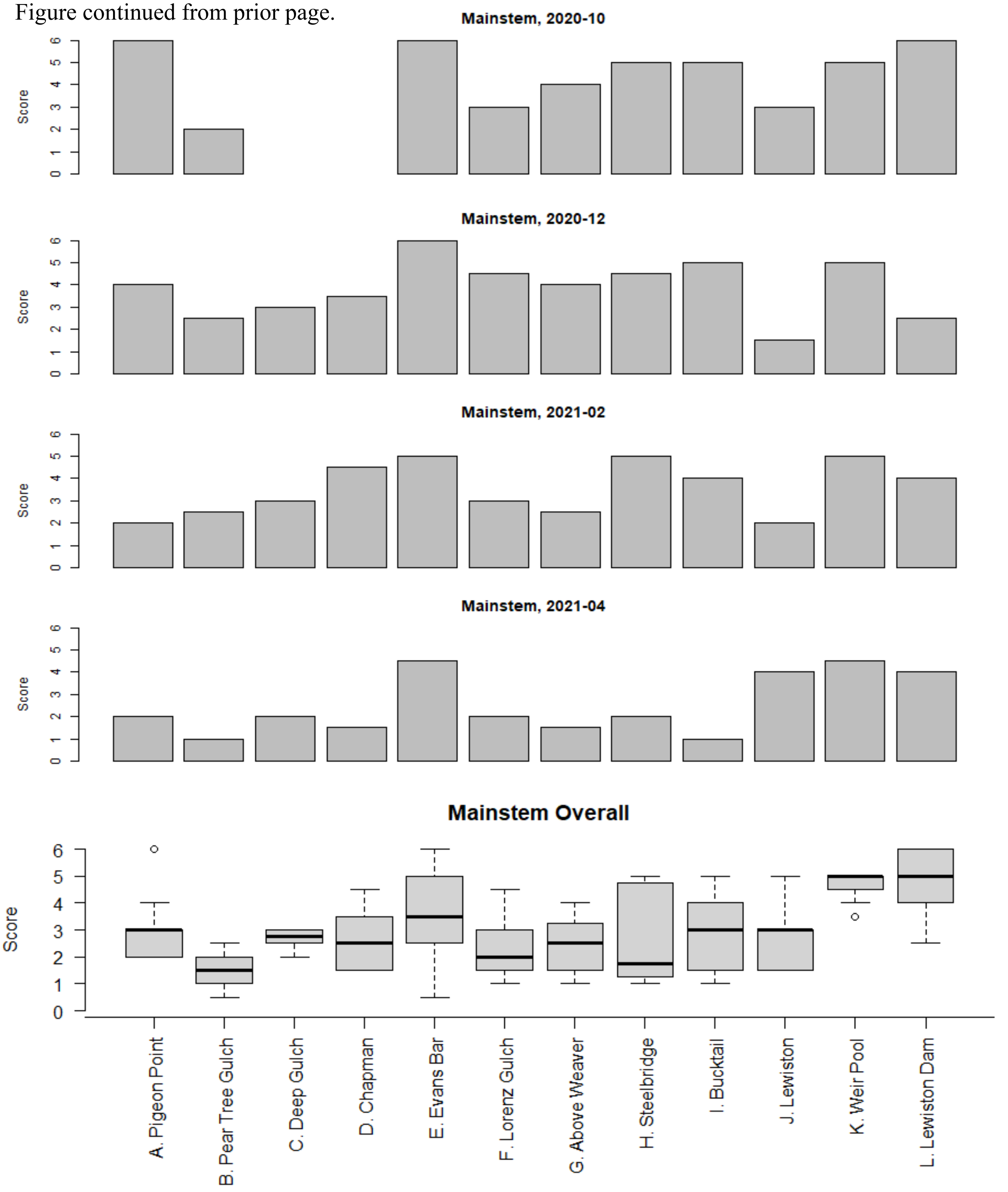


Figure continued on next page.

Figure continued from prior page.



Mainstem, 2020-10

Mainstem, 2020-12

Mainstem, 2021-02

Mainstem, 2021-04

Mainstem Overall

Figure 6: Bar graphs showing periphyton scores at each mainstem site for each date, plus box plot showing variation across time at the sites.

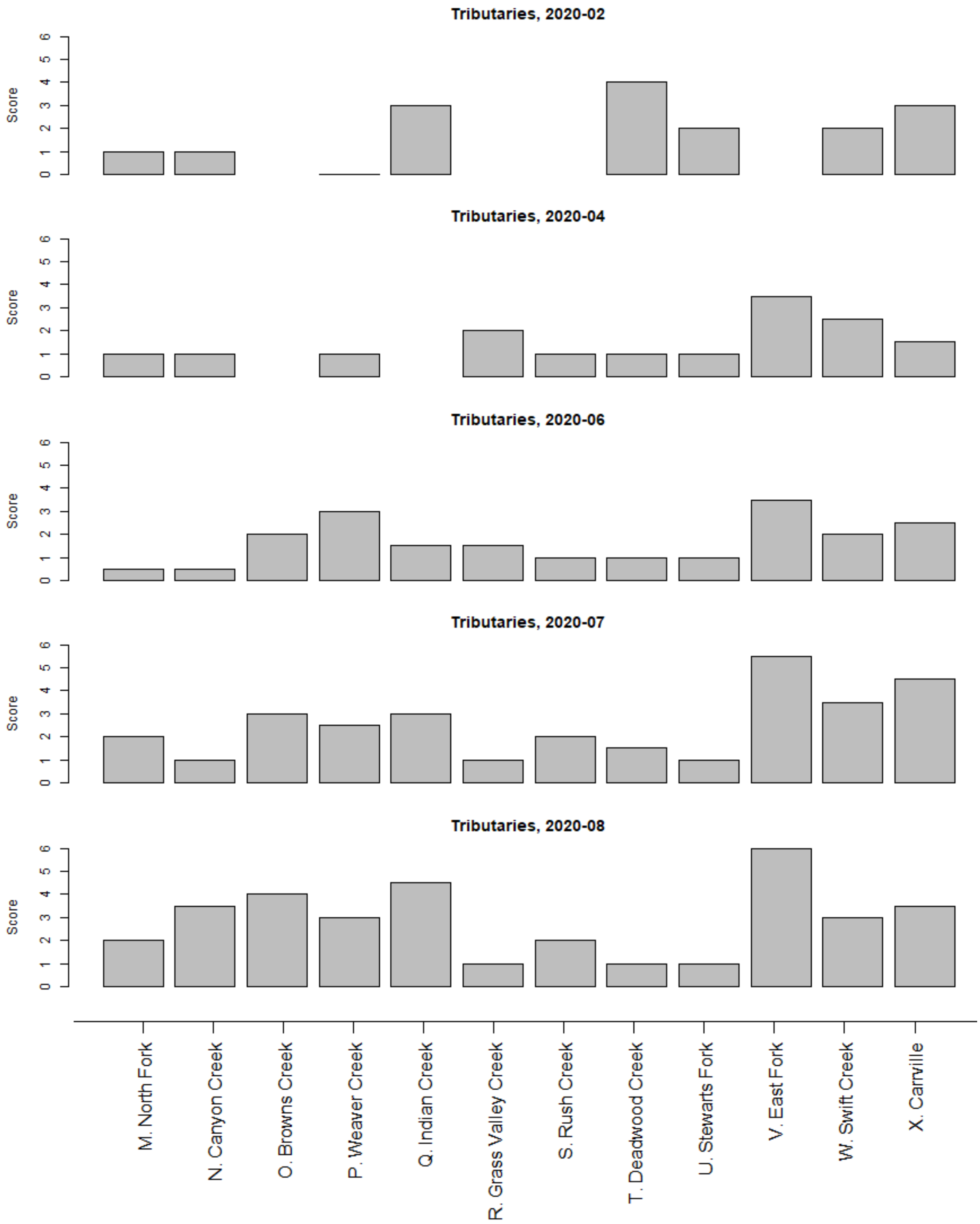


Figure continued on next page.

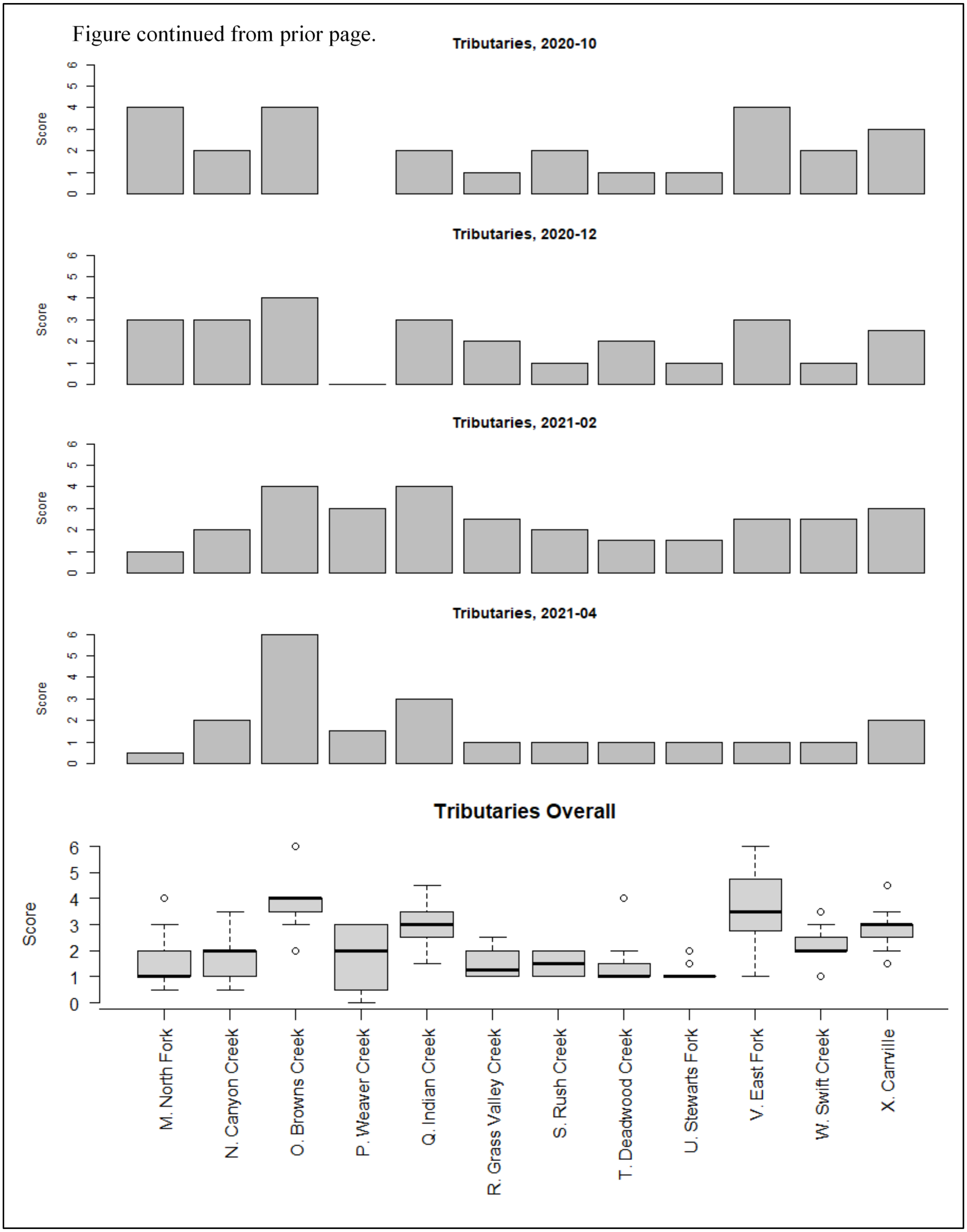


Figure continued from prior page.

Figure 7: Bar graphs showing periphyton scores at each tributary site for each date, plus box plot showing variation across time at the sites.

have temporal fluctuations in periphyton cover, although some had their peak scores in cooler seasons while others peaked in warmer seasons. Statistical testing of these patterns will be reserved for the future when multiple years of data are available. Figure 6 and Figure 7 provide bar graphs for each sampling time across sites, and box-plot summaries of sites through time. These plots provide greater visual representation of a longitudinal pattern in the mainstem river with the higher scores occurring at the sites closest to the dams. However, the representation of temporal patterns may be less visually clear. For tributaries, the boxplots illustrate that some are reliably high and some reliably low.

BIODIVERSITY

Samples of organisms for biodiversity studies often include meager quantities of some taxa, and ecological variations may complicate identification of everything sampled. At present, 35 taxa have been identified (mostly to genus) and an additional 72 morphotypes[1] are recorded, for a potential total of 107 taxa. Table 3 shows the identified taxa with their number of detections. These include 1 bryophyte, 12 taxa and 4 morphotypes of filamentous algae (which includes *Vaucheria*, a member of Xanthophyceae), 15 taxa and 66 morphotypes of diatoms, 2 morphotypes of green algae with clustered cells, 1 other green alga, and 5 taxa of cyanobacteria. Given the morphology of many diatoms resulting in very different appearances depending on view angle, the number of morphotypes is likely to reduce as identification progresses. Tallies of identified taxa plus morphotypes will be referred to as “potential taxa”.

The sites with the highest number of potential taxa (the greatest alpha-diversity) were the tributary Browns Creek during August 2020 with 30 potential taxa, and the mainstem at Evans Bar (the first site downstream of Browns Creek) during February 2021 also with 30 potential taxa. The lowest alpha-diversity site was Deadwood Creek during both biodiversity samplings with 4 potential taxa,

---

[1] A morophotype is a presumed distinct taxon based on distinguishing morphological characters, but that has not been successfully identified to a known name.

Table 3: Identified taxa with frequency of detection.
This table shows those taxa that have been identified (mostly to genus). An additional 72 morphotypes are being tracked that are not listed here. Palmer Score and Pollution Index are from Palmer (1969) and show pollution tolerance scores and index calculation values.

Taxon	Detections August 2020	Detections February 2021	Palmer Score (Pollution Index)
Bryophyta			
Fissidens	1	1	
Filamentous Algae			
Bulbochaete	1	2	
Cladophora	9	10	24 (-)
Desmidium?	1	5	
Microspora	8	13	
Mougeotia	9	11	
Oedegonium	3	2	
Spirogyra	9	8	37 (-)
Stigeoclonium	7	10	69 (2)
Tribonema?	1	0	
Ulothrix	1	2	33 (-)
Vaucheria	1	2	
Zygnema	5	1	
Diatoms			
Cocconeis	18	20	17 (-)
Cymbella	16	17	24 (-)
Didymosphenia geminata	4	10	
Encyonema	9	14	
Epithemia	20	16	
Fragilaria	7	15	33 (-)
Gomphoneis	6	10	
Gomphonema	0	3	48 (1)
Hannaea	1	3	
Nitzschia sigmoidea	1	0	98 (3)
Pinnularia	2	2	18 (-)
Rhoicosphenia	3	8	
Rhopalodia	8	11	
Synedra	22	23	58 (2)
Tabellaria	6	21	
Other Algae			
Closterium	4	4	
Cyanobacteria			
Anabaena	2	3	36 (-)
Calothrix	2	0	
Microcystis	1	0	
Nostoc parmelioides	1	2	
Phormidium	8	13	52 (1)

although the list of potential taxa was partially different between the two samples. Across all sites, average alpha-diversity was 13 potential taxa in August 2020 and 18 in February 2021. As data accumulate across years, it is likely that cold versus warm water preferences of some taxa may become apparent and already several taxa (e.g. *Didymosphenia geminata*) showed more than two-fold changes in abundance between sampling seasons. How such seasonality may relate to possible food resource benefits for salmonids is not yet determined. Future reporting will include community analyses such as multivariate ordination to examine community trends; given the preliminary nature of this report, only broad observations of select taxa will be noted at this time.

Cladophora, a foundation for productive salmonid food webs according to Vadboncoeur and Power (2017), was observed at 9 sites in August 2020 and 10 sites in February 2021. Sites where *Cladophora* has been observed include mainstem and tributaries, both below the dam and in the above-reservoir sites. While filamentous algae are nearly always present in high abundance at Lewiston Dam, *Cladophora* has not been observed at this location.

Spirogyra is commonly found along with *Cladophora* at some sites, often as a minor component of samples dominated by *Cladophora* (relative abundance is a personal observation not represented in the data). However, at Lewiston Dam and above the reservoirs at the East Fork Trinity River, *Spirogyra* forms dense colonies with little or no *Cladophora* present.

Other filamentous algae commonly observed included *Microspora*, *Mougeotia*, and *Stigeoclonium*. Sites rarely lack detectable filamentous algae even when photographic monitoring scores are minimal.

Diatoms growing epiphytically on *Cladophora* commonly included *Cocconeis*, *Epithemia*, *Rhoicosphenia*, and a cigar-shaped morphotype. Although rarely observed, epiphytes were also found attached to *Spirogyra* and the cyanobacterium *Phormidium*.

The diatom *Didymosphenia geminata*, was detected at 4 sites in August 2020 and 10 sites in February 2021. These included one detection in the tributary North Fork Trinity River; otherwise all were mainstem sites from the Weir Pool to Pear Tree.

Other commonly observed diatoms included *Cymbella*, *Fragillaria*, *Tabellaria*, and a large number of morphotypes.

Among the cyanobacteria detected, only *Phormidium* was observed frequently with 8 detections in August 2020 and 13 in February 2021, (mis-identified as *Tolypothrix* during previous oral presentations such as Peterson 2020). *Phormidium* occurred as sparse threads mixed among abundant other taxa except for one sample: it was abundant at the Weaver Creek site in August 2020, when the tributary had stopped flowing and become a standing pond. The next most abundant cyanobacteria were *Anabaena* and *Calothrix* with no more than 3 detections during a sampling period and then only as a minor component of the periphyton community. While *Phormidium* and *Anabaena* are capable of producing cyanotoxins, toxin production and accumulation are complex topics that may include environmental conditions but are focused more on impacts to human health than ecological consequences (Velzeboer et al. 2000; Saker et al. 2005; Woods et al. 2012), so will not be discussed in depth.

DISCUSSION

Spatial Patterns

Periphyton are widespread and diverse in the Trinity River system. Patterns observed in the mainstem included an increase in periphyton scores in the upper river toward Lewiston Dam. Although not yet statistically analyzed, this pattern is visually striking across most photomonitoring dates, with perhaps some weakening during winter months. If this pattern persists across multiple years, it will deserve further investigation into the causes to understand if flow management can provide control over the abundance or taxonomic composition of periphyton. Reservoirs are known to impound nutrients from the watersheds above (Williamson et al. 2021), or even to foster nitrogen fixation within the reservoir (Carpenter et al. 2014). Nutrients may then be either metered-out in stable concentrations (Wurtsbough et al. 2005) or released in pulses caused by turnover of the water body or by large reservoir releases

(Williamson et al. 2021). Addition of water chemistry sampling would be valuable for understanding the pattern. The following hypothesis is proposed:

> ***Reservoir-Nutrient Hypothesis:*** *Trinity and Lewiston Reservoirs impound nutrients in a way that elevates nutrient concentrations in the river immediately below the dams.*

At the dam, biodiversity sampling showed the primary filamentous green alga (the one forming the bulk of the biomass) was *Spirogyra*. While this constitutes primary production that can be consumed by herbivorous macroinvertebrates, it is nutritionally poor compared to *Cladophora* with epiphytic diatoms (Power et al. 2008a). *Cladophora* becomes common within the first few river-kilometers below the dam (although this data collection does not specify where it comes to dominate). Highly nutritional diatoms that epiphytically inhabit *Cladophora* are thought to be a valuable foundation to food webs that benefit salmonids (Power et al. 2008a). Autochthonously-produced food available to salmonids likely increases downstream from the dam as *Cladophora* increases, resulting an an hypothesis:

> ***Dam-Herbivore Hypothesis:*** *Due to the lack of* Cladophora *in the river immediately below Lewiston Dam, herbivorous macroinvertebrates are less abundant and thus less autochthonous prey are available for juvenile salmonids than in downstream reaches where* Cladophora *is common.*

Longer-term monitoring data may not only be capable of testing the Dam-Herbivore Hypothesis, but may also offer an opportunity to identify nutrient spiraling within the river (Ensign and Doyle 2006).

The reason for the lack of *Cladophora* and abundance of *Spirogyra* at this location is unknown. Reasonable possibilities include the relatively constant cold temperature of water released from Lewiston Dam (Thomas Gast & Associates 2021; Carlisle et al. 2015) or the lack of geomorphically mobile sediment to enable disturbance via scouring. From these, the following hypotheses are proposed:

> ***Dam-Temperature Hypothesis:*** *The lack of* Cladophora *immediately below Lewiston Dam is caused by stable, cold, water temperatures favoring* Spirogyra.

Dam-Scour Hypothesis (alternative): *The lack of* Cladophora *immediately below Lewiston Dam is caused by a lack disturbance by scour of mobile sediments.*

Variation among tributaries is intriguing. While there will undoubtedly be speculation that nutrient loading from local communities or agricultural practices may influence the abundance in tributaries, IERC (2018) indicates that these effects can be rather limited to short distances (e.g. < 2 km) below point sources; indeed periphyton are often used in engineered systems for removal of nutrients from water (e.g. Kangas et al. 2017). However, inclusion of tributaries in this work was to provide watershed context for the mainstem river, not to elucidate water quality issues on specific streams. With regards to watershed context, one potential pattern may be relevant: when combined with local geological knowledge, it is notable that tributaries coming from the newer-granitic and ultramafic geologies in the Trinity Alps tend to score low for periphyton cover, while tributaries with either a sedimentary geology, or older decomposed-granitic geology, tend to be higher. With further data, the following hypothesis may be testable:

Tributary Geology Hypothesis: *Periphyton abundance in tributaries is dependent on the geology of the tributary watershed.*

Temporal Patterns

Within the mainstem Trinity River below the dams, periphyton cover scores tended to be highest from October through February (Figure 5). This was surprising in that concerns over algae among the public tend to peak during summer months. Warmer waters in summer are generally linked to cyanobacterial blooms and thus cyanotoxins (CSWRCB 2021). Many concerns raised during the 2018 bloom came from fishermen. Considering the winter peak pattern observed here in light of the popularity of winter steelhead fishing on the Trinity River, it seems odd that concerns over algae do not rise during the fall and winter.

The 2018 algal bloom that we believe was dominated by *Cladophora* did occur during summer. One possible explanation of the bloom was an extremely wet winter in 2017 leading to scouring disturbance events, and that the cold water of the mainstem Trinity River may lead to slower succession than observed on the Eel River where blooms often occur within the year of a scour disturbance (Vadeboncoeur & Power 2017). Thus, the 2017 water year may have initiated a slow succession that was not disrupted by flows in 2018 (a critically dry water year) and culminated in the summer-2018 bloom. A similar weather pattern, developed between 2019 (wet) and 2020 (critically dry) yet no major bloom of *Cladophora* was noted within the study reach of the mainstem Trinity River (a bloom of filamentous algae was noted downstream in the Big Bar area). Clearly, interannual variability exists in ways that are yet to be understood.

Two tributaries may have winter peaking patterns that are somewhat similar to the mainstem, but less distinct: Stewart's Fork and Deadwood Creek. Others such as Rush Creek, Canyon Creek, and the North Fork Trinity River had scores increased in hot summer months and persisted into the winter. Browns Creek showed an increasing pattern throughout the study period. Meanwhile the mainstem Trinity River above the reservoirs at Carrville, as well as Swift Creek and Weaver Creek had highest scores in hot summer months followed by reduced scores in the fall and winter. Indian Creek had a distinctly bimodal pattern with peaks in August and February. All this suggests that tributaries are highly variable in their temporal patterns and underscores the need for multiple years of sampling in order to conduct statistical analyses.

Biodiversity

Didymosphenia geminata was found at a variety of sites during the two sampling periods covered by this report, primarily in the mainstem below Lewiston Dam. By these data alone, *D. geminata* may seem mostly limited to the mainstem. However, during preliminary biodiversity sampling in February 2020, *D. geminata* was also detected above the reservoirs in the mainstem at Carrville and in Stewart's

Fork, plus two tributaries below the dams (Peterson 2020). With inclusion of those preliminary data, the available evidence is that *D. geminata* is widespread within the Trinity River and the lower portions of its tributaries, both below and above the reservoirs. This wide distribution is compatible with endogeny of *D. geminata* in the Trinity River (the Didymo Hypothesis), although the proximity of sampling sites to the mainstem and high potential for ectozoochory (either by wildlife or by human activities) prevent full certainty. Frequency of detection appears to increase during winter, which is consistent with its known preference for cold water habitats (Kumar et al. 2009), although many other taxa were also detected more frequently among the winter samples, with average diversity increasing from 13 to 18 per site.

Consistent with the Cyano Hypothesis, cyanobacteria were commonly found within biodiversity samples, particularly the genus *Phormidium*. The only sample where cyanobacteria were regarded as abundant was in Weaver Creek when the water had stopped flowing and become a standing pond. Presence of cyanobacteria in low amounts is generally not considered to be a public health concern (CSWRCB 2021), but these data do demonstrate their presence and the Weaver Creek case supports the idea that they can become dominant under low-water conditions.

Periphyton communities can be indicative of water quality, and particularly for nutrient loading. Palmer (1969; Table 3) is a common resource for translating periphyton taxa to nutrient loading. Palmer scored taxa for pollution tolerance from 14 (low tolerance to pollution) to 172 (high tolerance) and developed an organic pollution index calculated on the presence of 20 genera. The taxonomic understanding of Trinity River periphyton communities is limited, with 72 morphotypes still lacking accurate nomenclature. But for what can be ascertained from current identifications, only a few rank high for pollution tolerance (e.g. *Nitszscia*, scoring 98, with one detection; *Stigeoclonium*, scoring 69, with a total of 17 detections; *Synedra*, scoring 58, with 45 detections, and *Phormidium*, scoring 52, with of 21 detections). Meanwhile, *Cocconeis* with a tolerance rank of just 17 has 38 detections and *Cladophora* with a tolerance rank of 24 has 19 detections. The abundance of *Synedra* may be of some concern as it has a high pollution tolerance score and is abundantly present in nearly every sample, though the fact that it tolerates pollution does not mean that it only exists in the presence of pollution. Palmer's pollution index is intended to be calculated with a 1ml water sample, implying a sample of phytoplankton from the water column rather than a sample of periphyton. However, the total possible pollution index from the taxa identified within the Trinity River that are listed by Palmer would be 9, while an index of 15 would be required to rate the Trinity as probable for high organic pollution. Given the frequency of taxa with low pollution tolerance ranks, biodiversity sampling at present suggests that water quality in the Trinity system is high.

Comparison to Other Rivers

Similar to the lack of *Cladophora* immediately below Lewiston Dam, Jansen et al. (2020) found that *Cladophora* is reduced below a flow-regulating dam on the nearby Eel River, relative to an undammed fork, and that there was a corresponding shift to the invertebrate community. If our lack of *Cladophora* below the dam is found to be persistent then closer study of the similarity of the sites between the rivers could be fruitful. The Eel River, however, has a different suite of ecological challenges from the Trinity River, with a less consistent supply of summer water and a greater tendency to develop cyanobacterial blooms (Power et al. 2015). Therefore, comparisons between the two rivers may be limited.

The Klamath River also has a suite of ecological challenges that differ from the Trinity, due in large part to different temperature patterns and nutrient sources. Genzoli (2019) found that filamentous green algae in the Klamath River were dominated by *Cladophora* and *Ulothrix. Ulothrix* was detected only a few times in the Trinity. Genzoli (2019) also found greater amounts of cyanobacteria, especially *Phormidium*.

Comparable studies in the Rogue River are not available. However, a small study of periphyton in the immediate vicinity of the Medford water treatment facility (Hafele 2013) found a greater than 6-fold increase in algal cell density below the facility outflow and a shift toward more eutrophic taxa, particularly two species of *Nitzschia*. The work on the Trinity River here includes only a single detection of *Nitzschia*.

Algal studies in the North Umpqua River have found increased periphyton in reaches immediately below dams and suggest nitrogen fixation by cyanobacteria within reservoirs may be causative of periphyton blooms in the downstream rivers (Carpenter et al. 2014).

Recommendations on Future Periphyton Monitoring

The present data are rather temporally limited so conclusions are tentative and may change after a few more years of monitoring with differing water-year types. The intent of the study is to continue for a minimum of 3 years, but also assumed that there would be variation in hydrography among those years to provide analysis of periphyton patterns relative to geomorphic flow events. Geomorphic flows are expected to scour both algae and herbivorous macroinvertebrates. Algal growth following such events could proceed rapidly in the absence of the herbivores or it may be inhibited by the reduction of parent algal colonies. This study began in the first of a series of Critically Dry years as classified under the ROD (USDI 2000). Monitoring should continue until at least two years of different classification can be included, ideally with at least one Wet or Extremely Wet year, to provide ample variation for analysis of how peak flow levels affect periphyton quantities.

During biodiversity sampling, the use of a simple presence/absence determination was inadequate to determine where community domination shifts from *Spirogyra* to *Cladophora* within the mainstem. A simple change to methods that would require no further field effort would be to note if a filamentous alga is dominant within a biodiversity sample. Simple identification of two or three characteristic taxa is widely accepted for identifying terrestrial plant communities (Jennings et al. 2009). For freshwater algae, Carpenter et al. (2014) listed the 5 most abundant taxa per location. Thus, I propose that future biodiversity sampling record the dominant filamentous alga (or codominants if roughly equal in abundance) and any diatoms of sufficient abundance as to appear in at least half of the observed fields of view at 100x in the compound microscope.

My personal observation during sampling is that periphyton cover is fairly uniform within a particular site at a particular microhabitat, such as the downstream flows at depths targeted for photomonitoring. Therefore, my use of a single point location for photomonitoring should be representative of this microhabitat for the site. However, within-site variation has not been specifically sampled and analyzed for this study. Periphyton taxa are well known to vary across microhabitats at a very fine scale (Bergey et al. 2015), so site heterogeneity may be problematic for biodiversity sampling. Use of 3 scrubbing locations across two rocks is intended to minimize the influence of microhabitat heterogeneity while maintaining a time-efficient sampling scheme. To address these uncertainties, I suggest an additional study that would select a small number of sites to be sampled across a variety of microhabitats and with replication within microhabitats.

The patterns in periphyton abundance and seasonality within tributaries could benefit from multiple sampling sites per tributary. Such sampling could also better distinguish point-source pollution from watershed geology. However, that would have logistical challenges in that some tributaries may not have good access points sufficiently distant from the current sites, particularly during winter. Since distinction of geology and point-source pollution is not a primary goal of this study, I suggest that additional tributary sampling be deferred to future research, or that geology and point-source pollution be studied through testing of water chemistry. Analysis of isotopes may be an alternative for elucidation of nutrient sources (Peterson 1999).

The current study is intended to identify spatial and temporal patterns of periphyton, not to specifically determine the causative drivers. Seeking those drivers may be as simple as adding water temperature monitoring and testing of water samples for nutrient loads at these sites, plus perhaps the reservoirs. Opportunities will be sought to expand this study or collaborate with other studies so as to incorporate water temperature and chemistry.

As currently conducted, this study will provide a much improved understanding of how geomorphic disturbance relates to periphyton community development and abundance. But this does not determine the ideal quantity of periphyton to support salmonid populations in the Trinity River. Research on macroinvertebrates in the Trinity River is gaining interest (Starkey-Owens 2020; Williamshen 2021). Examination of macroinvertebrate production in relation to *Cladophora* and the relevance to modeling salmonid bioenergetics would be useful for quantifying benefits of periphyton. While I do not propose a specific study here, I recognize that one is needed for determining if blooms of *Cladophora* as seen in 2018 are a good thing, or too much of a good thing.

ACKNOWLEDGEMENTS

Much of the inspiration for this project arose from various discussions with James Lee and Kyle De Juilio. Valuable contributions also came from Eli Asarian, Cindy Buxton, Chris Laskodi, and Mary Power. Thanks also go to James, Kyle, Chris, and Jeanne McSloy for review of an early version of the report plus to John Bair and one anonymous person for formal peer review. This project was supported by the Trinity River Restoration Program.

LITERATURE CITED

Assarian, E. and J. Kann. 2006. Klamath River nitrogen loading and retention dynamics, 1996-2004. Kier Associates Final Technical Report to the Yurok Tribe Environmental Program, Klamath, California. Online at: https://klamathwaterquality.com/documents/Klamath_Nitrogen_Loading_Dynamics_1996_2004_Yurok_final_aug111.pdf.

Banish, N. J. 2017. Factors influencing Cladophora biomass abundance in the upper Clark Fork River, Montana. Masters Thesis, University of Montana. Online at: https://scholarworks.umt.edu/etd/11112.

Bellinger, E. G. and D. C. Sigee. 2015. Freshwater Algae: Identification, Enumeration and Use as Bioindicators. John Wiley & Sons, Ltd.

Bergey, E. A., C. A. Boettiger, and V. H. Resh. 1995. Effects of water velocity on the architecture and epiphytes of *Cladophora glomerata* (Chlorophyta). Journal of Phycology 31: 264-271.

Bothwell, M. L., B. W. Taylor, and C. Kilroy. 2014. The Didymo story: the role of low dissolved phosphorus in the formation of *Didymosphenia geminata* blooms. Diatom Research 29(3): 229-236. DOI: 10.1080/0269249X.2014.889041.

Buxton, T. H. 2021. History of fine sediment and its impacts on physical processes and biological populations in the restoration reach of the Trinity River, CA. Report TRRP-2021-1 for the Trinity River Restoration Program (TRRP). Trinity River Restoration Program, Weaverville, California. Online at: https://www.trrp.net/library/document/?id=2483.

Carlisle, D. M., S. M. Nelson, and J. May. 2015. Associations of stream health with altered flow and water temperature in the Sierra Nevada, California. Ecohydrology 9(6): 930-941. DOI: 10.1002/eco.1703

Carpenter, K. D. 2003. Water-quality and algal conditions in the Clackamas River Basin, Oregon, and their relations to land and water management. U.S. Geological Survey, Water-Resources Investigation Report 02-4189. Online at: https://pubs.usgs.gov/wri/WRI02-4189/.

Carpenter, K. D., C. W. Anderson, and M. E. Jones. 2014. Water quality and algal conditions in the North Umpqua River, Oregon, 1995–2007, and their response to Diamond Lake restoration: U.S. Geological Survey Open-File Report 2014-1098. DOI: 10.3133/ofr20141098

CSWRCB (California State Water Resources Control Board). 2021. Freshwater and Estuarine Harmful Algal Bloom (FHAB) Program. Available: https://www.waterboards.ca.gov/water_issues/programs/swamp/freshwater_cyanobacteria.html.

Diatoms of North America. 2021. Diatoms of North America, the source for diatom identification and ecology. Available: https://diatoms.org.

Dodds, W. K., V. H. Smith, and B. Zander. 1997. Developing nutrient targets to control benthic chlorophyll levels in streams: a case study of the Clark Fork River. Water Research 31(7): 1738-1750. DOI: 10.1016/S0043-1354(96)00389-2.

Ensign, S. H. and M. W. Doyle. 2006. Nutrient spiraling in streams and river networks. Journal of Geophysical Research 111(G4009): 1-13. DOI: 10.1029/2005JG000114.

Fleitz, A. 2018. Didymo Post-fire Helena BAER Monitoring. Report. USFS, Weaverville, California. Online at: https://www.trrp.net/library/document?id=2423.

Genzoli, L. 2019. Algae and aquatic plant assemblages below Klamath River dams, including the timing, extent, and toxicity of benthic cyanobacteria. Presentation to the Klamath Basin Monitoring Program, November 13-14, 2019. Online at: https://kbmp.net/images/stories/pdf/Meeting_Materials/Meeting_24/20_Genzoli_KBMP2019_Benthic_Algae.pdf.

Grunblatt, J., B. E. Meyer, M. S. Wipfli. 2019. Invertebrate prey contributions to juvenile Coho Salmon diet from riparian habitats along three Alaska streams: Implications for environmental change. Journal of Freshwater Ecology 34(1): 617-631. DOI: 10.1080/02705060.2019.1642243.

Hafele, R. 2013. Medford regional water reclamation facility outfall assessment study. Report to the Rogue Fly Fishers & Federation of Fly Fishers. Online at: https://www.nwexpo.com/Meford_Outfall_Report.pdf.

Hall, F. C. 2002. Photo point monitoring handbook: part A – field procedures. U.S. Forest Service General Technical Report PNW-GTR-256. Online at: https://www.fs.fed.us/pnw/pubs/pnw_gtr526.pdf.

Healey, T. 1964. Observations on Trinity River algae following the October 1 increase in flow below Trinity and Lewiston Dams. Memorandum, California Department of Fish and Game. Online at: https://www.trrp.net/library/document?id=1342.

Hill, B. H. and J. R. Webster. 1982. Periphyton production in an Appalachian river. Hydrobiologia 97: 275-280.

HVTEPA (Hoopa Valley Tribal Environmental Protection Agency). 2021. Hoopa Valley Tribal Environmental Protection Agency. Available: http://www.hoopatepa.org/water.html.

IERC (Integrated Ecology Research Center). 2018. Nutrient and pesticide monitoring within forested streams of Trinity County, California. Report to the County of Trinity. IERC, Blue Lake, California.

Jansen, L. S., A. O'Dowd, and K. Bouma-Gregson. 2020. A comparison of benthic algal and macroinvertebrate communities in a dammed and undammed Mediterranean river (Eel River watershed, California, USA). River Research and Applications 36: 1668-1681. DOI: 10.1002/rra.3695.

Jennings, M. D., D. Faber-Langendoen, O. L. Loucks, R. K. Peet, and D. Roberts. 2009. Standards for associations and alliances of the U.S. National Vegetation Classification. Ecological Monographs 79(2): 173-199. DOI: 10.1890/07-1804.1.

Kangas, P., W. Mulbry, P. Klavon, H. D. Laughinghouse, and W. Adey. 2017. High diversity within the periphyton community of an algal turfscrubber on the Susquehanna River. Ecological Engineering 108: 564-572. DOI: 10.1016/j.ecoleng.2017.05.010.

Kazanjian, G., M. Velthuis, R. Aben, S. Stephan, E. T. H. M. Peeters, T. Frenken, J. Touwen, F. Xue, S. Kosten, V. B. Van Der Waal, L. N. de Senerpont Domis, E. van Donk, and S. Hilt. 2018. Impacts of warming on top-down and bottom-up controls of periphyton production. Scientific Reports 8, 9901 (2018). DOI: 10.1038/s41598-018-26348-x

Kumar, S., S. A. Spaulding, T. A. Stohlgren, K. A. Hermann, T. S. Schmidt, and L. L. Bahls. 2009. Potential habitat distribution for the freshwater diatom Didymosphenia geminate in the continental US. Frontiers in Ecology and the Environment 7(8): 415-420. DOI: 10.1890/080054

Ode, P. R., A. E. Fetscher, and L. Busse. 2016. Standard Operating Procedure (SOP) for collection of field data for bioassessments of California wadeable streams: benthic macroinvertebrates, algae, and physical habitat [SWAMP Bioassessment Procedures]. California Water Boards. Online at: https://www.waterboards.ca.gov/water_issues/programs/swamp/bioassessment/sops.html.

Palmer, C. M. 1969. A composite rating of algae tolerating organic pollution. Journal of Phycology 5(1): 78-82. DOI: 10.1111/j.1529-8817.1969.tb02581.x.

Peterson, B. J. 1999. Stable isotopes as tracers of organic matter input and transfer in benthic food webs: a review. Acta Oecologica 20: 479-487. DOI: 10.1016/S1146-609X(99)00120-4.

Peterson, E. B. 2020. Trinity River Periphyton. Presentation to the Trinity Management Council, September 2, 2020. Online at: https://www.trrp.net/DataPort/meetingitem.php?id=946.

Pfiester L. A., R. Lynch, and T. Wright. 1979. Species composition and diversity of periphyton in the Grand River Dam area, Mayes County, Oklahoma. The Southwestern Naturalist 24(1): 149-164. Online at: https://www.jstor.org/stable/3670635.

Power, M. E., M. S. Parker, and W. E. Dietrich. 2008a. Seasonal reassembly of a river food web: floods, droughts, and impacts of fish. Ecological Monographs 78(2): 263-282. DOI: 10.1890/06-0902.1.

Power, M., R. Lowe, P. Furey, J. Welter, M. Limm, J. Finlay, C. Bode, S. Chang, M. Goodrich, and J. Sculley. 2008b. Algal mats and insect emergence in rivers under Mediterranean climates: towards photogrammetric surveillance. Freshwater Biology 54:2101-2115. DOI: 10.1111/j.1365-2427.2008.02163.x.

Power, M. E., K. Bouma-Gregson, P. Higgins, and S. M. Carlson. 2015. The thirsty Eel: summer and winter flow thresholds that tilt the Eel River of northwestern California from salmon-supporting to cyanobacterially degraded states. Copeia 2015(1): 200-211. DOI: 10.1643/CE-14-086

Saker, M. L., J. Fastner, E. Dittmann, G. Christiansen, and V. M. Vasconcelos. 2005. Variation between strains of the cyanobacterium *Microcystis aeruginosa* isolated from a Portuguese river. Journal of Applied Microbiology 99: 749-757. DOI: 10.1111/j.1365-2672.2005.02687.x.

Spaulding, S. A. and L. Elwell. 2007. Increase in nuisance blooms and geographic expansion of the freshwater diatom *Didymosphenia geminata*. USGS Open-File Report 2007-1425. U.S. Geological Survey, Reston, Virginia. Online at: https://pubs.usgs.gov/of/2007/1425/report.pdf.

Starkey-Owens, T. 2020. Impacts of flow releases on invertebrate drift and juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) diet on the Trinity River below Lewiston Dam. Masters Thesis, Humboldt State University, Arcata, California. Available: https://www.trrp.net/library/document/?id=2546.

Taylor, B. W. and M. L. Bothwell. 2014. The Origin of Invasive Microorganisms Matters for Science, Policy, and Management: The Case of *Didymosphenia geminata*. BioScience 64(6): 531-538. DOI: 10.1093/biosci/biu060.

Thomas Gast & Associates. 2021. Analysis and model evaluation of long-term data collected at the Willow Creek outmigrant trap. Report 20190910YTFP for the Trinity River Restoration Program (TRRP). Thomas Gast & Associates Environmental Consultants, Arcata, California. Online at: https://www.trrp.net/library/document?id=2492.

Trinity Journal. 2021. Toxic algae bloom found in Trinity River. Newspaper report published 2021-07-21. Trinity Journal, Weaverville, California. Online at http://www.trinityjournal.com/news/environment/article_29af2aae-ea67-11eb-9b9f-0fb383363eeb.html.

Trush, W. J., S. M. McBain, and L. B. Leopold. 2000. Attributes of an alluvial river and their relation to water policy and management. Proceedings of the National Academy of Sciences 97(22) 11858-11863. DOI: 10.1073/pnas.97.22.11858.

USDI (U.S. Department of Interior). 2000. Record of decision, Trinity River mainstem fishery restoration final environmental impact statement/environmental impact report. U.S. Department of Interior, Washington D.C. Online at: https://www.trrp.net/library/document/?id=227.

Vadeboncoeur, Y. and M. E. Power. 2017. Attached Algae: The cryptic base of inverted trophic pyramids in freshwaters. Annual Review of Ecology, Evolution, and Systematics 48:255-279. DOI: 10.1146/annurev-ecolsys-121415-032340.

Velzeboer, R. M. A., P. D. Baker, J. Rositano, T. Heresztyn, G. A. Codd, and S. L. Raggett. 2000. Geographical patterns of occurrence and composition of saxitoxins in the cyanobacterial genus Anabaena (Nostocales, Cyanophyta) in Australia. Phycologia 39(5): 395-407. DOI: 10.2216/i0031-8884-39-5-395.1.

Whittaker, R. H. 1972. Evolution and measurement of species diversity. Taxon, 21: 213-251. DOI: 10.2307/1218190.

Williamshen, J. S. 2021. Response of invertebrate drift to dam-release restoration pulse flows from Lewiston Dam on the Trinity River, CA. Masters Thesis, Humboldt State University, Arcata, California Available: https://www.trrp.net/library/document?id=2500.

Williamson, T. J., M. J. Vanni, and W. H. Renwick. 2021. Spatial and Temporal Variability of Nutrient Dynamics and Ecosystem Metabolism in a Hyper-eutrophic Reservoir Differ Between a Wet and Dry Year. Ecosystems 24: 68-88. DOI: 10.1007/s10021-020-00505-8.

Woods, S. A., F. M. J. Smith, M. W. Heath, T. Palfroy, S. Gaw, R. G. Young, and K. G. Ryan. 2012. Within-mat variability in anatoxin-a and homoanatoxin-a production among benthic *Phormidium* (cyanobacteria) strains. Toxins 4: 900-912. DOI: 10.3390/toxins4100900.

Wurtsbough, W. A., M. A. Baker, H. P. Gross, and P. D. Brown. 2005. Lakes as nutrient “sources” for watersheds: a landscape analysis of the temporal flux of nitrogen through sub-alpine lakes and streams. Verh. Internat. Verein. Limnol. 29: 645-649. DOI: 10.1080/03680770.2005.11902758.

APPENDIX A: MONITORING SITE DESCRIPTIONS

Photographs are from April, 2021, unless otherwise noted.

Site A: Pigeon Point

River at 40.7685°, -123.1278°, 189.4 river-km from the ocean.

Site is a pool tail-out on river-right. Exact sampling location varies by about 30 m depending on flow level in order to avoid eddies that collect dislodged periphyton.


Upstream


Downstream

Site B: Pear Tree Gulch

River at 40.7660°, -123.1177°, 190.6 river-km from the ocean.

Site is an extensive run on river-right adjacent to the 2006 Pear Tree Channel Rehabilitation site.


Upstream


Downstream

Site C: Deep Gulch

River at 40.7011°, -123.0448°, 206.4 river-km from the ocean.

Site is a recently constructed (2017) riffle crest / point bar on river-right that was added in order to monitor recent Channel Rehabilitation.

Upstream

Downstream

Site D: Chapman

River at 40.6994°, -123.0415°, 206.7 river-km from the ocean.

Site is a recently constructed (2019) riffle / point bar on river-right that was added in order to monitor recent Channel Rehabilitation.

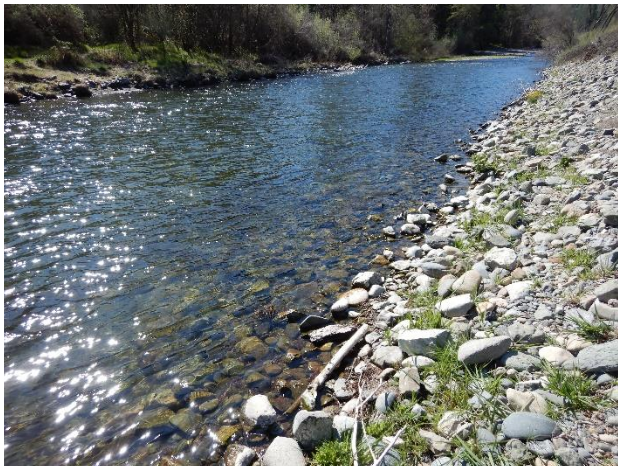
Upstream

Downstream

Site E: Evans Bar

River at 40.6777°, -123.0284°, 210.1 river-km from the ocean.

Site is a lengthy run on river-left adjacent to what is probably the largest area of un-restored dredge tailings among the sampling sites except for the above-dam Carrville site (Site X). Located on river-left just upstream of the historic Evans Bar bridge and current community crossing location.



Downstream Upstream

Site E: Evans Bar (Previously)

River at 40.6846°, -123.0272°, 209.3 river-km from the ocean.

The first site sampled for Evans Bar was located about 800 m downstream, just below the fish counting weir. That site was only used once, in February, 2020, as an eddy had formed below the point-bar at the subsequent sampling time and the point-bar itself formed a rather strong riffle.

Downstream Upstream

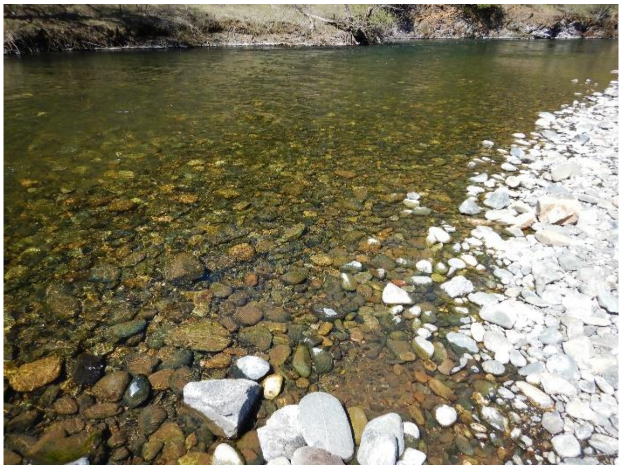
Photographed February, 2020.

Site F: Lorenz Gulch

River at 40.6650°, -122.9671°, 218.2 river-km from the ocean.

Site is a riffle / point-bar below a pool tail-out on river-right. This is the upstream end of the Lorenz Gulch Channel Rehabilitation site (2013) and the adjacent bar was raked to reduce compacting from its prior use by locals as a boatramp.

Upstream



Downstream

Site F: Lorenz Gulch (Previously)

River at 40.6616°, -122.9673°, 218.5 rkm from the ocean.

This previously used site is approximately 300 m downstream from the current site and is on river-right at the lower end of a constructed mid-channel island. The site was moved due to accessibility challenges through dense vegetation and with flows above baseflows.

Upstream

Downstream

Photographed February, 2020.

Site G: Above Weaver

River at 40.6540°, -122.9326°, 225.5 river-km from the ocean.

Site is on river-left of a long run adjacent to the 2007 Indian Creek Channel Rehabilitation site and at the upper end of the 2015 Upper Douglas City Channel Rehabilitation. The log just below the sampling site (visible in the downstream photo below) was placed during the 2007 restoration, however, the ground was not disturbed at the sampling location.


Downstream


Upstream

Site H: Steelbridge

River at 40.6756°, -122.9184°, 233.0 river-km from the ocean.

Site is at the Steelbridge river access along a long, broad run, just upstream of the uppermost boatramp on river-left (typically accessed by wading up from the ramp).


Downstream


Upstream

Site I: Bucktail

River at 40.7038°, -122.8468°, 243.3 river-km from the ocean.

Current site is near the top of a riffle just below the Bucktail Bridge, on river-right.

Upstream

Downstream

Site I: Bucktail (Previously)

River at 40.7080°, -122.8472°, 243.8 river-km from the ocean.

From April through December, 2020, the site was placed just upstream of the Bucktail boatramp. The site was on private land, requiring access to remain below the ordinary high-water line, which would be difficult due to vegetation if flows were greater than about 2000 cfs.

Downstream

Upstream

Photograph from April, 2020.

Site I: Lowden (Previous to Bucktail)

River at 40.6983°, -122.8527°, 242.3 river-km from the ocean.

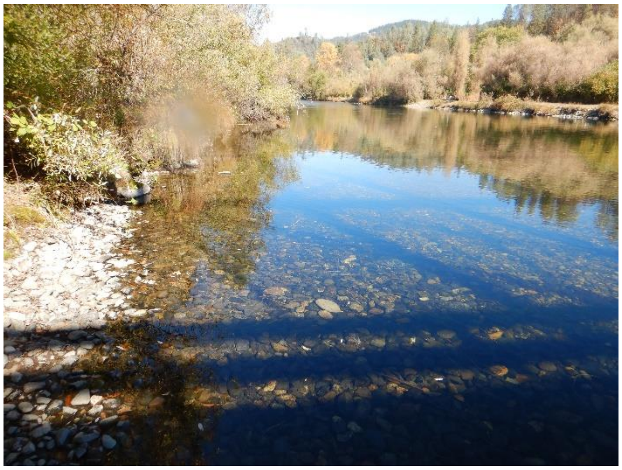
This initial site to represent the mainstem between Rush Creek and Grass Valley Creek was located on a shallow riffle below the constructed meander at Lowden Ranch Channel Rehabilitation site. This location was found to be problematic in how the hydrology changes over the riffle at different flow levels.

Downstream Upstream
Photographs from February, 2020.

Site J: Lewiston

River at 40.7071°, -122.8088°, 243.2 river-km from the ocean.

Site is on river-right in a long run, just upstream of Old Lewiston Bridge.



Upstream Downstream
Photographs from October, 2020.

Site J: Lewiston (Previously)

River at 40.7081°, -122.8082°, 251.0 river-km from the ocean.

Site was on river-right at a riffle-crest formed by the placement of boulders in a pre-TRRP restoration effort. This site was used only once (February 2020) and moved due to imperfect flow conditions over the riffle crest, plus anticipated access challenges with higher flows.


Upstream Downstream

Photographs from February, 2020.

Site K: Weir Pool

River at 40.7197°, -122.8025°, 252.6 river-km from the ocean.

Site is along the riffle below the Weir Pool, on river-right.


Upstream Downstream

Site L: Lewiston Dam

River at 40.7266°, -122.7958°, 254.2 river-km from the ocean.

Site is on river-right along a run downstream of the top-most riffle below the dam. This location has substrate typical of other periphyton monitoring sites, water should be somewhat mixed from the dam gates and the fish-ladder, yet is above fish hatchery effluent outputs, and should be accessible across a good range of flows.

Upstream

Downstream

Site L: Lewiston Dam (Previously)

River at 40.7269°, -122.7952°, 254.2 river-km from the ocean.

This temporary site was used just once (February, 2021) while seeking an optimal location. It was improved over the original site in that the rock substrate was smaller, but still lacked much typically rounded river-rock of gravel-to-cobble sizes.

Upstream

Downstream

Site L: Lewiston Dam (Previously)

River at 40.7265°, -122.7953°, 254.2 river-km from the ocean.

This is the original site used for the Dam through all 2020 sampling dates. The substrate consists of rip-rap and cobble at the head of a boulder-enforced riffle. Furthermore, there is some potential for the water chemistry to be influenced by outflow from the fish-ladder into the hatchery (though it is well upstream of hatchery effluent outlets. Additionally, access to the site became awkward due to COVID-19 restrictions.

Downstream Upstream

Photographs from October, 2020.

Site M: North Fork

Tributary at 40.7825°, -123.1288°, 1.78 stream-km above river confluence, which is 189.7 river-km from the ocean.

Site is at the USGS Flow Gage location on river-right at the end of a run formed as a long pool tail-out. This is the same location as the USGS streamgage.

Upstream Downstream

Photographs from April, 2020.

Site M: North Fork (Previously)

Tributary at 40.7809°, -122.1284°, 1.60 rkm above river confluence, which is 189.7 rrkm from the ocean.

This site was sampled just once in February, 2020. It is on river-right at a pool tailout that is a very popular swimming hole for locals. The site was moved in anticipation of various possible complications with a popular swimming hole.

Upstream Downstream

Photographs from February, 2020.

Site N: Canyon Creek

Tributary at 40.7377°, -123.0496°, 1.34 stream-km above river confluence, which is 200.9 river-km from the ocean.

Site is located above the town-site of Junction City on river-left. Access involves descending a steep bank from the road right next to a large cottonwood tree, crossing a broad sandy floodplain, then either wading upstream or squeezing through vegetation as flows increase.

Downstream Upstream

Photographs from June, 2020.

Site O: Browns Creek

Tributary at 40.6477°, -122.9856°, 2.73 stream-km above river confluence, which is 214.9 river-km from the ocean.

Site is a run on private property owned by TRRP geomorphologist, Todd Buxton. The location has significant bedrock but with substantial gravels overlain.

Downstream

Upstream

Site P: Weaver Creek

Tributary at 40.6528°, -122.9403°, 0.18 rkm above river confluence, which is 224.8 rkm from the ocean.

Site is on river-right of the tail-out of a small pool, upstream of the site access for the Indian Creek and Upper Douglas City Channel Rehabilitation projects. This location was not visibly flowing in August, 2020, and was dry in October, 2020, with standing water remaining in the pool above.

Upstream

Downstream

Site P: Weaver Creek (previously)

Tributary at 40.6519°, -122.9398°, 0.05 rkm above river confluence, which is 224.8 rkm from the ocean.

Site on river-right a riffle-crest close to the river. It was used twice (February and April, 2020) and moved due to proximity to the river where it is often inundated by spring restoration flows.

Upstream

Downstream

Photographs from February, 2020.

Site Q: Indian Creek

Tributary at 40.6568°, -122.9135°, 0.18 stream-km above river confluence, which is 227.4 river-km from the ocean.

Site is a run located on the downstream side of the Highway 299 bridge over Indian Creek and does receive some shading from the bridge and from adjacent riparian vegetation. While accessed from river-left, the site is effectively in mid-stream.

Downstream

Upstream

Site R: Grass Valley Creek

Tributary at 40.6888°, -122.8592°, 0.60 stream-km above river confluence, which is 241.6 river-km from the ocean.

Site is just upstream of Upper Hamilton Pond, on river-right along a run.

Upstream

Downstream

Site R: Grass Valley Creek (Previously)

Tributary at 40.6885°, -122.8594°, 0.64 stream-km above river confluence, which is 241.6 river-km from the ocean.

The prior site was on river-right of the creek just as it arrived at the Upper Hamilton Pond. This site would become backwatered when beavers maintained high-water in the pond, yet the still flowed. The bed was largely sandy, but with sufficient gravel and cobble for appropriate periphyton substrate. The shift in position was for a more clearly comparable site and both scored the same on the first date of sampling at the new site (April, 2021).

Upstream

Across / Downstream

Site S: Rush Creek

Tributary at 40.7383°, -122.8399°, 2.13 stream-km above river confluence, which is 247.3 river-km from the ocean.

Site is a run on river-left, located on downstream side of where powerlines cross Rush Creek. The narrow canyon and heavy riparian vegetation result in this site being fairly shaded.

Downstream

Upstream

Photographs from February, 2021.

Site T: Deadwood Creek

Tributary at 40.7170°, -122.8015°, 0.16 stream-km above river confluence, which is 252.3 river-km from the ocean.

Site is accessed from river-right but is effectively mid-stream, along a run just above the culvert that passes under the road to the Fish Hatchery.

Upstream

Downstream

Photographs from February, 2021.

Site U: Stewart Fork

Tributary at 40.8726°, -122.9175°, 16.00 stream-km above river confluence (submerged by Trinity Lake), which is 268.6 river-km from the ocean.

Site is on river-left along a riffle through a broad bend, located on USFS property and accessed via a steep bank just after the road fords a small creek. Landowners have not been contacted so care should be taken to stay on USFS lands.

Downstream

Upstream

Site U: Stewart Fork (Previously)

Tributary at 40.8613°, -122.8949°, 13.30 stream-km above river confluence (submerged by Trinity Lake), which is 268.6 river-km from the ocean.

Located on river-left at the Bridge Camp Campground. This site was monitored through October, 2020. Snow on the road demonstrated a need to move it downstream to a winter-accessible location.

2020 04 08 14 30

Downstream

2020 04 08 14 30

Upstream

Site V: East Fork

Tributary at 41.0101°, -122.6193°, 6.70 stream-km above river confluence (submerged by Trinity Lake), which is 288.8 river-km from the ocean.

Site is on river-left along a run with presumably old mine tailings formed into a levy that directs flow into the bridge for East Side Road.

Downstream

Upstream

Site W: Swift Creek

Tributary at 40.9684°, -122.7314°, 5.30 stream-km above river confluence (submerged by Trinity Lake), which is 290.9 river-km from the ocean.

Site is on river-right of a run through coarse alluvial deposits, located below the Preacher Meadow Campground. This reach of Swift Creek runs through the largest distinct glacial moraine within the Trinity River watershed.

Upstream

Downstream

Site W: Swift Creek (Previously)

Tributary at 40.9857°, -122.7081°, 2.57 rkm above river confluence, which is 290.9 rkm from the ocean.

This site was used only once (February, 2020). It was located on the upstream side of the Highway 3 bridge over Swift Creek, within the highway right-of-way. It was moved due to proximity to private lands and an even more bouldery alluvium than the current site. *No photographs available.*

Site X: Carrville

River at 41.0562°, -122.6977°, 298.9 stream-km above river confluence, which is river-km from the ocean. Although this site is technically on the mainstem Trinity River, this study is focused on the river below the reservoir dams so this site is generally treated as a tributary to the reservoirs.

Site is a run on river-right adjacent to a vast area of dredge tailings. This site can become inundated by Trinity Lake when completely full, but was deemed reasonable for periphyton monitoring since lentic conditions are rare and brief, while regularly flowing riverine conditions should quickly flush any lentic influences from surface substrates.

Upstream

Downstream