California Regional Water Quality Control Board
North Coast Region

and

Aquatic Ecosystems Analysis Laboratory
John Muir Institute of the Environment
University of California, Davis

Shasta River Water Quality Related Investigations - 2004

April 2005

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Introduction

Staff of the North Coast Regional Water Quality Control Board (Regional Water Board) are in the process of developing temperature and dissolved oxygen Total Maximum Daily Loads (TMDLs) for the Shasta River. In July and August 2004, Regional Water Board and UC Davis Aquatic Ecosystems Analysis Laboratory staff monitored various water quality, physical, and biological attributes of the Shasta River to gain a more complete understanding of water quality dynamics of the Shasta River. The results are being used to support TMDL development analyses.

This report presents the monitoring methodologies and results.

2004 Monitoring Plan and Methods

The components of the Shasta River 2004 Monitoring Plan included: (1) aquatic vegetation surveys, (2) stream sediment characterization, (3) riparian density characterization, (4) light intensity measurements, (5) water quality monitoring, and (6) stable isotope analysis of suspended material and macrophytes. The geographic scope of this monitoring was those portions of the Shasta River from Lake Shastina to the mouth at locations where Regional Water Board staff had access to the river from property owners. The monitoring occurred from July 26 to August 6, 2004.

Aquatic Vegetation Surveys

Purpose and Background: Dissolved oxygen levels in the Shasta River reflect a pronounced diurnal fluctuation (NCRWQCB 2004), apparently driven by photosynthesis and respiration of aquatic plants. The purpose of the aquatic vegetation surveys was to characterize the spatial distribution, composition, and biomass of aquatic plants in the Shasta River and Lake Shastina. Information from the surveys has been used to better understand the role of aquatic plants on dissolved oxygen levels in the Shasta River, and has been incorporated in the Shasta River water quality model (Tennessee Valley Authority RQUAL and ADYN) being developed in support of the Shasta River TMDLs.

Methods: The types of aquatic plants in the Shasta include (1) benthic algae, called periphyton, attached to substrate or other plants, (2) rooted vascular plants, called macrophytes, and (3) suspended algae, called phytoplankton. The objective of the surveys was to characterize the type, composition, and biomass of aquatic plants at a reach-scale. In this case a "reach" is defined as a length of river with similar plant types and species of similar cover and density. The length of a reach was determined on-site by visual inspection and cataloguing of the plant species presence and cover. Where Regional Water Board staff had been granted access to the river by the property owner, we walked the riverbank or floated the river, and catalogued the plants present. The upstream and downstream boundaries of the reaches were noted on USGS topo maps in the field. In some cases, but not all, coordinates were logged using Global Positioning System.

The percent cover of macrophytes was made by visual estimation. Teams of two to five Regional Water Board and UC Davis staff individually estimated the percent cover for a given reach, and then reached a unanimous decision of the percent cover. Due to significant small-scale variability, no percent cover estimates were made of the periphyton communities.

The macrophytes were identified to the species level by UC Davis staff using dichotomous keys from the Jepson Manual of Higher Plants of California (Hickman 1993). Notes on native versus exotic status were taken from the same source. Periphyton and phytoplankton samples were identified to species by Aquatic Analysts of White Salmon, Washington according to Standard Methods 10200.D.2 (APHA 1992).

The methods for collecting and determining the biomass (ash free dry mass [AFDM] and Chlorophyll and Pheophyton a [Chl a and Pheo a]) of the aquatic plants varied depending on the nature of the plant community (i.e. periphyton-dominated, macrophyte-dominated, or phytoplankton-dominated) at a given river location, as detailed below.

For the ***periphyton-dominated communities***, algae samples were collected at locations with microhabitats of similar depth (1 to 2 feet) and flow velocity (1 to 2 feet per second) and free from riparian and topographic shading. These site-selection criteria and sample methodology were also employed for periphyton surveys conducted in summer 2004 on the Klamath River. The periphyton samples were collected according to Standard Methods 10300 B.2.a (APHA 1995). Three rocks were collected from the sites for sampling of periphyton composition (speciation and enumeration) and abundance (AFDM, Chl a and Pheo a). Prior to processing, unattached debris was rinsed from each rock. An area corresponding to the size of a standard microscope slide (1 inch by 3 inch) was marked, scraped from a rock, and placed into a Nalgene bottle with Lugol's solution for preservation. A second rock was scraped from an equivalent area and placed in a Nalgene bottle preserved with $MgCO_3$ for chlorophyll a and pheophyton a analysis, according to Standard Methods 10200 H.3 (APHA 1995). The third rock was scraped as above and placed in a Nalgene bottle for analysis of AFDM, according to Standard Methods 10300 C.5 (APHA 1995). Samples were placed in a cooler with ice. Speciation and biomass of periphyton samples were analyzed by Aquatic Analysts.

For the ***macrophyte-dominated communities,*** samples were also collected at locations with microhabitats of similar depth (1 to 2 feet) and flow velocity (1 to 2 feet per second) and free from riparian and topographic shading. Samples of the dominant macrophyte species occurring at a site were collected from the area inside a milk crate (11 inches by 11 inches) and placed in a Ziploc bag on ice for subsequent confirmation of species identification and analysis of AFDM according to Standard Methods 10400 D.3.a.3 (APHA 1995) and chlorophyll a according to Standard Methods 10400 D.3.b (APHA 1995). The University of California at Davis' Aquatic Ecosystems Analysis Laboratory conducted analyses of the macrophyte samples.

For the ***phytoplankton-dominated communities*** samples were collected using a Kemmerer sampler at three depths (surface, mid, and near-bottom) consistent with

Standard Methods 10200 B.2.a (APHA 1995). Samples for species composition analysis were placed in a Nalgene bottle and preserved with Lugol's solution. Samples for chlorophyll a analysis (Standard Methods 10200 H.3) were placed in a Nalgene bottle preserved with $MgCO_3$. Samples for ash free dry weight analysis (Standard Methods 10300 C.5) were placed in a Nalgene bottle. All samples were placed in a cooler with ice. Aquatic Analysts processed the phytoplankton samples.

Stream Bottom Sediment Size Characterization

Purpose and Background: Sediment oxygen demand (SOD) measurements and analysis of sediment composition (% organic content and % finer than 63 microns) were conducted at six locations on the Shasta River in July 2003. The purpose of the bottom sediment characterization in 2004 was to characterize sediment composition in order to extrapolate the 2003 results of the SOD measurements to other reaches of the river.

Methods: Visual estimates of the percent composition by particle-size classes (i.e., cobbles, gravel, sand, and fines) were made at various locations within the Shasta River where access was granted. The visual estimates of the composition of the stream bottom sediments were made based on the size and texture of the substrate. Observations about the nature of the fine sediments were noted.

Riparian Vegetation Characterization

Purpose and Background: A riparian vegetation survey was conducted in 2001 for building input data sets for the flow and temperature model (Tennessee Valley Authority RQUAL and ADYN models) developed by Watercourse Engineering, Inc. for the Shasta River Resource Conservation District. Characterization of riparian conditions was made at additional locations in 2004 to supplement those done in 2001, using the same methods used in 2001.

Method: Descriptions of riparian conditions were noted according to the following descriptors: 0 = no trees, 1 = less than 2 trees per 100 feet, 3 = greater than 2 trees per 100 feet.

Light Intensity Measurements

Purpose and Background: In the water quality model being developed for the dissolved oxygen TMDL (Tennessee Valley Authority RQUAL and ADYN models), dissolved oxygen concentrations are governed in large part by the photosynthetic rate of macrophytes. One input factor that controls the photosynthetic rate is a light extinction coefficient. Light intensity measurements were made in the Shasta River to calculate appropriate light extinction coefficients. The light extinction coefficient is a measure of the amount of light penetrating the water surface.

Method: Light intensity measurements were made at the water surface and at 1-foot increments below the surface using a LI-COR Radiation Sensor according to manufacturer's directions.

Water Quality Monitoring

Purpose and Background: Measurements of temperature, dissolved oxygen, pH, and specific conductance were made to supplement measurements conducted by Regional Water Board staff in 2002 and 2003. Further, measurements of dissolved oxygen at 15-minute intervals were used to calculate photosynthetic and respiration rates.

Method: Discreet measurements of temperature, dissolved oxygen, pH, and specific conductance were made at each aquatic plant sample location using YSI 600XL datasondes. Measurements of these parameters were also made at 15-minute intervals at six locations from July 30 to August 5, 2004 using YSI 6600 datasondes.

Stable Isotope Analysis

Purpose and Background: The heavy isotopes of carbon and nitrogen are useful as biological tracers. Primary producers (i.e. green plants) take up the isotopes in the concentration in which they are found in the environment and incorporate them into their tissue. In streams and rivers with access to the open ocean, typical sources of the heavy isotope ^{15}N include marine derived material (e.g. anadromous fish including salmon), or anthropogenic sources (human or animal waste or synthetic fertilizers), both of which are naturally enriched in the heavy isotope. Therefore, water samples containing algae, and samples of aquatic macrophytes growing in the river were collected to determine the presence of anthropogenic sources of nitrogen in the Shasta River system.

Method: The methods and results of the stable isotope analysis are presented in **Appendix B**.

Results

Regional Water Board and UC Davis Aquatic Ecosystems Analysis Laboratory staff surveyed approximately 2/3 of the length of the Shasta River from Dwinnell Dam to the mouth. Those reaches surveyed and the associated sample points for the various components of the Monitoring Plan are summarized in **Tables 1 and 2** and shown on **Figures 1a, 1b, and 1c**.

Aquatic Vegetation Survey Results

The results of the aquatic vegetation surveys are presented in **Tables 3 to 8**. The benthic and suspended algae species (i.e. periphyton and phytoplankton) identified in the Shasta River and Lake Shastina are presented in **Table 3**. The algae species composition and associated density and biovolume at each sample point are summarized in **Table 4**. Algal biomass results are presented in **Table 5**. The macrophyte species identified in the Shasta River are presented in **Table 6**. The total percent cover of macrophytes per reach is presented in **Table 7**, along with the macrophyte species composition per reach. Finally, the biomass of the macrophyte samples is shown in **Table 8**. **Figures 1a, 1b,**

and 1c identify the river reaches distinguished by varying macrophyte species assemblages and cover. **Appendix A** describes the general life history and habitat affinities of the aquatic macrophytes of the Shasta River.

Stream Bottom Sediment Size Characterization Results

Visual estimates of the percent composition of stream bottom sediments by particle-size class are presented in **Table 9**. Regional Water Board staff have developed estimates of SOD rates at those locations where sediment composition observations were made, based on the 2003 SOD measurement results (NCRWQCB 2004) and published SOD rates (Bowie *et. al.* 1985). These SOD estimates and the 2003 SOD measurement results are included in **Table 9**.

Riparian Vegetation Classification Results

The characterization of riparian classes (# of trees per 100 feet) is presented in **Table 10** and **Figure 2**.

Light Intensity Measurements

Light extinction coefficients for locations in the Shasta River are presented in **Figure 3**.

Water Quality Monitoring

Dissolved oxygen and pH measurement results taken at 15-minute intervals at six Shasta River locations from July 30 to August 5, 2004 are presented in **Figures 4 a – f**. Temperature and specific conductance measurement results taken at 15-minute intervals at six Shasta River locations from July 30 to August 5, 2004 are presented in **Figures 5 a – f**.

Stable Isotopes

Results of the stable isotope analysis are presented in **Appendix B.**

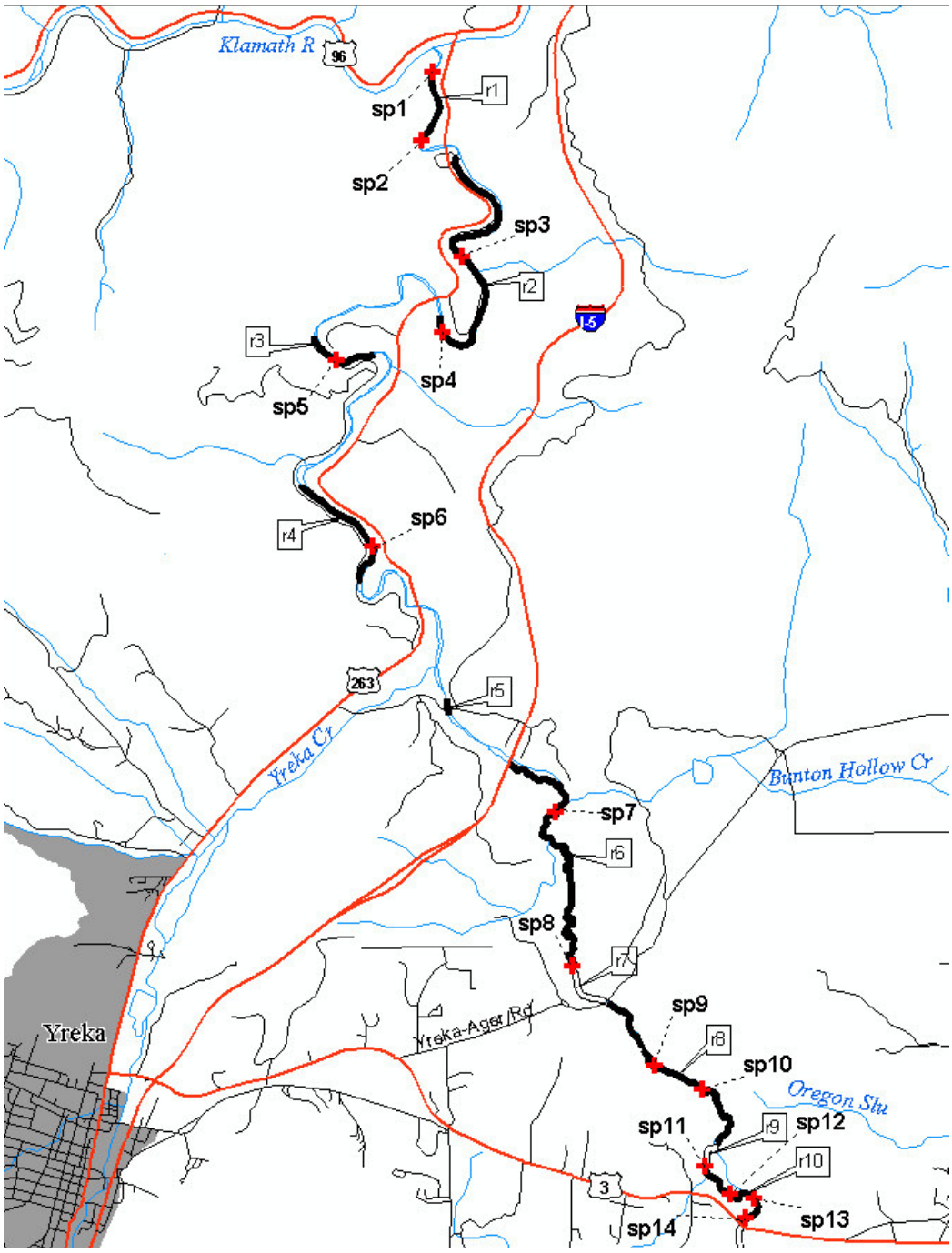


Figure 1a. Shasta River survey reaches and sample points – mouth to Highway 3.

This figure shows the reaches of the Shasta River from the mouth to Highway 3 that were surveyed. "r" = Reach; "sp" = Sample Point. The reaches are defined by the macrophyte species growing within the reach, and by the density of those macrophyte species. The sample points correspond to locations where macrophyte or algae samples were collected, where water quality measurements were taken, where light measurements were made, and/or where stream bottom sediment size characterizations were estimated.

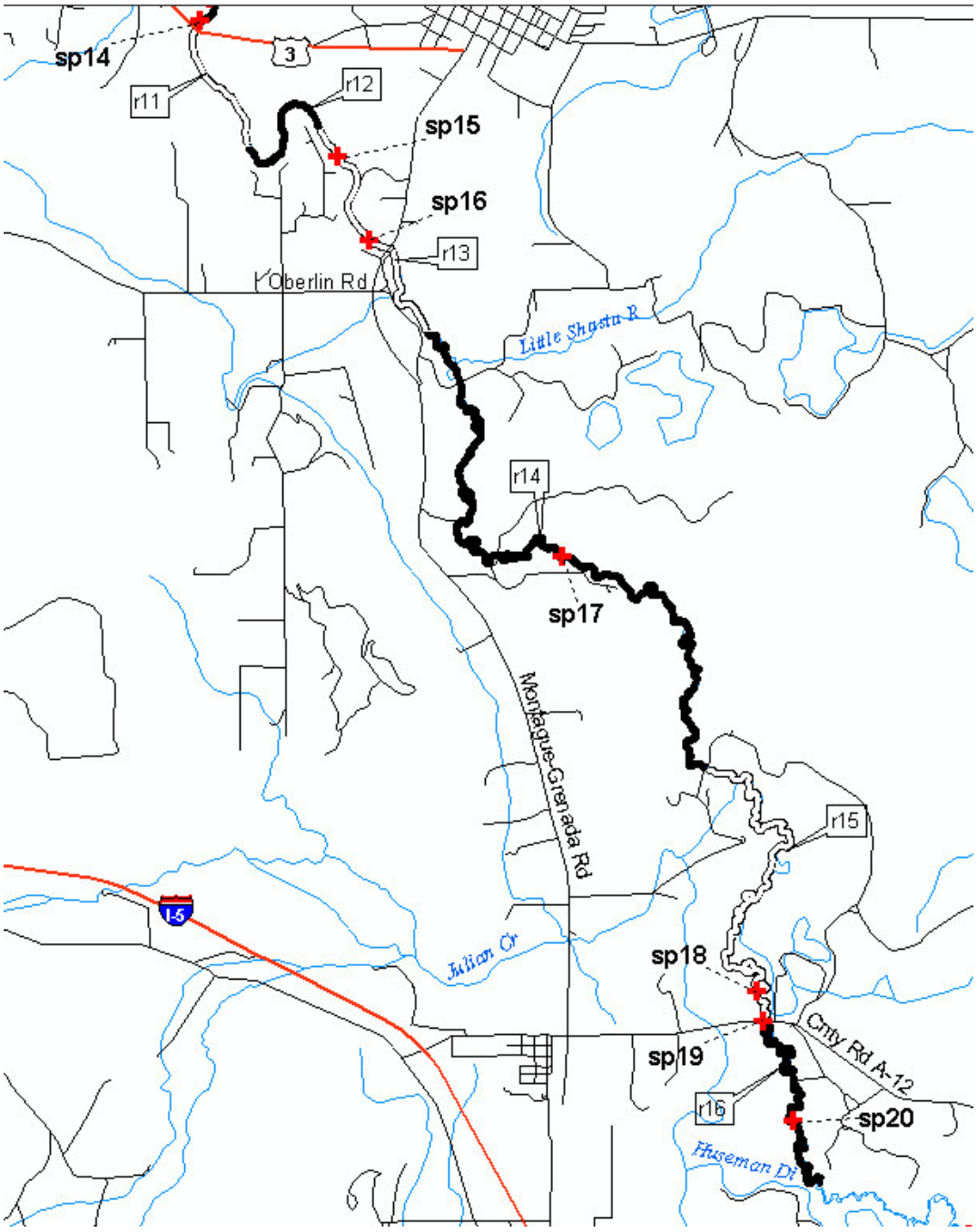


Figure 1b. Shasta River survey reaches and sample points – Highway 3 to Highway A12.

This figure shows the reaches of the Shasta River from the mouth to Highway 3 that were surveyed. "r" = Reach; "sp" = Sample Point. The reaches are defined by the macrophyte species growing within the reach, and by the density of those macrophyte species. The sample points correspond to locations where macrophyte or algae samples were collected, where water quality measurements were taken, where light measurements were made, and/or where stream bottom sediment size characterizations were estimated.

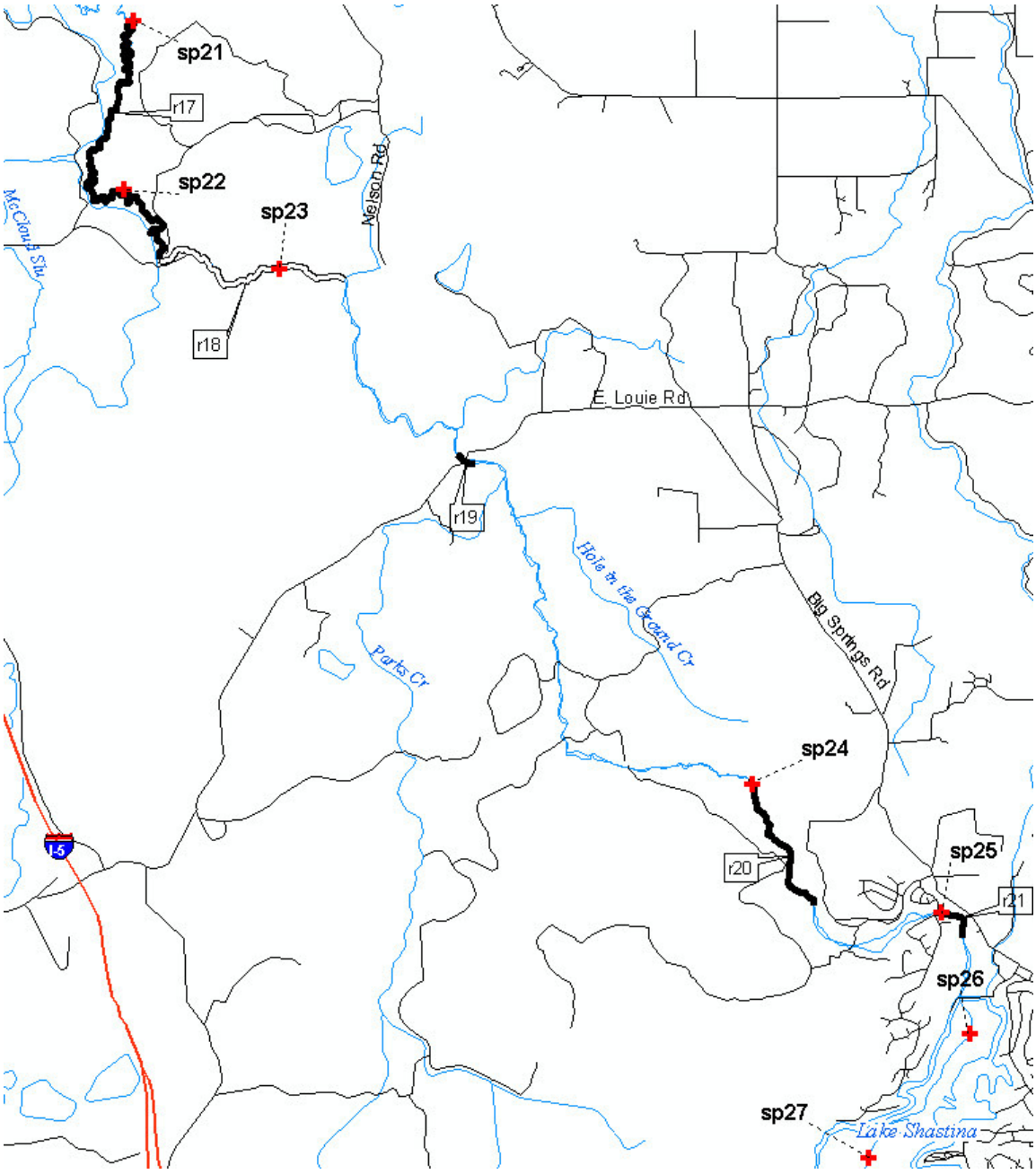


Figure 1c. Shasta River survey reaches and sample points – Highway A12 to Lake Shastina.

This figure shows the reaches of the Shasta River from the mouth to Highway 3 that were surveyed. "r" = Reach; "sp" = Sample Point. The reaches are defined by the macrophyte species growing within the reach, and by the density of those macrophyte species. The sample points correspond to locations where macrophyte or algae samples were collected, where water quality measurements were taken, where light measurements were made, and/or where stream bottom sediment size characterizations were estimated.

Table 1. Shasta River Reach Locations

	Downstream			Upstream			Length
Reach #	River Mile	Latitude	Longitude	River Mile	Latitude	Longitude	Miles
1	0.17	41.82907	-122.59406	0.67	41.82253	-122.59572	0.5
2	1	41.82131	-122.59149	2.87	41.80709	-122.59372	1.87
3	4.05	41.80537	-122.60862	4.51	41.80381	-122.60149	0.46
4	5.73	41.79217	-122.61022	6.58	41.78361	-122.60351	0.85
5	8.01	41.77265	-122.59309	8.06	41.77195	-122.59291	0.05
6	8.58	41.76743	-122.58577	10.53	41.74985	-122.57828	1.95
7	10.54	41.74971	-122.57820	10.91	41.74619	-122.57432	0.37
8	10.92	41.74610	-122.57416	12.26	41.73360	-122.56129	1.34
9	12.27	41.73348	-122.56139	12.62	41.72968	-122.56084	0.35
10	12.63	41.72955	-122.56076	13.1	41.72648	-122.55833	0.47
11	13.11	41.72635	-122.55839	13.87	41.71711	-122.55296	0.76
12	13.88	41.71698	-122.55287	14.64	41.71846	-122.54546	0.76
13	14.65	41.71832	-122.54539	16.09	41.70248	-122.53437	1.44
14	16.1	41.70236	-122.53426	21.14	41.66806	-122.50532	5.04
15	21.15	41.66800	-122.50514	24.09	41.64840	-122.49943	2.94
16	24.1	41.64827	-122.49949	25.82	41.63538	-122.49394	1.72
17	27.48	41.63148	-122.47807	30.57	41.60932	-122.47508	3.09
18	30.58	41.60920	-122.47500	32.03	41.60749	-122.45266	1.45
19	33.88	41.59108	-122.43857	33.98	41.59035	-122.43700	0.1
20	37.8	41.56129	-122.40413	38.87	41.54945	-122.39558	1.07
21	39.92	41.54873	-122.38061	40.22	41.54642	-122.37742	0.3

Notes: Refer to river reaches shown in Figures 1a, 1b, and 1c.
River miles are based on the 1:24 K hydrography developed by David Lamphear of the Institute for Forest and Watershed Management.

Table 2. Shasta River Sample Points and Analyses Performed

Sample Point	River Mile	Latitude	Longitude	Periphyton	Macrophyte	Phytoplankton	Water Isotopes	Macrophyte Isotopes	Light Intensity	Sediment Composition
1	0.17	41.82907	-122.59406				X			
2	0.67	41.82253	-122.59572	X					X	X
3	1.97	41.81232	-122.59095		X			X	X	
4	2.77	41.80568	-122.59338	X	X			X		X
5	4.26	41.80320	-122.60598		X					
6	6.33	41.78671	-122.60168	X						X
7	9.18	41.76305	-122.58015		X			X		X
8	10.56	41.74943	-122.57821		X			X		X
9	11.45	41.74048	-122.56863		X			X		X
10	11.78	41.73841	-122.56300						X	
11	12.45	41.73151	-122.56267	X						X
12	12.70	41.72903	-122.55961							
13	12.89	41.72870	-122.55689						X	X
14	13.06	41.72691	-122.55784		X		X	X	X	X
15	14.83	41.71620	-122.54350		X			X	X	X
16	15.39	41.70964	-122.54027	X			X		X	X
17	18.88	41.68466	-122.52021		X			X		X
18	23.90	41.65044	-122.50005		X		X	X	X	X
19	24.11	41.64813	-122.49947	X						
20	25.20	41.64027	-122.49638		X			X		X
21	27.49	41.63134	-122.47804		X		X	X	X	
22	29.71	41.61580	-122.47944				X		X	X
23	31.58	41.60841	-122.46046		X			X	X	X
24	37.88	41.56071	-122.40302	X	X		X	X	X	X
25	39.95	41.54870	-122.38003				X			X
26		41.53615	-122.37824			X			X	
27		41.52337	-122.39329			X			X	

Notes: Refer to river reaches and sample points shown in Figures 1a, 1b, and 1c.
River miles are based on the 1:24 K hydrography developed by David Lamphear of the Institute for Forest and Watershed Management.

Table 3. Shasta River and Lake Shastina Algal Species List

Species Code	Species Name
ABFA	Anabaena flos-aquae
ACMN	Achnanthes minutissima
AFPR	Amphora perpusilla
CAVM	Caloneis ventricosa minuta
CCMG	Cyclotella meneghiniana
CHXX	Chlamydomonas sp.
COPC	Cocconeis placentula
COPD	Cocconeis pediculus
CXER	Cryptomonas erosa
EPSX	Epithemia sorex
GFAN	Gomphonema angustatum
NVCV	Navicula cryptocephala veneta
NZAM	Nitzschia amphibia
NZCM	Nitzschia communis
NZDS	Nitzschia dissipata
NZFR	Nitzschia frustulum
OSXX	Oscillatoria sp.
RDMN	Rhodomonas minuta
RHCU	Rhoicosphenia curvata
RPMS	Rhopalodia musculus
SCQD	Scenedesmus quadricauda
SNRD	Synedra radians
STAM	Stephanodiscus astraea minutula
TEMN	Tetraedron minimum

Only those species with greater than 0.5% density are presented in Table 1. Many of the algae species identified in the samples are common to mesotrophic to eutrophic waters (Sweet 2004).

Table 4. Shasta River and Lake Shastina Algae Species Composition, Density, and Biovolume by Sample Location

Shasta River Locations

Sample Point	Total Density (# / cm2)	Total Biovolume (um3 / cm2)	Species code (percent density)															
			ACMN	AFPR	CAVM	CCMG	COPC	COPD	EPSX	GFAN	NVCV	NZAM	NZCM	NZDS	NZFR	OSXX	RHCU	RPMS
2	420724	330919497	8.8%				16.7%	8.8%	22.5%								11.8%	
4	49697	33736551					34.5%	4.8%	29.8%						7.1%		7.1%	
6	126288	38327170					33.0%	19.0%					12.0%		8.0%		9.0%	
11	1897236	1892140144				1.9%	38.1%	2.9%	21.0%								15.2%	
16	106817	70312298		3.3%	4.3%		44.6%										21.7%	6.5%
19	101902	28541419					31.2%				3.2%			5.4%		5.4%	47.3%	
24	180339	62962692		12.6%			13.4%		9.2%	7.6%							21.8%	
22	283749	121939714					81.1%	1.9%		2.8%					0.9%		8.5%	
Yreka Cr @ AG Rd	709907	117009444		10.1%							14.3%	17.6%		16.0%	9.2%			

Lake Shastina Samples

Sample Point	Total Density (# / mL)	Total Biovolume (um3 / mL)	Species Code (percent density)								
			ABFA	CHXX	CXER	RDMN	SCQD	SNRD	RHCU	STAM	TEMN
26 (0 m)	3458	1695955	25.2%		7.0%	29.6%	6.1%				17.4%
26 (2 m)	2553	1625504	20.0%		5.8%	25.0%	6.7%				27.5%
26 (12 m)	9	5951	20.0%		20.0%					20.0%	40.0%
27 (0 m)	2988	1296019	18.9%	7.5%	14.2%	26.4%					20.8%
27 (2 m)	2472	1840360	40.2%		7.2%	8.2%	11.3%				13.4%
27 (7 m)	619	261800	15.6%					8.9%	6.7%	11.1%	22.2%

Notes: Algae species names and associated codes are listed in Table 3.
Only the most abundant species (i.e. greatest % density) are presented, which explains why the % density at a given site is < 100.

Table 5. Shasta River and Lake Shastina Algal Biomass

Shasta River - (Mainstem)				
	Sample Point	Chlorophyll a (ug/cm2)	Pheophytin a (ug/cm2)	AFDW (mg/cm2)
	2	25.79	5.74	2.97
	4	2.95	2.25	1.98
	6	5.7	4.7	3.33
	11	27.15	22.74	19.10
	16	6.79	5.19	5.97
	19	15.3	6.7	3.32
	24	23.8	9.2	4.81
	Yreka Cr @ Anderson Grade Rd	33.9	8.0	6.38

Lake Shastina				
	Sample Point	Chlorophyll a (ug/L)	Pheophytin a (ug/L)	AFDW (mg/L)
	26 (0 m)	46.70	8.20	66.40
	26 (2 m)	40.90	2.00	61.00
	26 (7 m)	35.0	1.9	54.40
	27 (0 m)	26.30	21.80	50.40
	27 (2 m)	5.50	0.90	33.40
	27 (7 m)	8.5	1.8	49.40

	AFDW is the weight lost after ignition (dry wgt - ash wgt), divided by the sample area. It provides a rough estimate of the organic material in the sample.

Table 6. Shasta River Macrophyte Species List

Species Code	Species Name
AZME	Azola mexicana
BEER	Berula erecta
CEDE	Ceratophyllum demersum
ELCA	Elodea canadensis
EQXX	Equisetum spp
LEMI	Lemna minor
MYSI	Myriophyllum sibiricum
POCR	Potamogeton crispus
POIL	Potamogeton illinoensis
POPE	Potamogeton pectinatus
RAAQ	Ranunculus aquatilus
SCXX	Scirpus spp
SPEM	Sparganium emersum
TYLA	Typha latifolia
UNID	unidentified succulent
VECA	Veronica catenata
XXXX	other

Table 7. Shasta River Macrophytes: Percent Cover and Species Composition by Reach

Shasta River - (Mainstem)																		
	Reach	Total Cover in Reach (%)	Species code (percent of macrophyte species composition)															
			AZME	BEER	CEDE	ELCA	EQXX	LEMI	MYSI	POCR	POIL	POPE	RAAQ	SCXX	SPEM	TYLA	UNID	VECA	XXXX
	1		Reach not surveyed for macrophyte assemblages															
	2	40				15%						15%		55%		15%			
	3	5				10%			5%	15%	15%	15%		10%	15%	15%			
	4	5				2%			1%			2%		95%					
	5	15									80%	20%							
	6	50	2%		5%	15%		3%	10%	10%	15%	20%		5%	10%			5%	
	7	95	5%			2%		5%	3%		18%	25%		13%	12%	10%		7%	
	8		Reach not surveyed for macrophyte assemblages															
	9	25			3%	2%			3%		40%	20%	10%	8%	2%				
	10	70				1%		10%	1%	3%	60%	5%	1%	14%	5%	1%		5%	
	11	30				1%		10%	1%	3%	60%	5%	1%	14%	5%	1%		5%	
	12	90									25%	60%						10%	5%
	13	10				5%			10%		30%	40%						10%	5%
	14	70			4%	20%	1%		5%			25%		15%	10%	10%		10%	
	15	15				20%		5%				35%		20%	5%	10%		5%	
	16	10				60%						20%		15%					5%
	17	40	4%	5%	18%	23%		5%	13%			13%		10%		5%		4%	
	18	85	2%	15%	10%	10%		3%	5%		10%	30%		10%		5%			
	19	70	Species assemblage was not identified																
	20	75	2%	25%	15%	10%		3%	10%			15%					15%		5%
	21	35	5%		15%			10%				70%							

Note: Macrophyte species names and associated codes listed in Table 6.

Table 8. Shasta River Macrophyte Biomass

Sample Point	Dry sample (g)	Chlorophyll-a (ug/g dry material)	Phaeophytin-a (ug/g dry material)	AFDM (g/m2)
3	28	29	98	383
4	37			750
5	38			823
7	22	70	232	413
8	28			505
9	42			761
14	20	27	90	369
15	30			621
17	74	82	275	1594
18	15			117
20	4	18	62	77
21	21			340
23	59	110	384	748
24	171	46	157	3088

Table 9. Stream Bottom Sediment Composition and Sediment Oxygen Demand Rate Estimates

Sample Point / Location	SOD_{20} Rate[1] (g/m2/d)	Percent Composition[2] Fines	Sands	Gravel	Cobble	Boulder	Bedrock	Notes
2	0.1	5	5	5	10	10	45	Fines largely of organic origin.
4	0.1	5	10	15	15	5	15	Fines largely of organic origin.
6	0.1	5	10	10	5	40	20	Fines largely of organic origin.
7	0.2	10	20	60	10	0	0	
7	0.2	20	20	50	10	0	0	
9	0.2	15	15	25	25	20	0	
11	0.2	15	20	30	25	10	0	
13	2.0*	35	40	25	0	0	0	Fines largely of organic origin.
14	1.5*	20	20	30	20	10	0	
15	1.5	35	30	25	10	0	0	Fines blanket channel bottom.
16	1.5*	20	20	30	25	5	0	Fines largely of organic origin.
U/S of SWUA diversion	2.0	40	30	20	10	0	0	Fines largely of organic origin.
17	0.1	5	90	5	0	0	0	
18	0.1	5	25	70	0	0	0	
20	0.1	5	40	25	20	10	0	
22	0.2	30	60	10	0	0	0	Fines:50% clay, 50% organic
U/S of GID diversion	2.0	30	40	20	10	0	0	Fines largely of organic origin.
23	0.5	20	50	30	0	0	0	
24	0.5	20	20	30	30	0	0	Fines--floculant organic material
25	0.2	5	0	10	75	10	0	

Notes:

1. SOD_{20} ($g/m^2/d$) is the SOD rate corrected for temperature of 20 C. See explanation in text

2 Percent substrate composition are visual estimates made by Regional Water Board and UC Davis staff.

* Measured SOD rates (NCRWQCB 2004).

Table 10. Shasta River Riparian Classification

Reach Location	Downstream River Mile	Upstream River Mile	Length Miles	Riparian Category
Near mouth at USGS gage	0.17	0.67	0.5	2
D/S of Pioneer Bridge	1	2.87	1.87	1
End of Old Shasta River Rd	4.05	4.51	0.46	2
D/S of Hwy263	5.73	6.58	0.85	2
U/S of I5	8.58	10.53	1.95	2
D/S of Y-A Rd to d/s of M-G Rd	10.54	14.64	4.1	1
D/S and U/S of M-G Rd; M-G Rd is at RM 15.50	14.65	16.09	1.44	2
U/S M-G Rd to Freeman Rd	16.1	19.26	3.16	0
Short reach u/s of Freeman Road	19.26	19.72	0.46	2
U/S Freeman Rd to near DeSoza	19.72	21.64	1.92	0
Near DeSoza Lane	21.64	21.98	0.34	2
D/S and U/S of A12; A12 is at RM 24.11	21.98	25.82	3.84	0
U/S of A12	27.48	28.33	0.85	0
Short reach d/s of GID	28.33	28.9	0.57	2
D/S and U/S of GID; GID is at RM 30.58	28.9	32.42	3.52	0
Approx 2 miles d/s of Dwinnell Dam	37.84	38.87	1.03	1
Upstream of Riverside Road	39.92	40.22	0.3	2

Notes:

Riparian Category:	Criteria:
0	No trees
1	Less than 2 trees per 100 feet
2	Greater than 2 trees per 100 feet
3	Gallery forest

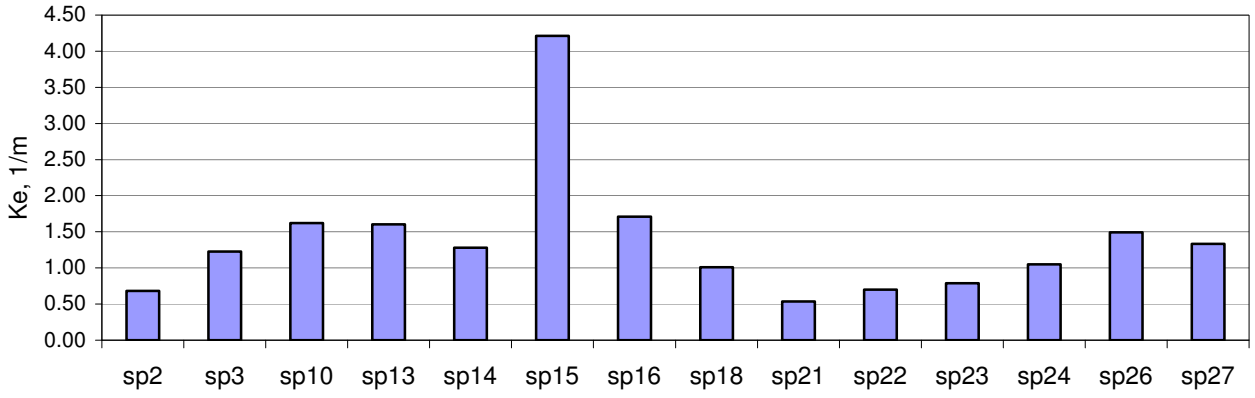
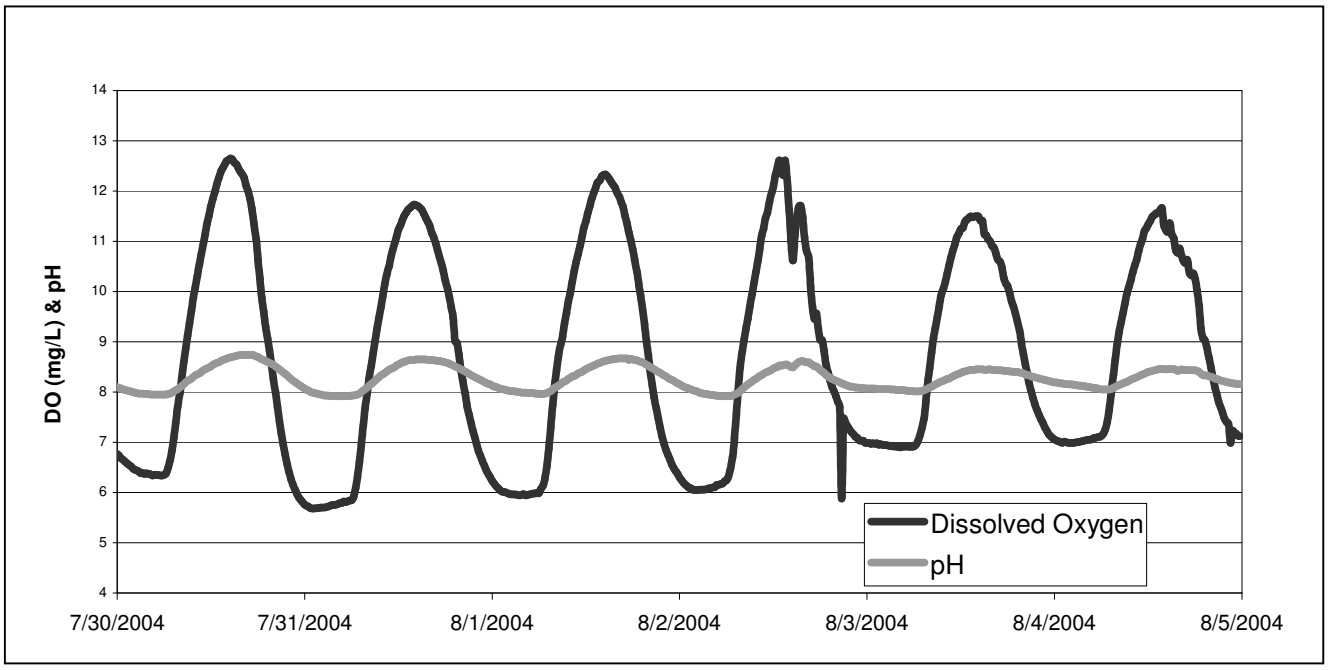


Figure 2. Light extinction coefficients for locations in the Shasta River.

(a)



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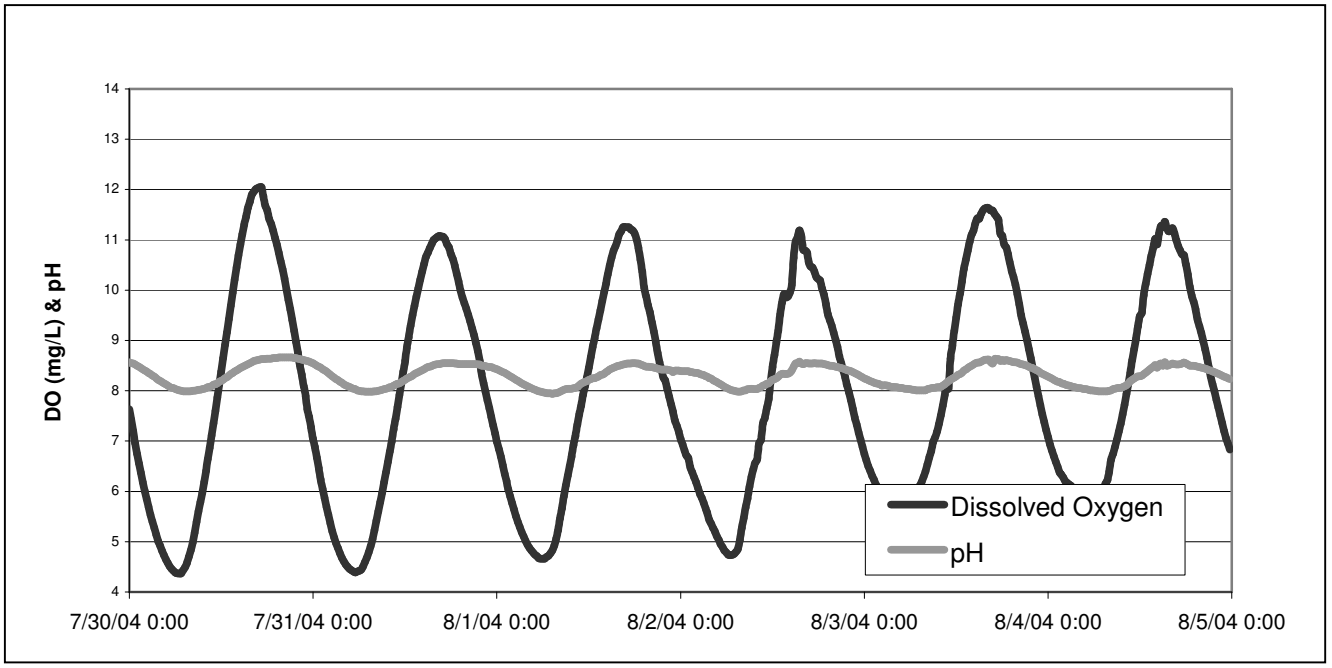
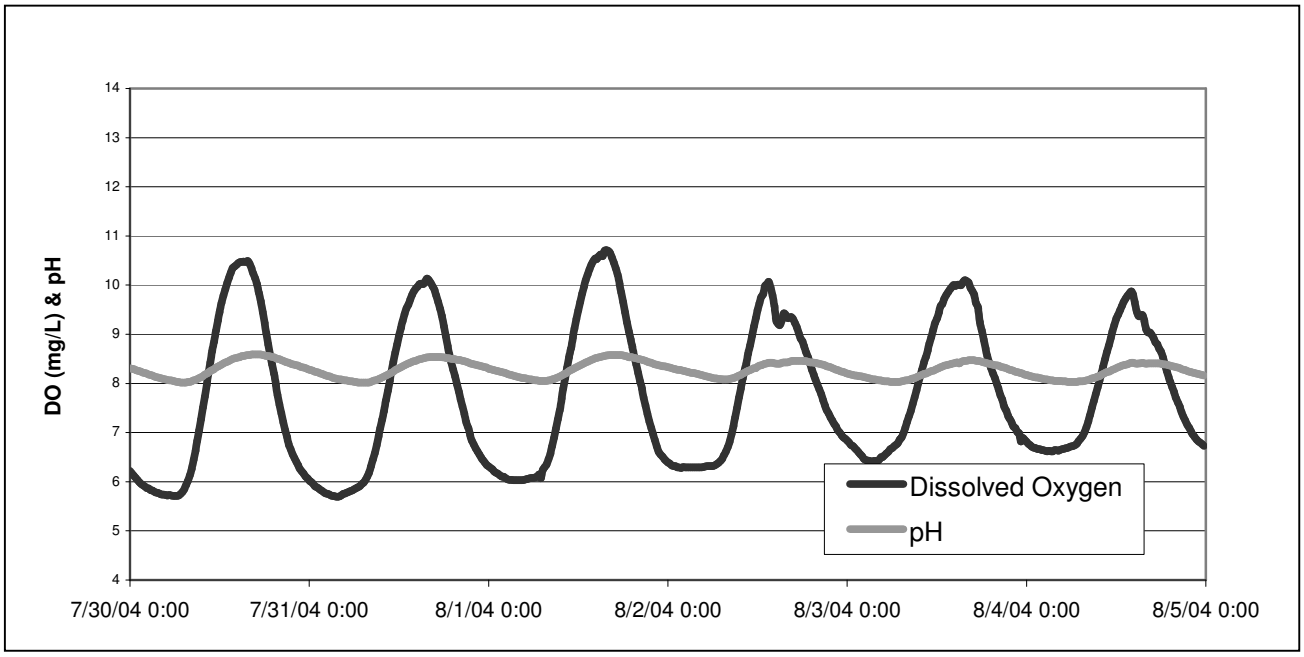


Figure 3. Shasta River dissolved oxygen and pH measurements from July 30 to August 5, 2004: (a) Yreka-Ager Road, (b) Highway 3.

(c)



(d)

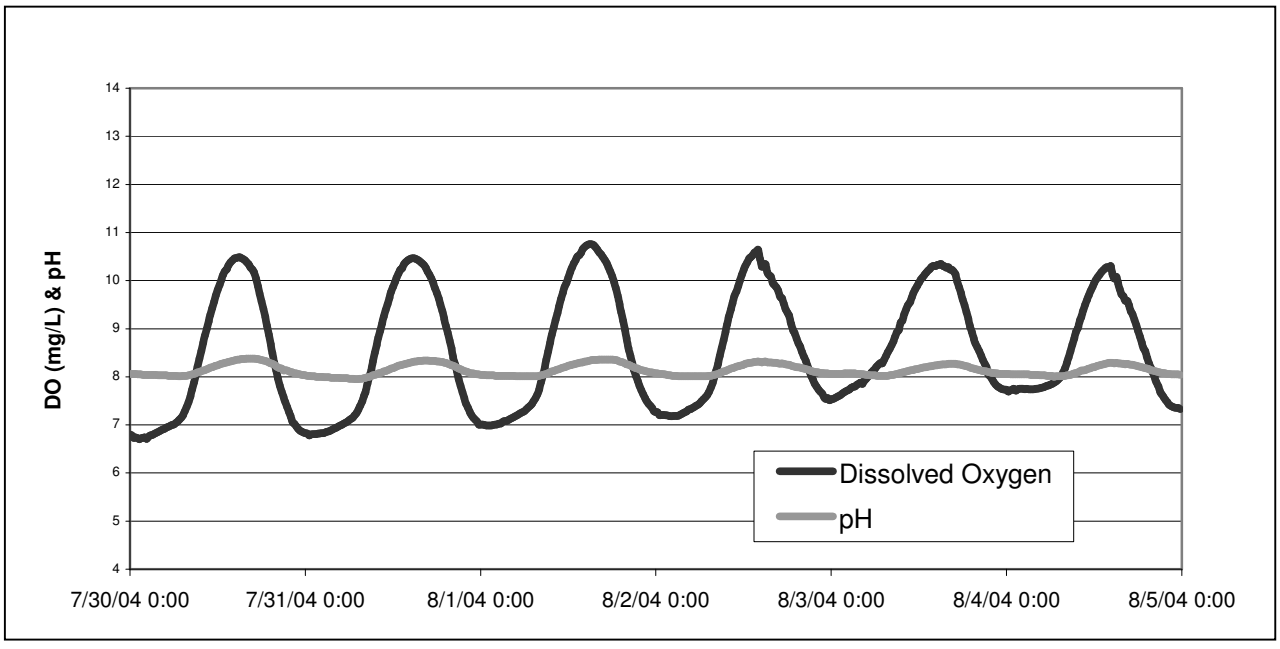
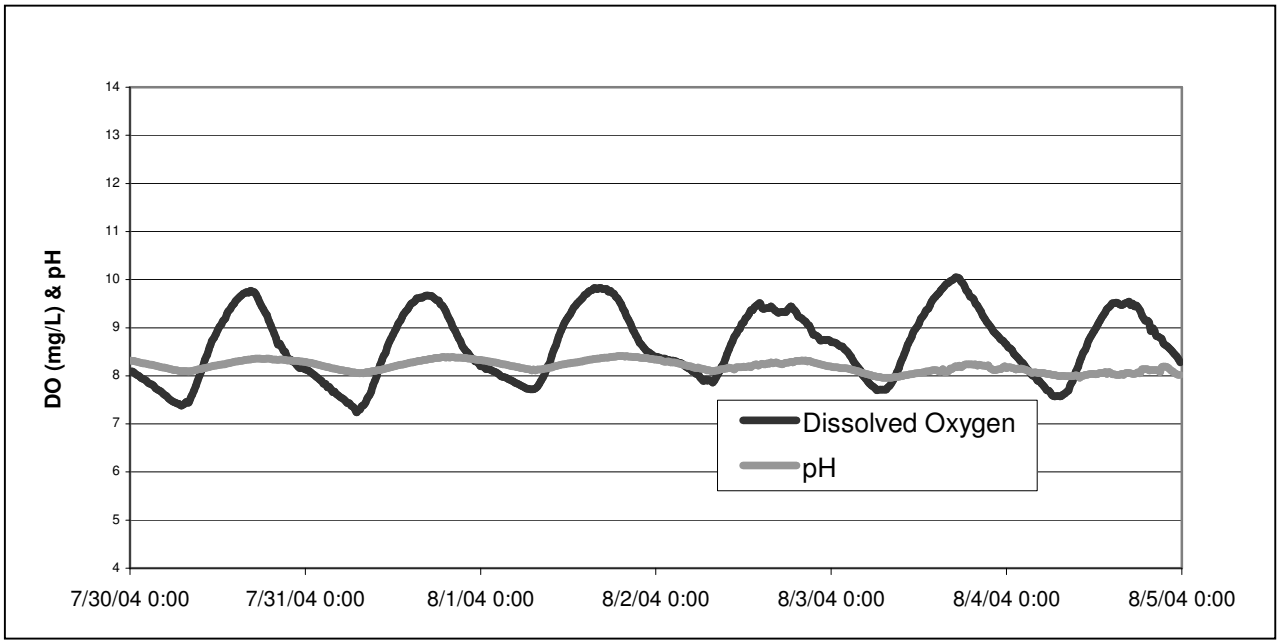


Figure 3. Shasta River dissolved oxygen and pH measurements from July 30 to August 5, 2004: (c) Montague-Grenada Road, (d) Freeman Road.

(e)



(f)

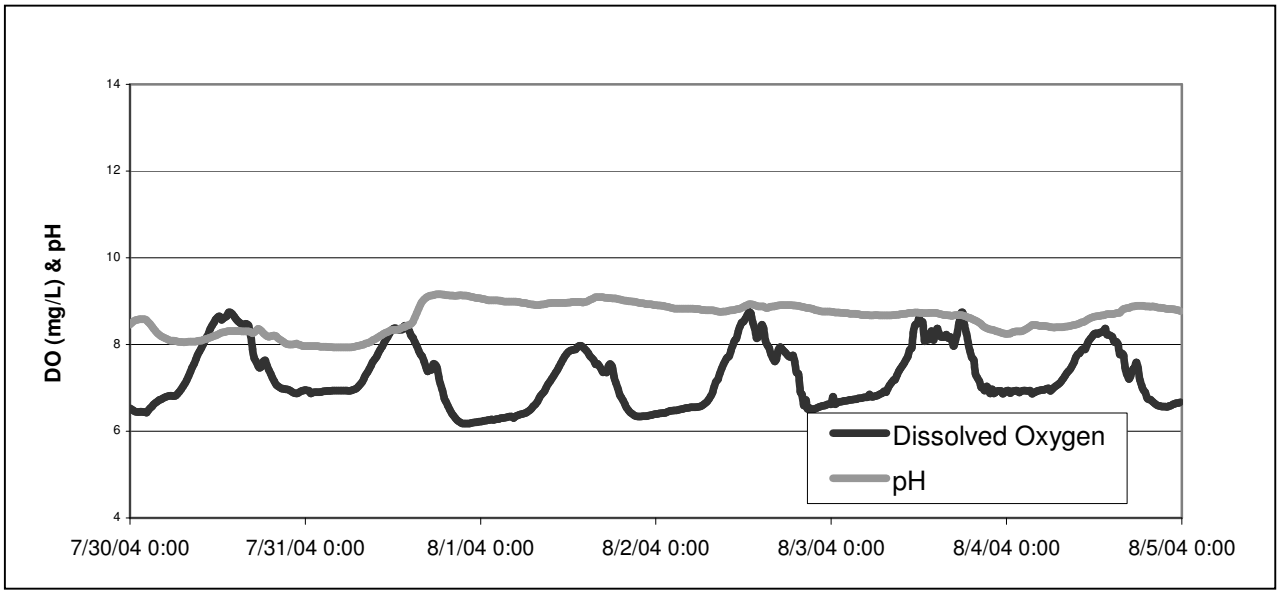
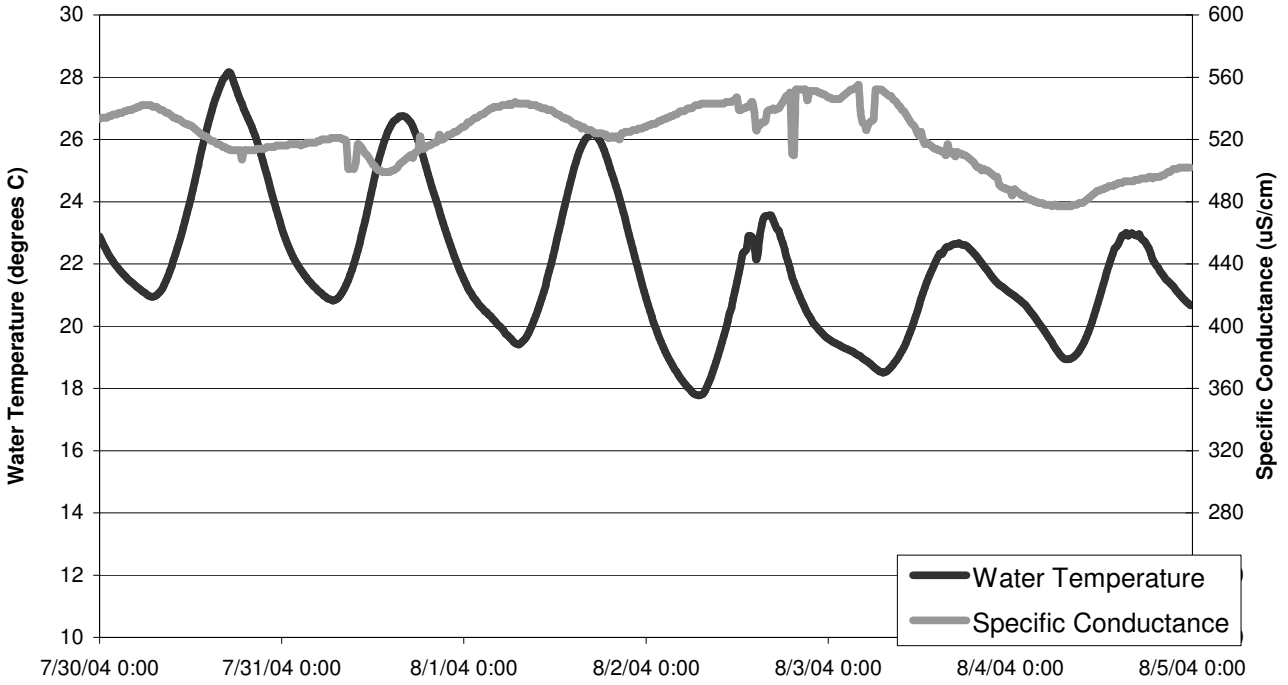


Figure 3. Shasta River dissolved oxygen and pH measurements from July 30 to August 5, 2004: (e) Highway A12, (f) Riverside Road.

(a)



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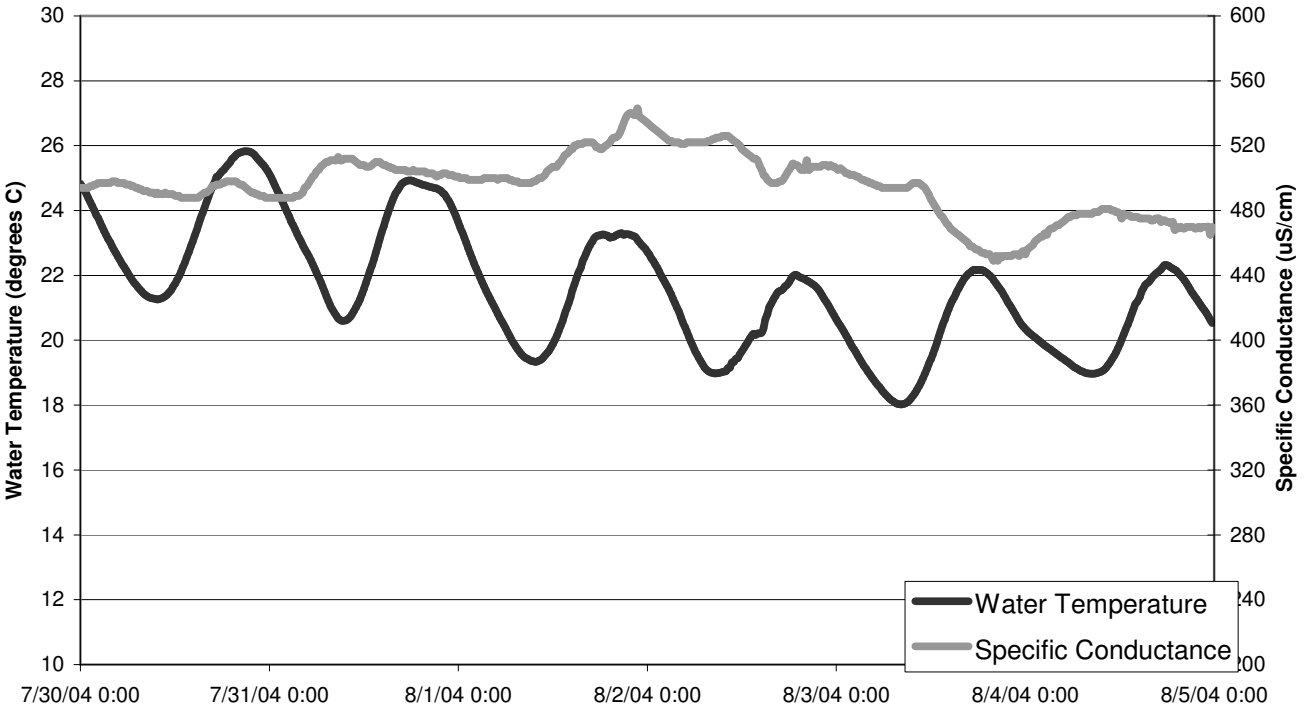
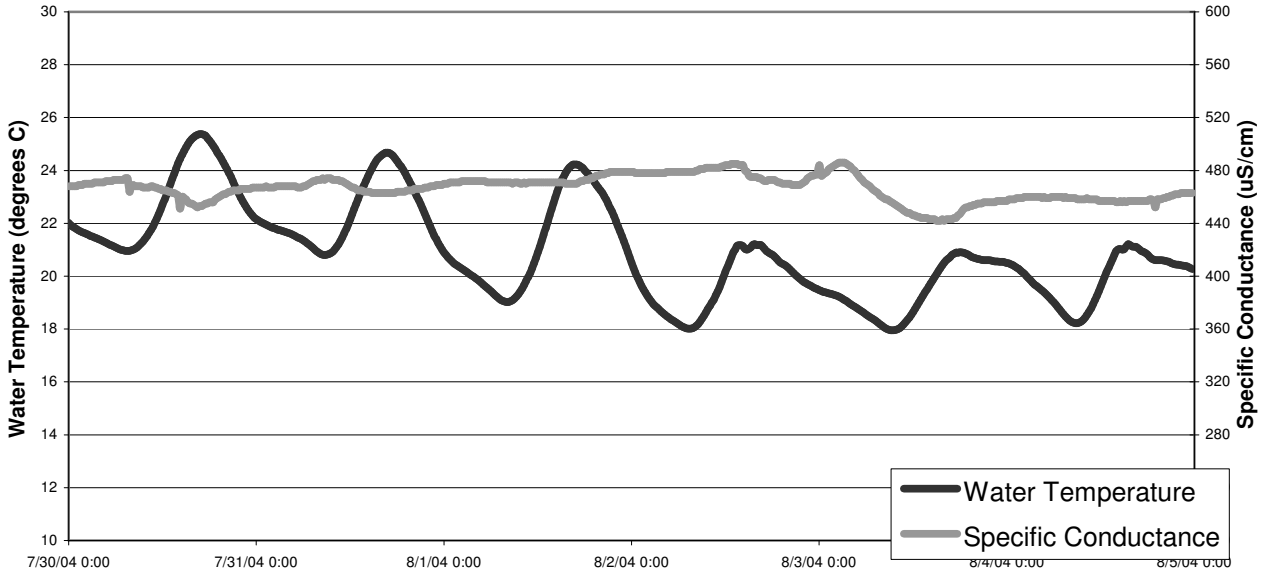


Figure 4. Shasta River temperature and specific conductance measurements from July 30 to August 5, 2004: (a) Yreka-Ager Road, (b) Highway 3.

(c)



(d)

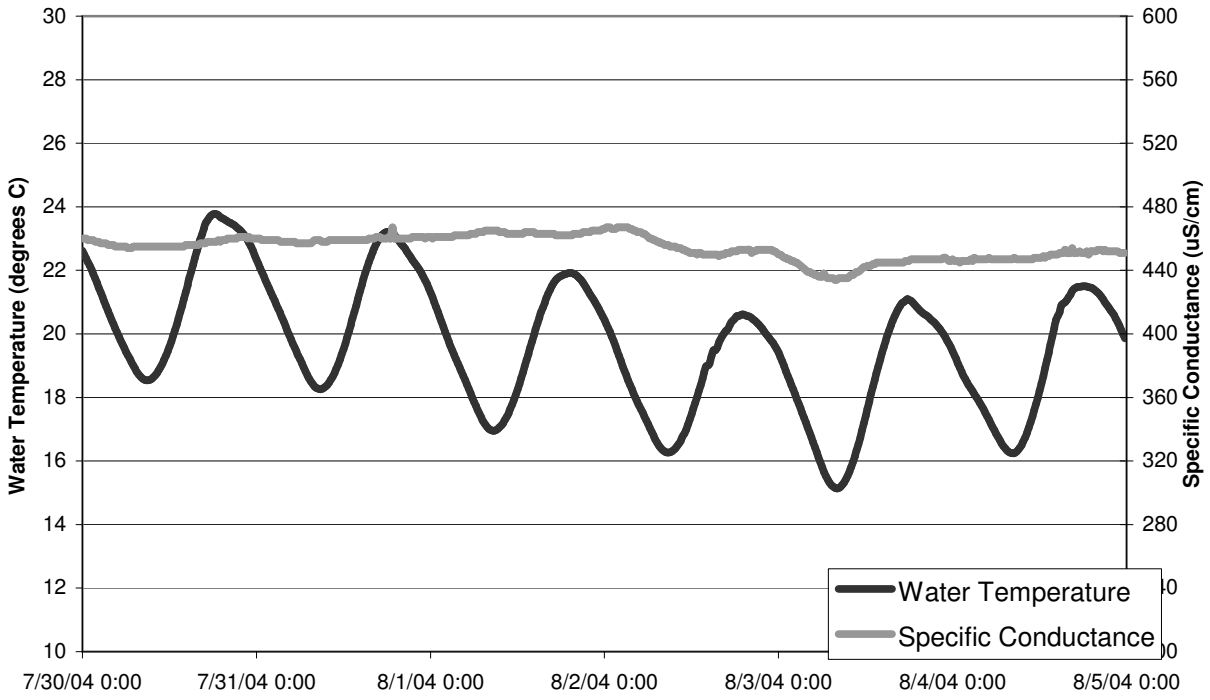
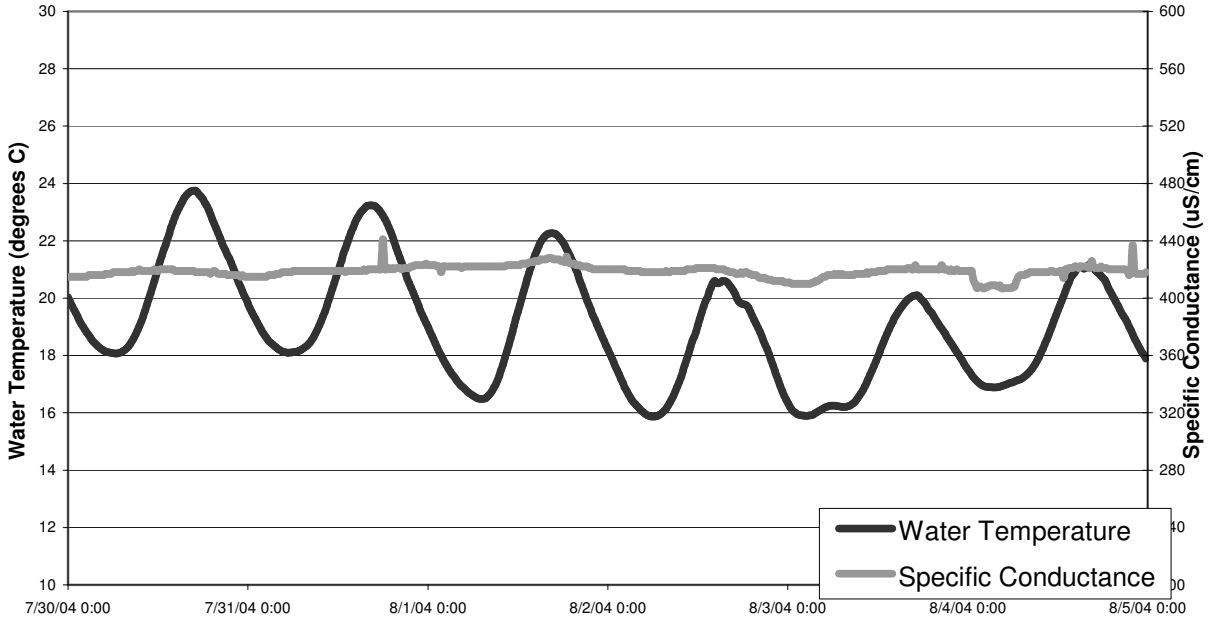


Figure 4. Shasta River temperature and specific conductance measurements from July 30 to August 5, 2004: (c) Montague-Grenada Road, (d) Freeman Road.

(e)



(f)

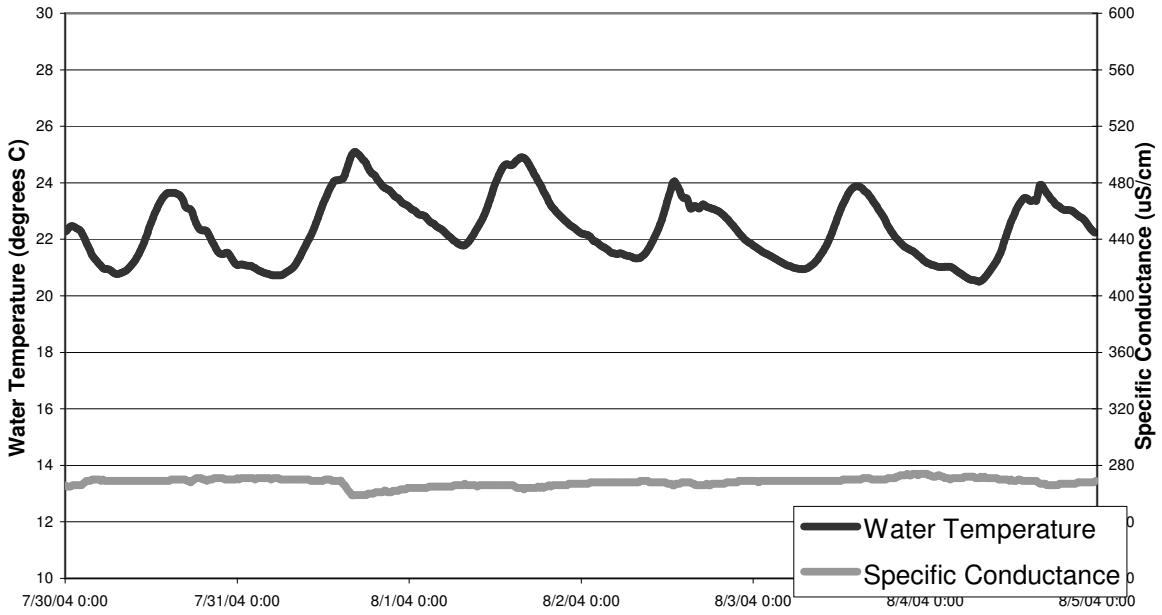


Figure 4. Shasta River temperature and specific conductance measurements from July 30 to August 5, 2004: (e) Highway A12, (f) Riverside Road.

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Appendix A - Aquatic Macrophytes of the Shasta River

The aquatic macrophytes of the Shasta River can be divided into the groups listed below. These morphological groups are taken directly from the Dawson et al. (1999). Following a brief discussion of their general life histories and habitat affinities, each species is described individually.

- Emergent broad-leaved herbaceous
  - *Berula erecta (BEER)*
  - *Solanum dulcamara*
  - *Veronica anagalis-aquaticus*
  - *V. catenata (VECA)*
- Emergent reeds, sedges, rushes
  - *Equisetum* spp. *(EQXX)*
  - *Juncus* spp.
  - *Scirpus acutus*
  - *Scirpus americanus*
  - *Sparganium emersum* ssp. *Emersum (SPEM)*
  - *Typha latifolia (TYLA)*
- Floating-leaved (rooted)
  - *Potamogeton crispus (POCR)*
  - *Potamogeton illinoensis (POIL)*
  - *Potamogeton pectinatus (POPE)*
- Free-floating
  - *Azolla mexicana (AZME)*
  - *Lemna minor (LEMI)*
- Amphibious
  - *Mimulus guttatus*
- Submerged broad-leaved
  - *Elodea canadensis (ELCA)*
- Submerged linear-leaved or fine-leaved
  - *Ceratophyllum demersum (CEDE)*
  - *Myriophyllum sibiricum (MYSI)*
  - *Ranunculus aquatilus (RAAQ)*

Characteristic Habitats of Aquatic Macrophytes

Substrate types and flow types are listed in order of relative importance as habitat for the aquatic macrophytes morphological group (adapted from Dawson, 1999):

Emergent broad-leaved herbaceous

	Sediment type:	Flow type:
Berula erecta *Solanum dulcamara* *Veronica anagalis-aquaticus* *V. catenata*	1. Silt 2. Clay 3. Gravel/Pebble 4. Sand	1. Upwelling 2. Ripple 3. No flow

Emergent reeds, sedges, rushes

Equisetum spp. *Scirpus acutus* *Juncus* spp. *S. americanus* *Typha latifolia* *Sparganium emersum* ssp. *Emersum*	1. Peat 2. Silt 3. Clay 4. Sand	1. No perceptible flow 2. Smooth 3. No flow

Floating-leaved (rooted)

Potamogeton crispus *P. illinoensis* *P. pectinatus*	1. Silt 2. Clay 3. Sand 4. Gravel/Pebble	1. No perceptible flow 2. Smooth 3. Unbroken standing waves

Free-floating

Azolla mexicana *Lemna minor*	1. Silt 2. Clay 3. Gravel/Pebble	1. No perceptible flow 2. Smooth 3. No flow

Amphibious

Mimulus guttatus	1. Peat 2. Clay 3. Silt 4. Gravel/Pebble	1. Upwelling 2. No perceptible flow 3. Rippled

Submerged broad-leaved

Elodea canadensis	1. Peat 2. Silt 3. Sand 4. Clay	1. No perceptible flow 2. Smooth 3. Rippled

Submerged linear-leaved or fine-leaved

Ceratophyllum demersum *Myriophyllum sibiricum* *Ranunculus aquatilus*	1. Sand 2. Gravel/Pebble 3. Silt 4. Clay	1. Upwelling 2. Smooth 3. No perceptible flow

Berula erecta (BEER) (Apiaceae – dicot)

"Water parsnip" "Water cress"

CA native. Africa, Eurasia.

This bushy broadleaf was only found in the upper reaches surveyed. In the Hidden Valley area, there were many individuals. It is quite distinctive. The entire plant is considered toxic and has been implicated in cases of livestock poisoning.

The flowers are small and white in secondary umbels (entire inflorescence is an umbel of umbels) on round-stemmed, several-branched stalks.

Solanum dulcamara (Solanaceae)

"Nightshade"

Native to northern Eurasia. Invader in CA central coast, Modoc Plateau, Canada, and Eastern US.

This plant was widespread but uncommon in the upper Shasta River. It did not occur in the canyon. It grows with about 2/3 of its mass outside of the wet edge of the stream. It did not seem to occur away from the stream edge.

Berries and flowers are very distinctive on Nightshade. Berries are poisonous.

Veronica anagalis-aquatica, Veronica catenata (VECA), and hybrids (7) (Scrophulariaceae – dicot)

"Water Speedwell" "Chain Speedwell"

Native to Europe. Invader throughout CA excluding the Mojave, Modoc, and Sonoran regions; naturalized widely in North and South America.

This plant most often grows near the banks of the stream. It has both submersed and above-water leaves. The submersed leaves tend to be smaller and lighter in color. Flowers are about 3/8 of an inch in diameter, white with pink centers to lavender in color.

There are two species of this genus in the Shasta River. *V. catenata (VECA)* and *V anagalis-aquatica* have been seen to hybridize freely, resulting in individuals indistinguishable from either species as well as individuals that fall in between the two species in appearance.

The plant was present in most of the valley reaches of the river, not present in the canyon.

An example that looks more like *V. anagalis-aquatica*.

An example of *V. catenata (VECA)*.

Note the smaller number of flowers and buds. Though this photo shows a much darker color plant than the other photos, that color difference is not indicative. The only easily-observed, consistent difference is in the number of flowers.

The photo below illustrates the variation in color of the submersed portion of the plant. Though this is a rare case, *Veronica* does occasionally form mats that obstruct flow.

Equisetum arvense (Equisetaceae – pteridophyte)

"Field Horsetail"

CA native. Distribution throughout CA excluding the Mojave and Sonoran regions; North America; also Europe, Asia.

E. arvense grows near water, typically in dense clumps. It is rarely over 2 feet tall. We only found it in one place in the Shasta River, around river mile 20.

Fertile stems are usually well below 1.5 feet tall and tan or brown in color. They grow in the earlier part of the growing season and wilt soon after.

The green stems are generally infertile, though some will carry an inflorescence. They develop later in the growing season; usually after the fertile stems have wilted.

Juncus spp. (Juncaceae – monocot)

"Rush"

Likely that all species present in Shasta River are native to CA. There are few invader species of this genus in CA and none of them typically grow in the region studied. *Juncus* is distributed worldwide, but predominantly the northern hemisphere.

There are dozens of species of *Juncus* in Northern California. The plant generally grows less than 3 feet tall in clumps such as in the photo above. The stems are round, usually somewhat blue-green in color and are not hollow. There are no flat-bladed leaves or sharp edges as in grasses and sedges. *Juncus* species are typically associated with wetlands and streamsides. There are a few species that will grow directly in the stream, but most often their roots are only periodically inundated.

Juncus was rare throughout the valley and canyon.

Sparganium emersum ssp. Emersum *(SPEM)* (9) (Typhaceae – monocot)

"Bur-reed"

CA native. Found throughout most of northern CA; to Alaska, Canada.

This reed grows along the edges of the stream, "feet in the water", or in very shallow areas. It usually occurs in large strips that come a foot or more into the channel and extend several feet onto dry land. The plant is generally about 2.5 to 3 feet tall. It is a much lighter green than the two other large reeds present in the Shasta River.

Sparganium grew mostly in the middle reaches of the river, only in one area of the canyon and not at all in the upper reaches.

The blades of the leaves are widely triangular, almost flat with a keel, and often twisted. The inflorescences are carried on round-stemmed stalks that zigzag at each node.

The spiny fruit are round and about the size of a quarter (or smaller) in diameter; they are carried close to the stem.

There were instances of a *Sparganium* that was growing completely submerged, often in swift-flowing water. This plant never had inflorescences, therefore we were unable to identify if it was just more *S. emersum emersum (SPEM)* that had managed to root deeper in the stream channel during low water, or if it was another *Sparganium* species.

Scirpus acutus var. *occidentalis* (11) and *S. americanus* (10) (Cyperaceae – monocot)

"Bulrush"

CA native (temperate North America), *americanus* found in South America as well

Both of these species grow along the banks. They grow in water as deep as a foot, or out of the water entirely, but always very close to the wet edge of the stream.

This photo shows flowers of *S. acutus.* *S. americanus* has very similar flowers.

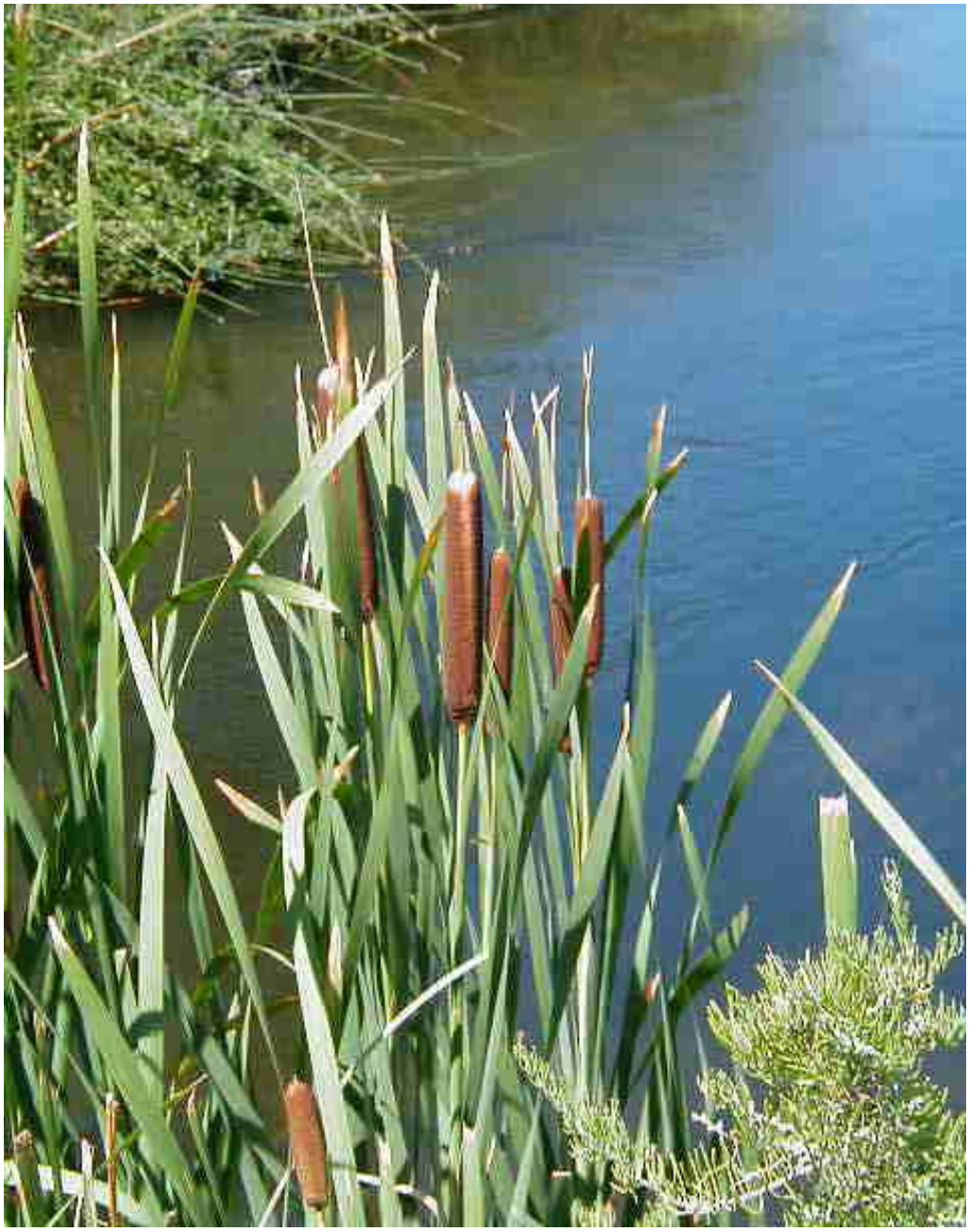
Scirpus is grey-green in color and has small, feathery, terminal inflorescences. There are two species of Bulrush in the Shasta River; *S. acutus* and *S. americanus. S. acutus* has round stems. *S. americanus* has triangular stems, with concave sides. Of the two, *acutus* is generally the larger, and was much more common; only a few examples of *americanus* were found.

Scirpus is abundant in the Shasta River. It grows in canyon as well as valley reaches.

Typha latifolia (TYLA) (12) (Typhaceae – monocot)

"Broad-leaved Cattail"

CA native. Found throughout temperate regions of North and Central America, Eurasia, and Africa.



As with *Sparganium*, the leaves are basal and tend to twist. The stems of the inflorescence are round, about a quarter inch diameter and straight. Found in most of the same places as *Scirpus*, but not as abundant.

Potamogeton crispus (POCR) (3) (Potamogetonaceae - monocot)

"Crispate-leaved Pondweed"

Native to Eurasia. Found worldwide.

This plant was rare in the Shasta River. It generally was found mixed in with *P. illinoensis (POIL).* It is easy to distinguish from *illinoensis* by its much smaller, much wavier leaves.

Potamogeton illinoensis (POIL) (1) (Potamogetonaceae - monocot)

"Shining Pondweed"

CA native. Present in most of CA, to Baja CA, British Colombia, Texas, Caribbean and Central America.

The leaves of this plant are typically about 4 to 5 inches long with a slightly translucent quality (especially the submerged leaves) and prominent veins running lengthwise. The leaves tend to be slightly wavy but not curled and not as wrinkled along the edges as *Potamogeton crispus (POCR)*.

This plant is common in the Shasta River and grows in both valley and canyon reaches.

The inflorescence of this plant is held above the water. It is generally 1 to 1.5 inches in length and about 3/8 to half of an inch in diameter. Club-like, greenish to brownish in color.

This plant is generally seen in large to huge clumps, growing in water that is between 1.5 and 5 feet deep. It often chokes the entire stream width, slowing the water significantly. The photo above shows a section of the stream that is filled with *P. illinoensis (POCR)*; the red color on the surface of the water is from the tiny, free-floating plant *Azola mexicana (AZME)*, which gathers (similar to *Lemna minor (LEMI)*) against obstructions in the surface flow of the stream – in this case the floating leaves and inflorescences of the *P. illinoensis (POIL)*.

Potamogeton pectinatus (POPE) (4) (Potamogetonaceae - monocot)

"Fennel-leaf Pondweed"

CA native. Found worldwide excluding South America

This Potamogeton has leaves that are threadlike and look very similar to the stems. The stems are branched low on the plant but not branched above. Inflorescences are carried on the ends of stems and are typically interrupted as shown above.

This is the most common plant in the Shasta River. It grows abundantly in most reaches and is present almost every reach.

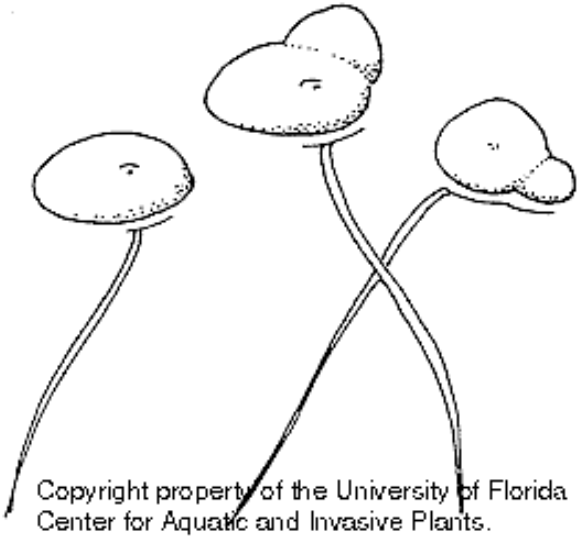
This photo shows a typical clump of *P. pectinatus (POPE).* This plant can grow to significantly restrict flow in the stream, similar to *P. illinoensis (POIL).* Notice the variation in color, ranging from light green to reddish brown. No part of this plant rises above the surface of the water.

Lemna minor (LEMI) (8) (Lemnaceae – monocot)

"Duckweed"

CA native. Found worldwide.

In this photo, *Lemna* is the green, the *Azolla* is red.



The total length of one *Lemna minor (LEMI)* is about a half an inch at most.

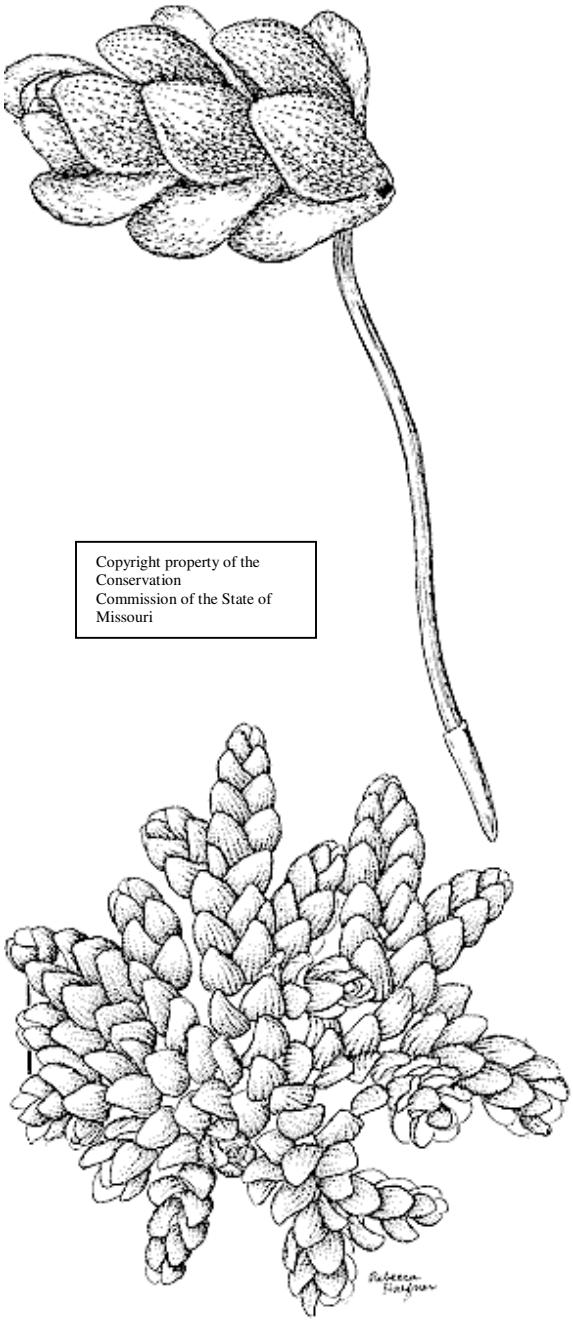
Lemna grows only in slower waters. It is present in most of the valley reaches, never in the canyon. It is not particularly abundant.

Azolla mexicana (AZME) (Azollaceae – pteridophyte)

"Mexican Mosquito Fern"

CA native. Sacramento Valley, northern Sierra Nevada. Presence in Shasta River seems to be a recent event, as it is not listed in the Jepson Manual as growing in the region. Found to British Columbia, central U.S. and South America.

Azolla is rare in the Shasta River, and tends to be mixed in with *Lemna*



Looks similar to *Lemna minor (LEMI)* at a distance, but it is more fern-like, slightly larger (up to ¾ of an inch long, and turns rusty-red in the full sunlight.

Grows in large colonies, obscuring the water surface completely.

Spore reproduction.

Mimulus guttatus (Scrophulariaceae – dicot)

"Seep-spring monkeyflower" "Common monkeyflower"

CA native. To Alaska, western Canada, Rocky Mtns, northern Mexico.

This flower is quite variable and may hybridize with several other *Mimulus* species. It is also quite variable in habitat. We found it growing in floating mats in the natural spring in Hidden Valley. Some individuals in the mat were not rooted to the substrate at all, but some were rooted lightly. In contrast, we also found some individuals growing in the soil of a very wet meadow below the spring. It is noted, however, that the plant grows only near springs. We found no examples of this species growing along the main river.

Elodea Canadensis (ELCA) (2) (Hydrocharitaceae – monocot)

"Common Waterweed" "American Waterweed" "Canadian Waterweed" "Oxygen Weed"

CA Native. Found throughout most of CA, to B.C., eastern U.S. Naturalized in Europe.

The leaves of this plant are generally less than a quarter of an inch wide at the base, and about a quarter of an inch long. They come off the stem in whorls of 3 at very regular intervals along the stem, gradually getting much denser (vertically) at the tips of stems.

This plant rarely blooms, but when it does have flowers (between July and September), they will be small (3/8 of an inch across) with 3 white petals, on the end of long, thread-like stalks. These flowers will be held at but not above the surface of the water. An example of a flower is shown in the photo to the left, in the lower right hand portion of the plant.

The photo above shows typical stems of the plant. It is the only plant with small leaves and long stems of this sort in the study area. *Myriophylum* and *Ceratophylum* could possibly be mistaken for this plant, but their leaves are very "dissected", meaning they are fans of threadlike material instead of small triangles as in *Elodea*.

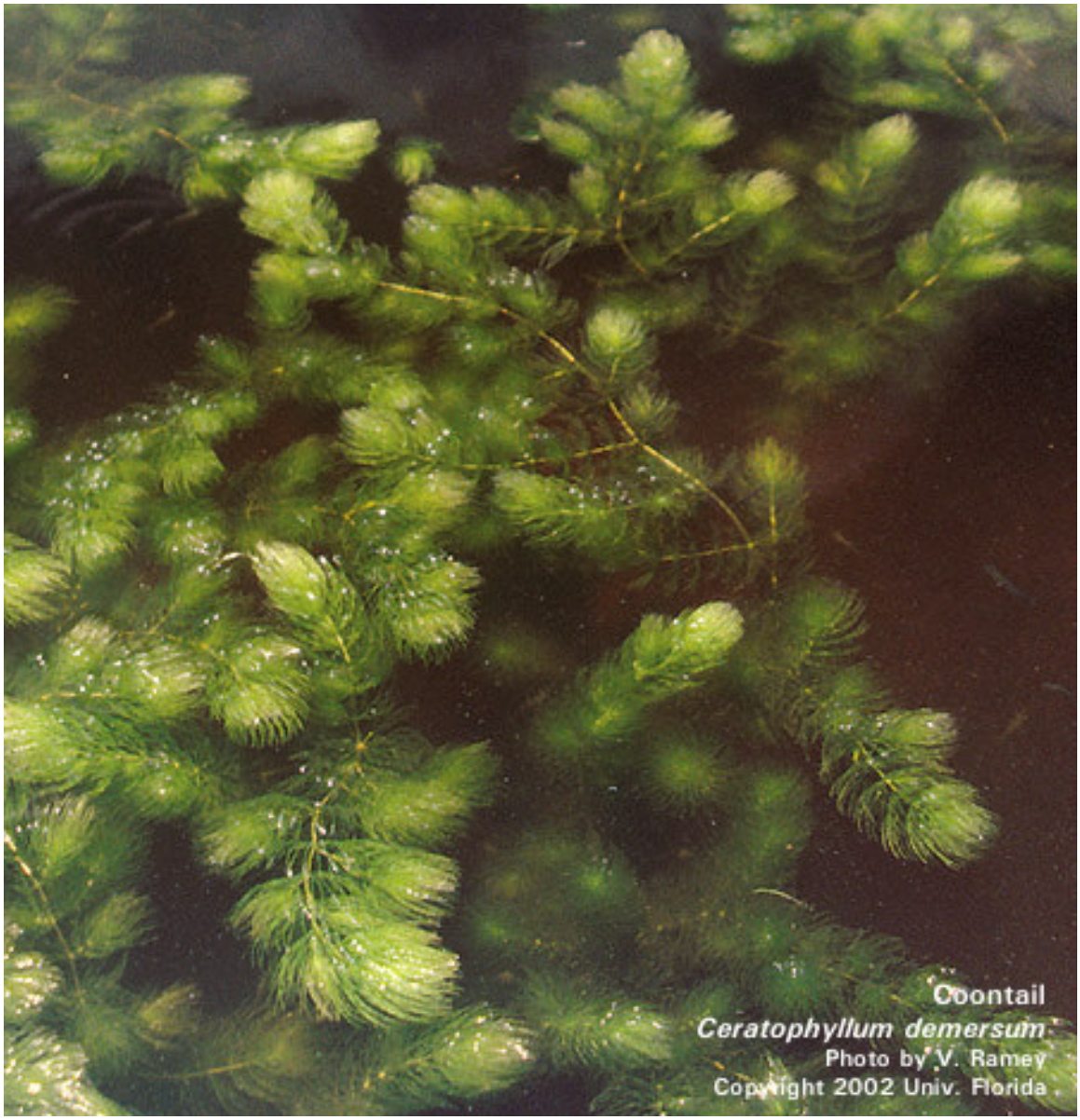
Elodea Canadensis (ELCA) never protrudes from the water. It can be found in large clumps and mixed with other submerged plants. It generally grows in shallow water to a depth of 3 feet at most. The photo above shows a typical clump. There is a small amount of *Potamogeton pectinatus (POPE)* mixed in with the *Elodea*.

This plant is very common in many reaches in both canyon and valley.

Ceratophyllum demersum (CEDE) (6) (Ceratophyllaceae – dicot)

"Coontail" "Hornwort"

CA native. Found worldwide.



Grows in dense clumps. Usually does not grow in huge mats. The photo above shows an individual that is somewhat lighter in color than is typical in the Shasta River.

Note the much denser leaves at the ends of stems.

Ceratophylum demersum (CEDE) grows only in the valley reaches and was more common in the upper reaches of the valley. It is not very abundant.

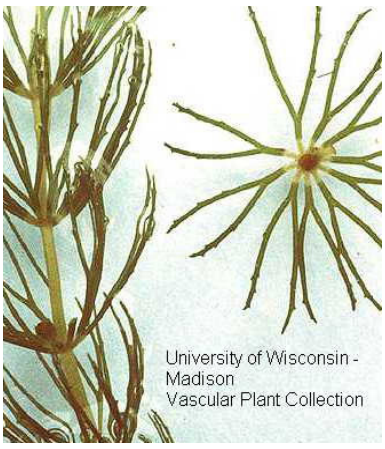
Myriophylum sibiricum (MYSI) (6) (Haloragaceae – dicot)

"Northern Water Milfoil"

CA native. Found throughout most of northern CA, in the Mojave River; to British Columbia, eastern U.S. Also found in Eurasia.

This plant has a gestalt similar to *Ceratophyllum* "Coontail", but on closer examination it has leaves that are *pinnate* (a central rib with many ribs coming off of it from two sides, like a feather) rather than branched.

Myriophyllum sibiricum (MYSI)



Ceratophyllum demersum (CEDE)

Also, note that the leaves of the Milfoil are not toothed, whereas the Coontail leaves have small teeth along one edge.

Myriophyllum sibiricum (MYSI) leaves do not become more dense towards the ends of the stems. *Elodea Canadensis (ELCA)* and *Ceratophyllum demersum (CEDE)* both become denser towards the ends of the stems.

Myriophylum sibiricum (MYSI) was present in canyon and valley reaches, but it was not very abundant.

Ranunculus aquatilus (RAAQ) (5) (Ranunculaceae – dicot)

"White Water-Buttercup"

CA native. Found throughout CA excluding the Channel Islands. Also found in the Great Basin. To Alaska, eastern North America, Mexico.

Another fine-leaved plant, but it is far less dense. The leaves come off of the stem in an alternating pattern instead of in whorls. The flowers are terminal on stalks instead of axillary.

Clumps of *Ranunculus* have a characteristic look due to the bare white stalks of the inflorescences, which carry one flower each.

It was only found in 3 valley reaches around river mile 12.5. It was not very abundant in any of them.

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Appendix B

Stable Isotope Analysis of Suspended Material and Macrophytes in the Shasta River

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APRIL, 2005

BACKGROUND

The nucleus of an atom consists of protons and neutrons surrounded by a cloud of electrons. Each element (e.g. carbon and nitrogen) has a specific and fixed number of protons in the nucleus, although the number of neutrons can vary. For example, carbon can have six, seven, or eight neutrons. Each proton and neutron has an atomic mass of one, and the sum of the protons and neutrons in the nucleus constitute the atomic mass of the element. Elements can vary in their atomic mass, which is the result of the addition of neutrons to the nucleus. Atoms of the same atomic number but different atomic mass are called **isotopes**. Thus, the naturally occurring isotopes of carbon are carbon-12 (6 protons + 6 neutrons), carbon-13 (6 protons + 7 neutrons), and carbon-14 (6 protons + 8 neutrons), which are abbreviated as ^{12}C, ^{13}C, and ^{14}C, respectively. ^{14}C undergoes radioactive decay and is called a radiogenic or "unstable" isotope. The radioactive decay of ^{14}C is the basis for radiocarbon (carbon-14) dating. ^{12}C and ^{13}C do not undergo radioactive decay and are called stable isotopes.

Most elements (including Carbon, Hydrogen, Oxygen, Nitrogen, and Sulfur) have two or more stable isotopes. Heavy isotopes of carbon and nitrogen are the most useful as biological tracers. Each has a heavy isotope (^{13}C and ^{15}N) with a natural abundance of ~1% and a light isotope (^{l2}C and ^{14}N) that makes up the remainder of the mass of the element (**Table 1**).

Table 1. Average Terrestrial Abundances of the Stable Isotopes of Carbon and Nitrogen

Element	Isotope	Abundance (%)
Carbon	^{12}C	98.89
	^{13}C	1.11
Nitrogen	^{14}N	99.63
	^{15}N	0.37

Primary producers (green plants) take up the isotopes in the concentration in which they are found in the environment and incorporate them into their tissue. When living organisms consume and metabolize the green plants that contain the two isotopes of nitrogen, they tend to excrete the lighter isotope and retain the heavier isotope in their bodies, a process called fractionation. As tissue is passed up the food chain, it tends to concentrate the heavier isotope leaving a tracer in the tissue. Isotopes of nitrogen are particularly useful in freshwater ecosystems for nitrogen source identification. In streams and rivers with access to the open ocean, typical sources of ^{15}N include marine derived material (e.g. anadromous fish including salmon), or anthropogenic sources (human or animal waste or synthetic fertilizers), both of which are naturally enriched in the heavy isotope. If evaluated in conjunction with isotopes of oxygen, the exact source of nitrogen to an ecosystem can be determined. Analysis of isotopes of oxygen

was beyond the scope of this study. However, if nitrogen is examined alone, the presence of an anthropogenic input can be detected. If primary producers (i.e. algal cells or macrophytes) are sampled, and they have a high concentration of the heavy isotope of nitrogen, there is a high probability that there are inputs of the heavy isotope to the system. Because of the rapid uptake of nitrogen by primary producers, any ^{15}N signal detected in primary producers would be the result of inputs occurring around the time of sampling. If salmon can be eliminated as a source, the most likely candidate is some type of anthropogenic input. Consequently, water samples containing algae, and samples of aquatic macrophytes growing in the river were collected to determine the presence of anthropogenic sources of nitrogen in the Shasta River system.

ANALYTICAL METHODOLOGY

Water samples were collected in high density polyethelene containers and stored on dry ice in the field. Samples of macrophytes were collected and stored in Ziploc bags on dry ice. The samples were transported to the Aquatic Ecosystem Analysis Laboratory at the University of California at Davis and stored at –30°C until analysis. Samples for natural abundance stable isotope analyses were dried at 55°C for ≥ 48 h. For samples collected on filters (i.e., seston and biofilm), entire filters were triturated, encapsulated, and analyzed. All isotopic analyses were performed at the stable isotope facility at the University of California at Davis (http://stableisotopefacility.ucdavis.edu) using a Europa Scientific Hydra 20/20 isotope ratio mass spectrometer with an analytical precision of ± 0.1‰ for carbon and ± 0.2‰ for nitrogen. Standard notation for reporting stable isotope data is the delta (δ) value. This notation is used to reflect the ratio of the heavier to lighter isotope expressed as the per mil (‰) deviation from arbitrary standards (PeeDee Belemnite carbonate for $\delta^{13}C$ and atmospheric N for $\delta^{15}N$) according to the equation $\delta^{15}N$ or $\delta^{13}C$ ‰ = $[((R_{sample} / R_{standard}) -1) \times 1000]$ where R is $^{15}N/^{14}N$ or $^{13}C/^{12}C$.

RESULTS AND DISCUSSION

Macrophytes

Each plant sample was analyzed for total N, total C, $\delta^{15}N$, and $\delta^{13}C$ based on 3 subsamples for each site. *Elodea canadensis* is prominent in the Shasta River and was present in most of the plant samples collected. For each sample where *Elodea* was present, it was analyzed separately for the same parameters, with 3 subsamples of just *Elodea*.

Figure 1 suggests a relatively strong relationship between river mile from Lake Shastina and $\delta^{15}N$ in the *Elodea canadensis* samples, with an increase in the level of ^{15}N from about 6.0 near the outlet of Lake Shastina to about 10.0 near the mouth of the Shasta River. By comparison, ^{15}N values from the Navarro River, a relatively prisitine north coast river, with no external inputs of heavy (enriched) nitrogen ranged from 0 (atmospheric N) to +3 ‰ (Johnson, unpublished data). Cabana and Rasmussen (1996) reported that $\delta^{15}N$ values

from primary consumers from pristine systems averaged 3.3 ‰. Primary consumers are expected to be 3.3-3.4 ‰ above the primary producers (Steffy and Kilham 2004), meaning that in pristine systems algae and macrophytes would have a $\delta^{15}N$ value of 0 ‰. All macrophytes sampled in the Shasta River below Lake Shastina were enriched in the heavy isotope. Natural sources of the heavy isotope are relatively limited. In watersheds that connect directly with the ocean, migrating salmon can provide a large natural source of ^{15}N. However, these samples were collected in July and August when no salmonid migration was taking place. Therefore, additions of marine-derived nitrogen to the system can be ruled out, and the most probable source was anthropogenic. Anthropogenic inputs from sewage to aquatic ecosystems have resulted in organisms enriched in the heavy nitrogen isotope (e.g., Lake et al. 2001, Steffy and Kilham 2004, Wainright et al. 1996)

There is also a distinct increase in the level of ^{15}N in all Shasta River macrophytes sampled from the outlet of Lake Shastina to the Klamath (**Figure 2**). The spikes in ^{15}N levels indicate local inputs of ^{15}N –enriched water. Although statistically there appears to be a negative relationship between river mile and $\delta^{15}N$, the relationship is anchored by the very high values of $\delta^{15}N$ located nearer the confluence of the Shasta with the Klamath. The majority of the macrophytes had $\delta^{15}N$ levels between 5 and 7 ‰, but there are a few locations with somewhat higher levels (above 8 ‰) throughout the entire length studied. All of these values suggest that anthropogenic sources of N account for a large fraction of the N being sequestered and incorporated by stream macrophytes.

Figure 1. Stable nitrogen isotope vs. river mile for *Elodea canadensis*. River mile 0 is the confluence with the Klamath River.

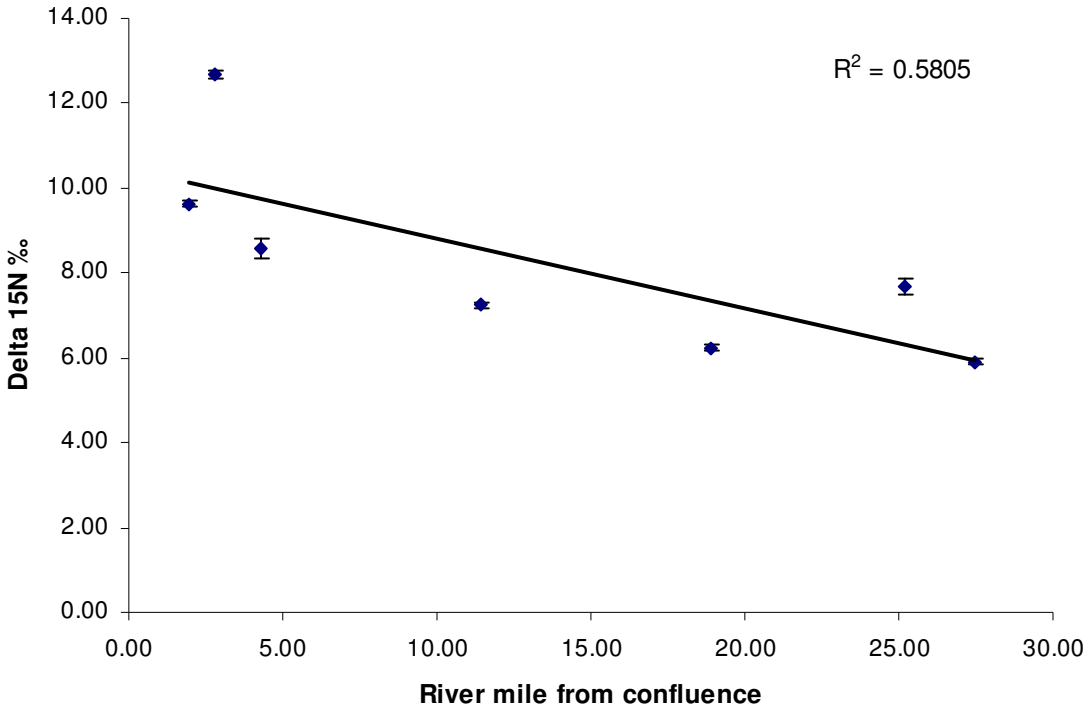
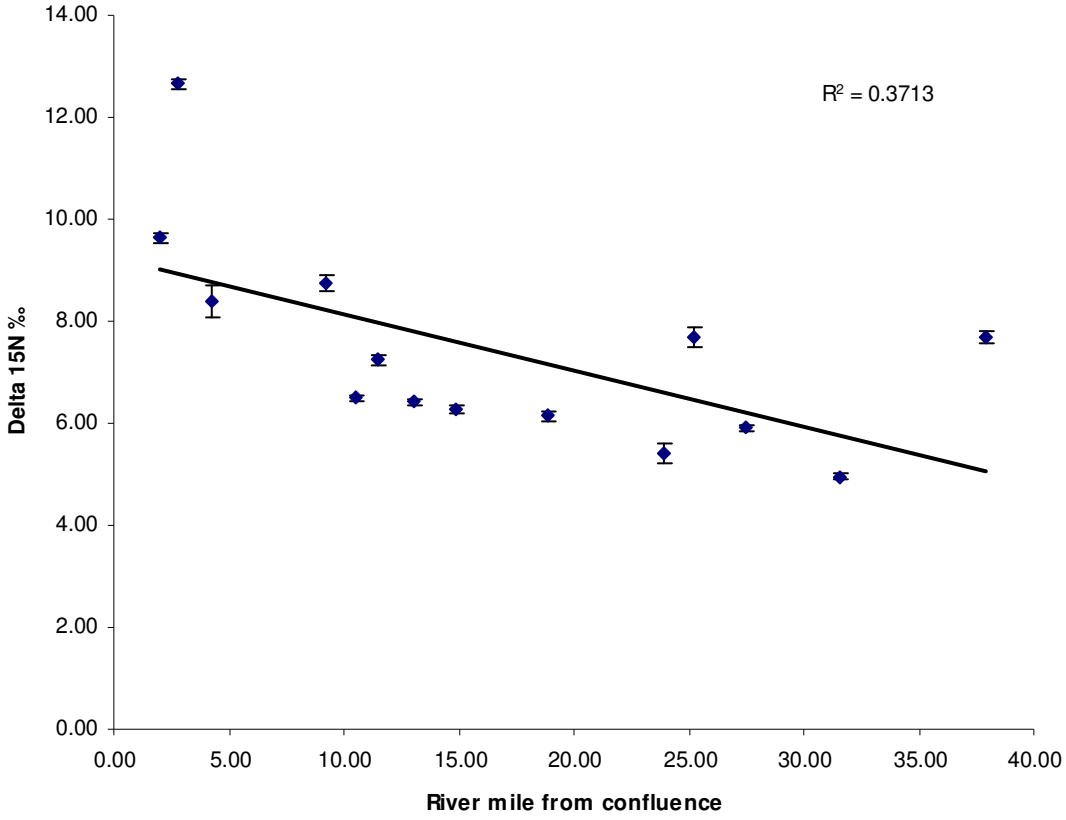


Figure 2. Stable nitrogen isotope vs. river mile for all macrophytes collected from the Shasta River. River mile 0 is the confluence with the Klamath River.

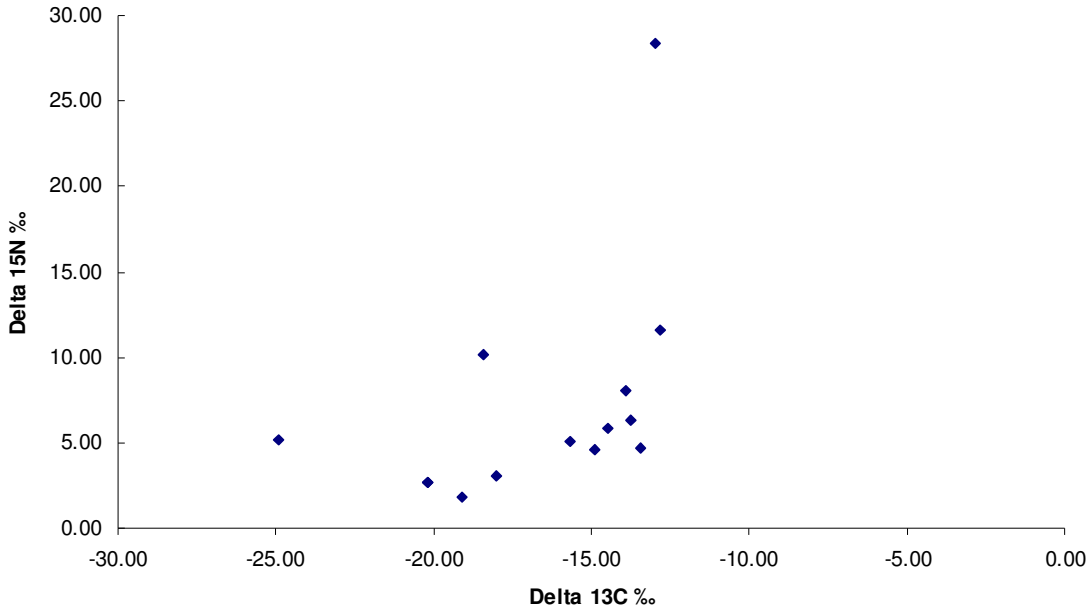


Suspended organic material

Suspended organic material was examined for stable isotope signatures in the same way as the macrophytes. Data are presented in two ways, a plot of the $\delta^{13}C$ vs. $\delta^{15}N$ (**Figure 3**) and $\delta^{15}N$ vs. river mile (**Figures 4 and 5**). **Figures 4 and 5** are similar to the plot for macrophytes except that samples were not collected at all of the same locations. The $\delta^{13}C$ values in Figure 3 provide an indication of the carbon source for material suspended in the water column. Generally, if the carbon source is the same for all samples in a river system, the values will be located similarly along the horizontal axis ($\delta^{13}C$). There is substantial scatter along the horizontal axis indicating that the carbon source for the material in the Shasta River is not similar. Although difficult to interpret, the carbon sources are probably both allochthonous (originating with organic matter falling into the river) and autochthonous (carbon fixed from carbon dioxide by green plants growing in the water or autotrophic bacteria). Although there is a trend for those samples that are slightly higher (less negative) in $\delta^{13}C$ to have somewhat greater $\delta^{15}N$ values, the relationship is not strong and is driven by a

single sample with an extreme $\delta^{15}N$ value. It is not certain why the sample has that large of a $\delta^{15}N$ value, although the sample was collected in Yreka Creek at Oberlin Road within the city limits. The values of $\delta^{13}C$ are within a normal range for rivers on the North Coast of California. For example, in the Navarro River, $\delta^{13}C$ values ranged from -33 to -18 (Kiernan and Johnson, unpublished data).

Figure 3. Plot of $\delta^{13}C$ and $\delta^{15}N$ from samples collected from the Shasta River, Parks Creek, and Yreka Creek. Values of $\delta^{13}C$ allow a determination of the carbon source to the food web, and the $\delta^{15}N$ provides information on the source of nitrogen to the system and the trophic position.



Figures 4 and 5 are plots of suspended organic material $\delta^{15}N$ against river mile. **Figure 4** contains all points sampled, and **Figure 5** is the same plot without the single outlier at river mile 27.49. As with the plots for macrophytes, there is a strong trend for an increase in $\delta^{15}N$ as water moves downstream. $\delta^{15}N$ values are lower for suspended material compared to macrophytes, with values from just under 3 to 8 ‰. The outlier in Figure 4 was omitted from the plot in Figure 5 to examine the relationship without the outlier. The value of the outlier is not exceptionally high, but was not similar to other samples from that location or any location upstream. This value could be the result of a sample contaminated with organisms from a higher trophic position (e.g., part of an insect), waste material from cows, or analytical error. All samples in the analysis were submitted together and it is unlikely that a single sample in the middle of the analysis would provide spurious results. If the results reflect actual values for the suspended material collected at the site, it is not certain where the material originated. Since the suspended organic matter moves downstream it is probable that this sample

reflects conditions at some point upstream, but the exact location is unknown. These high values for $\delta^{15}N$ confirm the conclusions drawn from the macrophyte stable isotope data that the sites are likely impacted by anthropogenic inputs of nitrogen.

Unless further analyses are performed, it is not possible to determine the exact source of the nitrogen, but the most probable sources are organic enrichment due to inputs of animal or human waste or synthetic fertilizers. Studies elsewhere that found values of $\delta^{15}N$ in primary producers (algae and macrophytes) between 9 ‰ and 12 ‰ were in areas with suspected inputs of sewage from leaking septic tanks (Steffy and Kilham 2004). Their conclusion was that the values were elevated above areas with sewers due to the leaking of nitrogen from on-site septic systems. Likewise, Lake et al. (2001) found that increased shoreline development around 17 freshwater sites lead to elevated $\delta^{15}N$ levels. They concluded that these elevated levels were probably due to increased human wastewater discharges to these small lakes. Animal waste (e.g., cattle, hogs, poultry) can similarly cause elevated $\delta^{15}N$ levels. Finally, synthetic nitrogen fertilizers are high in $\delta^{15}N$ and will also result in elevated $\delta^{15}N$ levels in surface waters if they are allowed to runoff into the stream.

Figure 4. Suspended organic material stable nitrogen isotope values plotted against river mile for the Shasta River. River mile 0 is the confluence with the Klamath River. All sample points are included in the analysis.

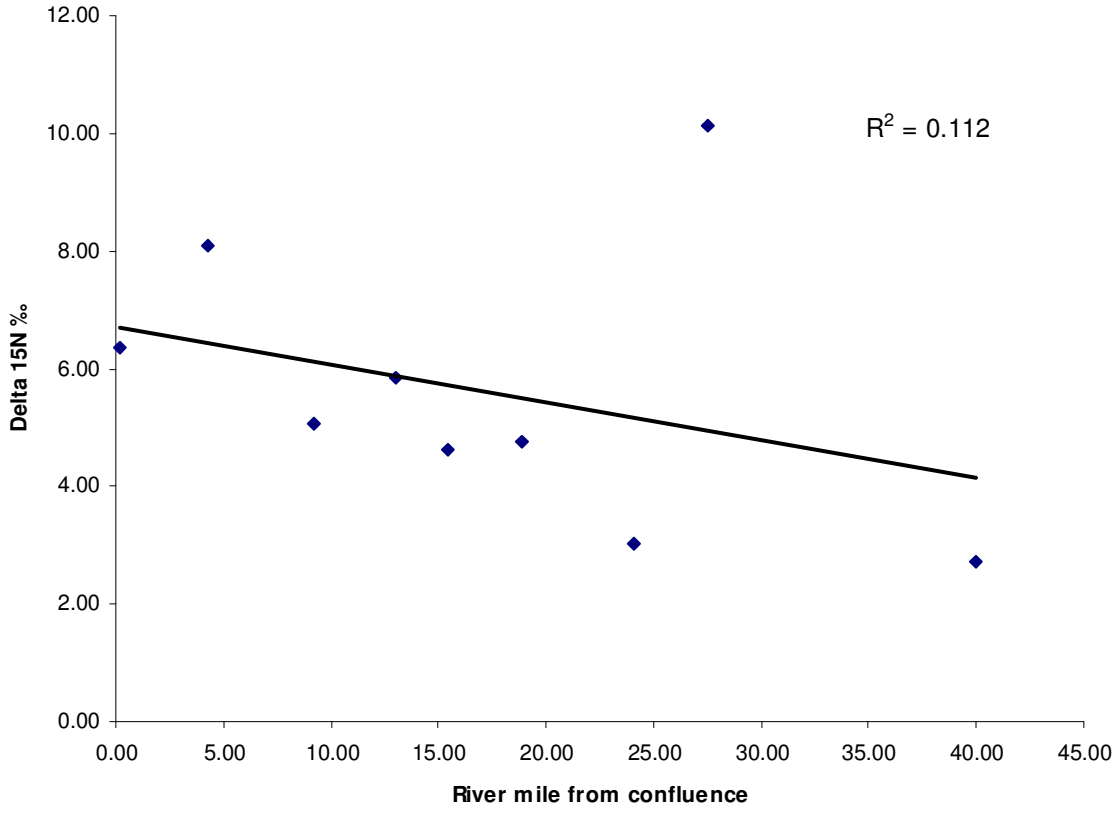
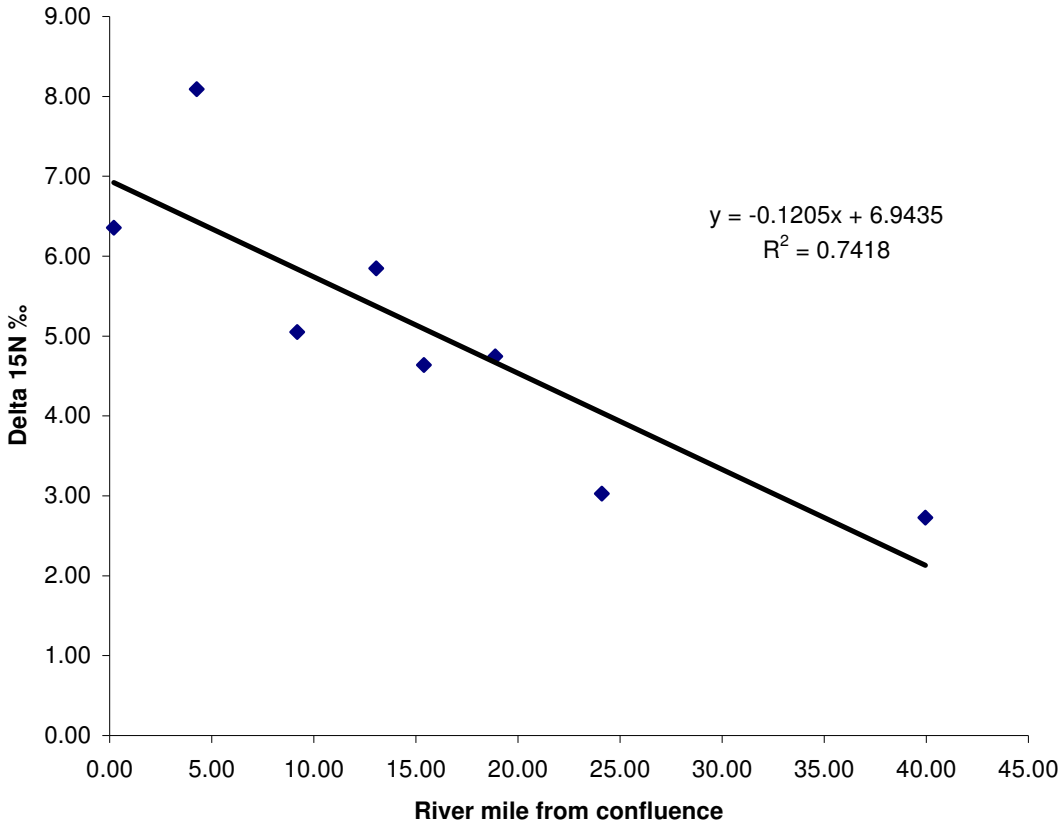


Figure 5. Suspended organic material stable nitrogen isotope values plotted against river mile for the Shasta River. River mile 0 is the confluence with the Klamath River. The single outlier point at river mile 27.49 is omitted from the plot.



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