TECHNICAL MEMORANDUM:

LONGITUDINAL ANALYSIS OF KLAMATH RIVER PHYTOPLANKTON DATA 2001-2004

PREPARED FOR THE

YUROK TRIBE ENVIRONMENTAL PROGRAM

BY

KIER ASSOCIATES, FISHERIES AND WATERSHED PROFESSIONALS
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INTRODUCTION

The Klamath Hydroelectric Project (KHP) in southern Oregon and northwestern California is currently undergoing the Federal Energy Regulatory Commission (FERC) project relicensing process, which requires, among other things, that the two states make a finding, under Section 401 of the federal Clean Water Act, that project operations will meet the state's water quality management as well a Clean Water Act Section 401 certification finding that as well as state of California 401 certification. As part of these processes, PacifiCorp (the KHP operators) conducted a water quality monitoring program to help determine KHP effects on Klamath River water quality. This program included a phytoplankton sampling component from 2001-2005. The complete set of 2001-2004 phytoplankton data were posted on PacifiCorp's website in October 2004; 2005 data have not yet been released. Raymond (2005) described PacifiCorp's phytoplankton sampling methodology and presented some summary statistics for the 2001-2004 data. Kann (2006) provided a detailed longitudinal analysis of the PacifiCorp 2001-2004 data for toxigenic *Microcystis aeruginosa*. However, to date, PacifiCorp's 2001-2004 dataset has not been comprehensively analyzed for general phytoplankton trends in the Klamath River system.

The purpose of this memo is to analyze and summarize PacifiCorp's 2001-2004 dataset, including the description of seasonal, annual, and longitudinal patterns in algal species composition and biovolume. Due to the importance of Upper Klamath Lake (UKL) to Klamath River nutrient and algal dynamics, phytoplankton data collected by the Klamath Tribes near the outlet of UKL are also utilized to provide a context for comparison.

METHODS

Field and Laboratory Methods

A total of 22 sites on the Klamath River and several of its tributaries were sampled for phytoplankton between the outlet of UKL (river mile 254.79) and the Klamath River's confluence with the Shasta River (river mile 173).   Locations of PacifiCorp mainstem sampling sites are shown in Figure 1 and Table 1. In 2002 only, samples were collected in Spencer Creek, Shovel Creek, Fall Creek, and the Shasta River; tributary data are not analyzed herein.

Sampling was performed by E&S Environmental Chemistry (Corvallis, Oregon) and laboratory analyses for chlorophyll *a* and phytoplankton species biovolume and abundance were performed by Aquatic Analysts (White Salmon, WA). Samples were collected approximately monthly from 2001-2004, with the number of sample stations and length of the sampling season varying between years (Figure 2). The start of the monitoring season varied from March in 2002-2003 to July in 2001, and monitoring ended each year in October or November.

Raymond (2005) provides the following description of the sampling methodology:

> "Samples were collected from approximately 0.5 m depth at the river and stream sites, and from 0.5 to 1.0 m depth in the reservoirs at sites near the dams. In addition, an integrated sample of the top 10 m of water in Copco and Iron Gate reservoirs was collected by lowering a weighted tube to 10 m, clamping off the top, retrieving the tube and draining it into a container. The contents of the container were mixed and dispensed into sample bottles. Approximately every 10th sample,

but at least one sample in every sample set, was duplicated for quality control purposes."

The Klamath Tribes of Oregon collected phytoplankton samples near the outlet of Upper Klamath Lake at Pelican Marina (river mile 255.50) in the year 2004 only at bi-weekly intervals. Samples were depth-integrated across the entire 1.5-2.5m water column and were processed by the same laboratory as PacifiCorp's samples (Klamath Tribes Upper Klamath Lake Phytoplankton Data; 1990-1999 and 2004-2005- Electronic data file)

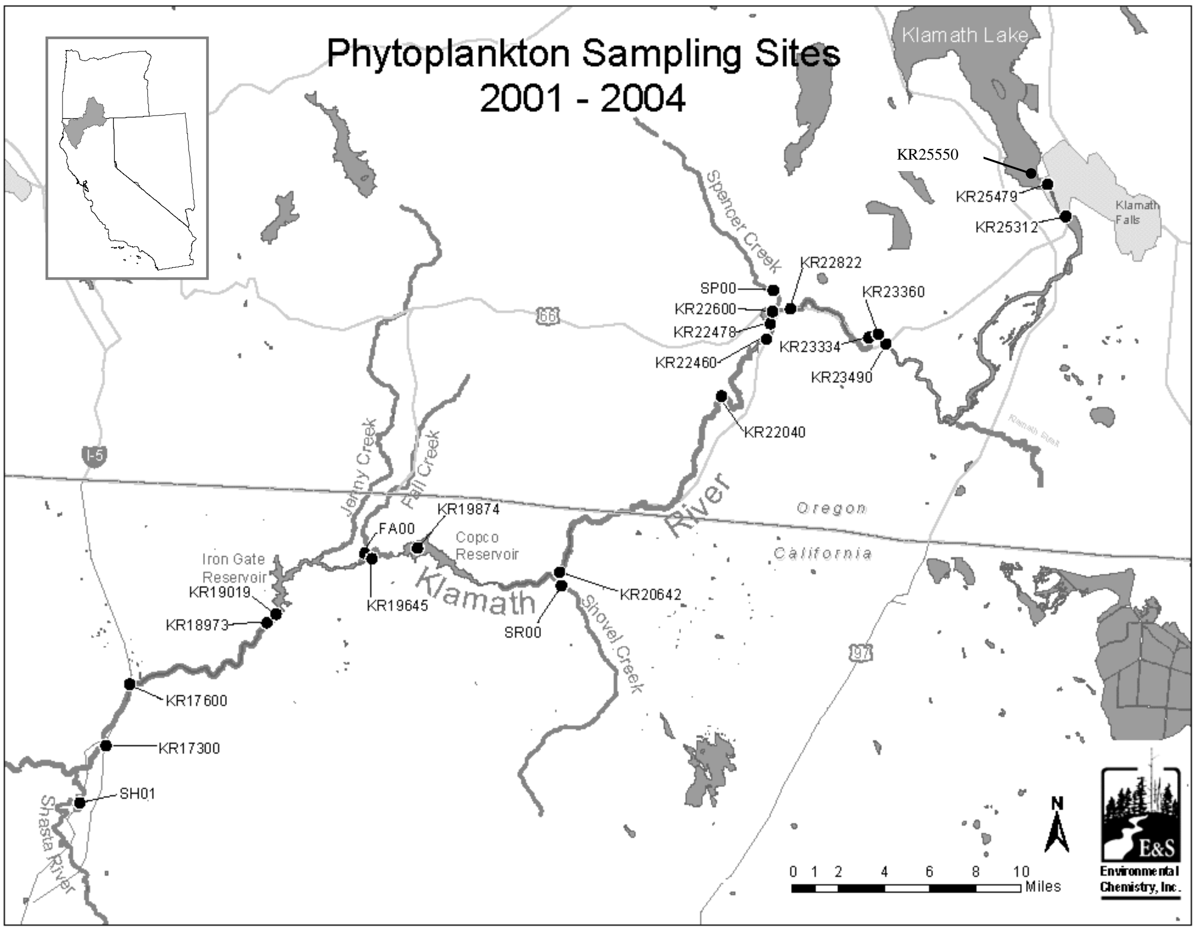


Figure 1. Phytoplankton samples collected in 2001-2004 in the vicinity of the Klamath Hydroelectric Project, by PacifiCorp and the Klamath Tribes. Figure adapted from Raymond (2005).

Table 1. Locations where PacifiCorp and the Klamath Tribes collected phytoplankton samples in the vicinity of the Klamath Hydroelectric Project in the years 2001-2004. Table adapted from Raymond (2005).

Data Collector	Site ID	River Mile	Latitude	Longitude	Site Name
PacifiCorp	KR17300	173.00	41.8362	-122.5825	Klamath River above Shasta River
PacifiCorp	KR17600	176.00	41.8301	-122.5937	Klamath River at I-5 Rest Area
PacifiCorp	KR18973	189.73	41.9310	-122.4423	Iron Gate dam Outflow
PacifiCorp	KR19019	190.19	41.9342	-122.4350	Iron Gate reservoir near dam
PacifiCorp	KR19645	196.45	41.9731	-122.3652	Copco 2 dam Outflow
PacifiCorp	KR19874	198.74	41.9794	-122.3333	Copco reservoir
PacifiCorp	KR20642	206.42	41.9721	-122.2016	Klamath River upstream of Shovel Creek
PacifiCorp	KR22040	220.40	42.0932	-122.0713	Klamath River upstream, of J.C. Boyle Powerhouse
PacifiCorp	KR22460	224.60	42.1217	-122.0494	Klamath River below J.C. Boyle dam
PacifiCorp	KR22478	224.78	42.1228	-122.0470	J.C. Boyle reservoir at Log Boom
PacifiCorp	KR22600	226.00	42.1351	-122.0313	J.C. Boyle reservoir at Hwy 66 Bridge
PacifiCorp	KR22822	228.22	42.1499	-122.0154	Klamath River above J.C. Boyle reservoir
PacifiCorp	KR23334	233.34	42.1353	-121.9489	Keno dam Outflow
PacifiCorp	KR23360	233.60	42.1345	-121.9482	Keno reservoir at Log Boom
PacifiCorp	KR23490	234.90	42.1222	-121.9194	Klamath River at Keno Bridge (Hwy 66)
PacifiCorp	KR25200	252.00	-	-	Lake Ewuana (coordinates not provided, river mile approximated from general location)
PacifiCorp	KR25312	253.12	42.2188	-121.7884	Link River at Mouth
PacifiCorp	KR25479	254.79	42.2383	-121.8053	Upper Klamath Lake at Fremont St Bridge
Klamath Tribes	KR25550	255.50			Upper Klamath Lake at Pelican Marina
PacifiCorp	SP00	0	42.1528	-122.0325	Spencer Creek near Mouth
PacifiCorp	SR00	0	41.9724	-122.2027	Shovel Creek near Mouth
PacifiCorp	FA00	0	41.9681	-122.3653	Fall Creek near Mouth
PacifiCorp	SH01	1	41.8231	-122.5944	Shasta River near Mouth

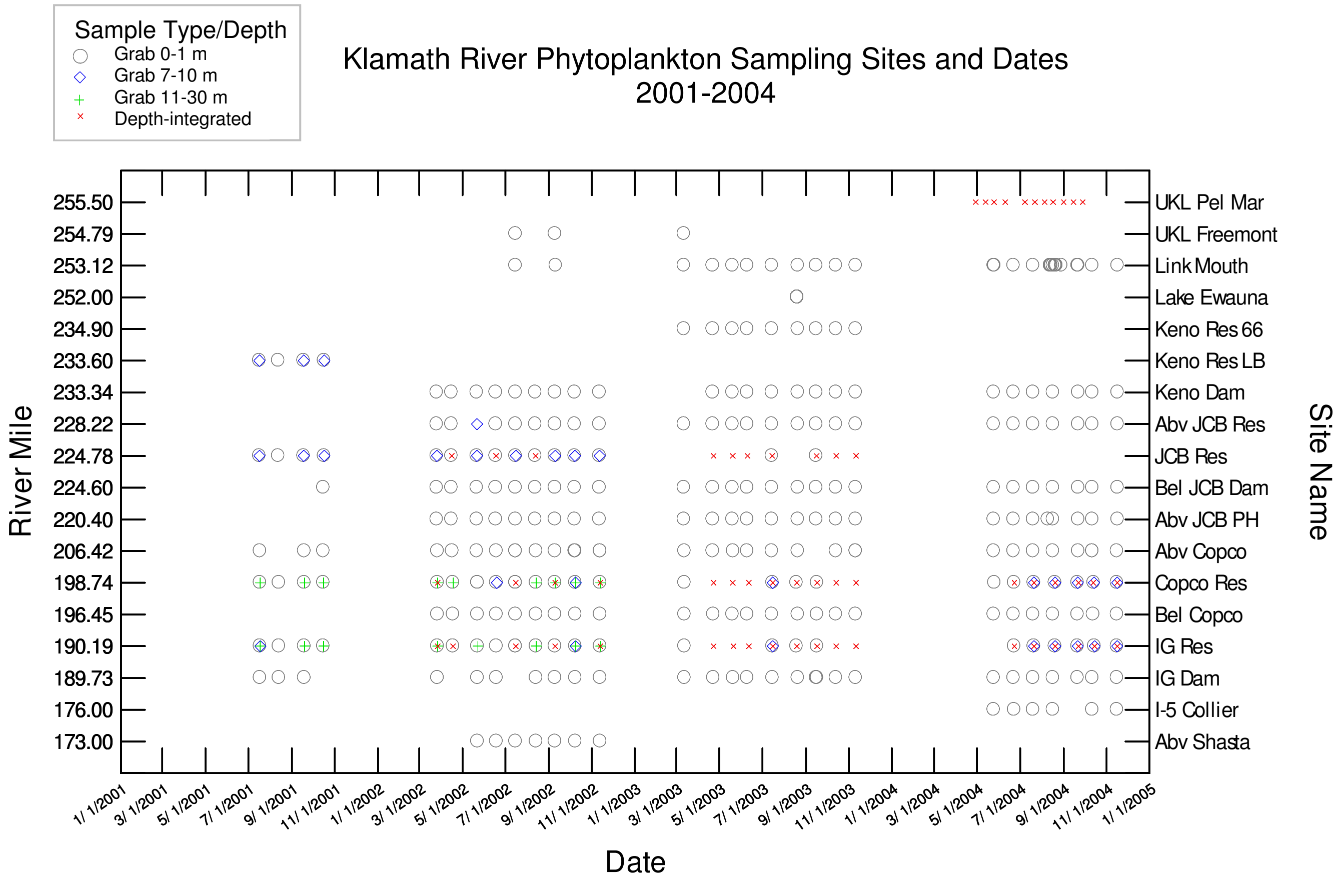


Figure 2. Timing of phytoplankton samples collected in the vicinity of the Klamath Hydroelectric Project by PacifiCorp in 2001-2004 and the Klamath Tribes in 2004.

Data Analysis Approach

Longitudinal Analyses

Longitudinal trends in the biovolume of total phytoplankton, nitrogen fixing phytoplankton, and major algal taxonomic groups (Chlorophyta, Chrysophyta, Cryptophyta, Cyanophyta, Diatoms, Euglenophyta, and Pyrrophyta) were evaluated for the years 2001 to 2004. Because river station samples represent surface grabs, longitudinal plots that include reservoir stations are for surface samples only (reservoir depth variability is evaluated separately below). These data were evaluated for all dates, and, separately for the June-September period when maximum phytoplankton biomass typically occurs.

Because UKL is known to exhibit large blooms of the nitrogen fixing blue-green alga, *Aphanizomenon flos-aquae*, and this and other species such as *Anabaena* can play an important role in introducing nitrogen into aquatic systems, specific analyses for total and percent biovolume of nitrogen fixing phytoplankton (NFP) were evaluated to assess the distribution and relative magnitude of these blue-green algal species.

Although the typical monthly sampling frequency makes it difficult to determine specific magnitude and seasonal trends in any given year, taken in its entirety the four available years of data provide adequate resolution to evaluate general seasonal and longitudinal patterns in algal species composition and biovolume. The robustness of longitudinal trends is enhanced by combining the data from all years and evaluating each sample station, with stations arranged in longitudinal (downstream-upstream) order (Figures 3-6 and Tables 2 and 3). The Klamath Tribes phytoplankton data from UKL (UKL Pel Mar in Figure 2 above) are biweekly but are only available for 2004. However, because the predominance of high blue-green algal biomass is well documented in UKL (Kann 1998; Kann and Welch 2005), this station is included below as a representation of phytoplankton conditions at the outlet of UKL. UKL chlorophyll *a* data were available for 2001-2004 and are shown in Figure 5.

Seasonal Analyses
Seasonal trends in surface samples (Figures 7-11) and at varying depths for reservoir stations (Figures 12-14) were evaluated for major taxonomic groups. Seasonal trends in surface samples for dominant phytoplankton species are shown in Figures 15-19.

RESULTS

Longitudinal Analysis

<u>Biovolume of Total and Nitrogen Fixing Phytoplankton</u>

Analysis of all dates
Box plots of total phytoplankton biovolume over all years, combined for all sample dates, show a declining longitudinal trend in biovolume from the headwaters at UKL to the station above JC Boyle powerhouse (RM 220.4), with the greatest median (red line in Figure 3) decreases occurring between UKL (RM 255.5) and Link Mouth (RM 253.12), between Keno Dam (RM 233.4) and above JC Boyle Reservoir (RM 228.22) and then, again, between below JC Boyle Dam (RM 224.6) and above the JC Boyle powerhouse (Figure 3; top panel). Upper quartile (UQ) values (top line of the box indicating the upper 25% of measurements) show a similar trend through the above JC Boyle reach, but then increase in JC Boyle Reservoir (RM 224.78).

Low values in samples above the JC Boyle powerhouse are highly influenced by bypass operations and often consist predominantly of spring water inflow. Between RM 220.4 (Abv JCB PH) and Abv Copco (RM 206.42) releases from JC Boyle reenter the river at the powerhouse increasing the median total biovolume above Copco to levels similar to those below JC Boyle Dam (Figure 3: top panel). However, the UQ value at the above Copco station was substantially lower than both the JC Boyle Reservoir station and the below JC Boyle Dam station (7x and 2.3x lower, respectively; Table 2). As discussed in Asarian and Kann (2006), flows and concentrations at this location are influenced by hydropower peaking operations from the J.C. Boyle Powerhouse.

From this point downstream, both median and UQ total biovolume showed an overall increase as the river traveled through the Copco/Iron Gate reservoir complex (Figure 3; Table 2). The median Copco and Iron Gate Reservoir values were 2-3 times greater than the median value above Copco, and the UQ values were 9.2 and 3.6 times higher, respectively. Below Iron Gate Reservoir, total phytoplankton biovolume decreases but remains elevated compared to that above Copco, where the upper quartile was 3 times higher and the median 2 times higher (Table 2). Continuing downstream from Iron Gate to Interstate 5 and above the Shasta River confluence (Figure 3: RM 173/176) levels returned to values similar to those above Copco station.

Total and Nitrogen-Fixing Phytoplankton Biovolume, Klamath River 2001-2004 (all dates)

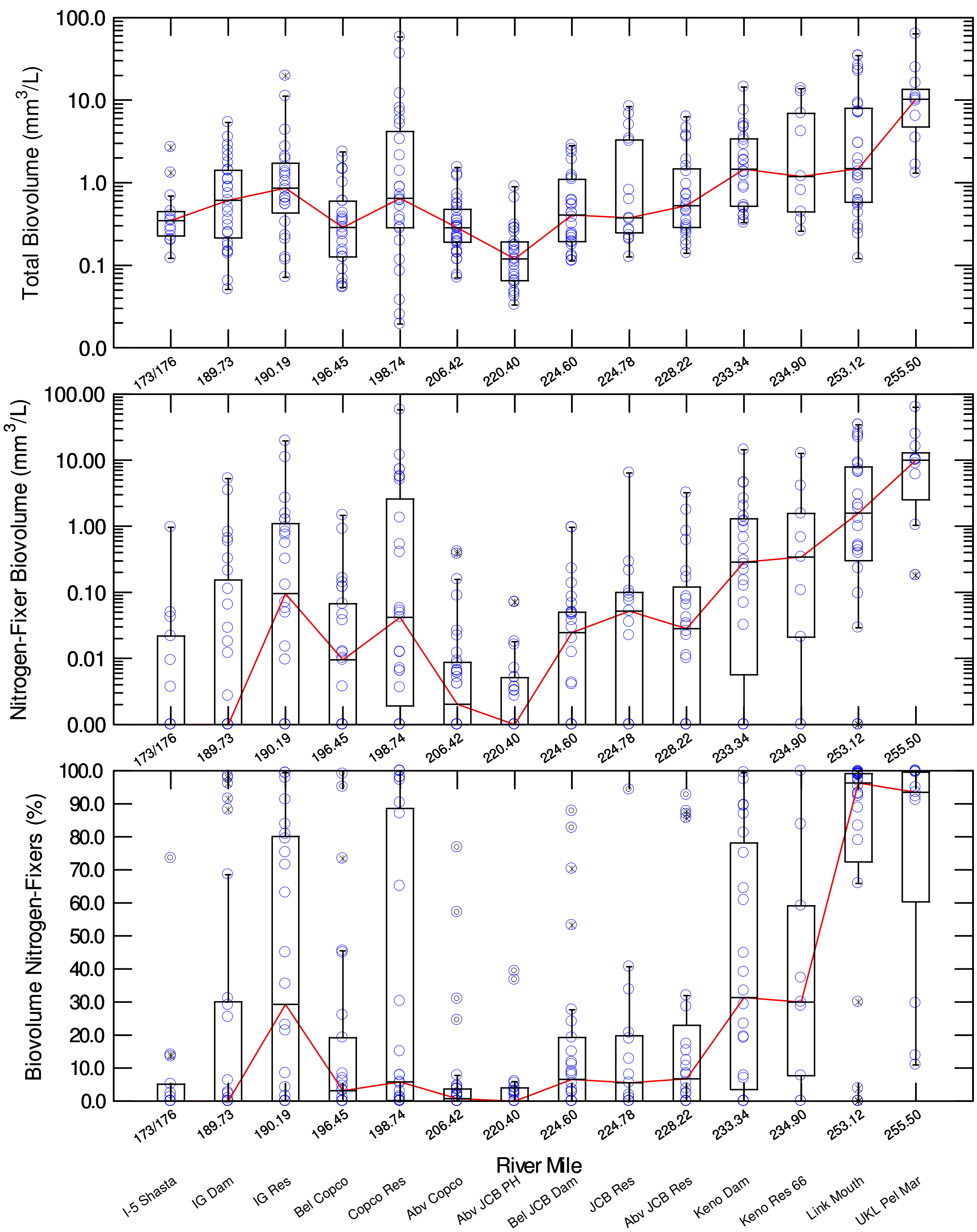


Figure 3. Total phytoplankton biovolume (top panel), total biovolume of nitrogen-fixing species (middle panel), and percent biovolume of nitrogen fixing species (bottom panel) of surface samples at major Klamath River sampling sites for the years 2001-2004, all months. The line inside each box is the median and the edges of each box are the 25th and 75th percentiles. The whiskers represent data points beyond 1.5 times the interquartile (75th-25th) range, while individual points shown in black are outliers.

A separate evaluation of NFP species (Figure 3; middle panel) showed a trend similar to total biovolume, with a consistent decline from UKL to the above Copco station (RM 206.42), and then a substantial increase through the Copco/Iron Gate Reservoir complex. However, both median and UQ values for NFP species showed a greater relative increase than did total biovolume, where median and UQ values for Copco Reservoir were 20 and 515 times higher than for above Copco, and were 50 and 138 times higher for Iron Gate Reservoir than for above Copco (Figure 3: middle panel; Table 2).

The most pronounced longitudinal trend occurred for the percent biovolume of NFP species (Figure 4: lower panel). Beginning at UKL, median percent NFP biovolume decreases from 94% down to <1% at the above Copco Station; and although the median then increased slightly in Copco Reservoir (to 5.8%), it rose to 29% in Iron Gate Reservoir. Further, the upper distribution of percent nitrogen fixers increased in both reservoirs to levels similar to those at UKL (the UQ was 89% and 80% for Copco and Iron Gate, respectively; Table 2).

June-September analysis

The basic trends for the June-September period followed that of the analysis using data from all dates; generally decreasing from UKL to above Copco and then increasing through the reservoir complex (Figure 4; Table 2). However, because June-September is the major growing season for blue-green algae blooms in the basin, the trends in biovolume and percent biovolume of NFP species tended to be more pronounced than the analysis using all dates (Figure 4; middle and bottom panels). For example, NFP biovolume and percent biovolume were 10.8 and 5.7 times higher in Copco Reservoir than they were at the above Copco station, and were 164 and 37 times higher in Iron Gate Reservoir

The overall distribution of June-September reservoir values was higher than that for the analysis including all dates, and the UQ values increased substantially from the above Copco Station (Figure 4). Compared to an UQ NFP composition of 24.5% above Copco, reservoir UQ NFP percent composition values returned to levels closer to UKL, exceeding ~90% in both reservoirs (Table 2) Despite declining between UKL and above Copco Reservoir, all parameters (total biovolume, NFP biovolume, and NFP percent biovolume) showed a clear increase in the Copco/Iron Gate Reservoir complex during the June- September period.

<u>Chlorophyll a</u>

Although not as pronounced for the analysis including all dates (Figure 5; top panel), the June-September analysis (Figure 5; bottom panel) for chlorophyll confirms the trends shown above for total phytoplankton biomass. Distribution of chlorophyll *a*, which provides an approximation of algal biomass, showed the same basic decreasing trend between UKL and above Copco (RM 206.42), then increasing (both median and UQ values) as the river traveled through the reservoir complex.

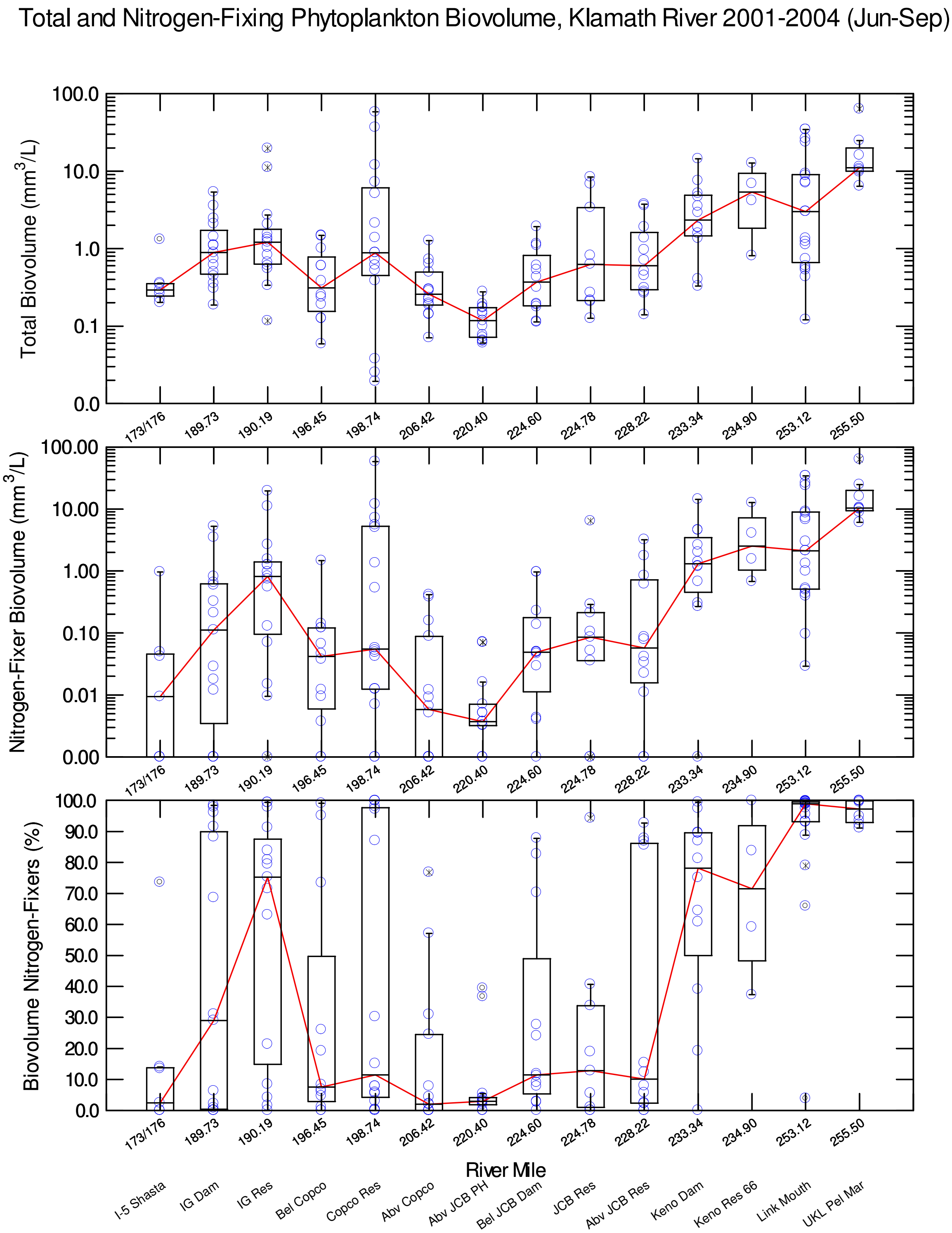


Figure 4. Total phytoplankton biovolume (top panel), total biovolume of nitrogen-fixing species (middle panel), and percent biovolume of nitrogen fixing species (bottom panel) of surface samples at major Klamath River sampling sites for the years 2001-2004, June 1- September 30.

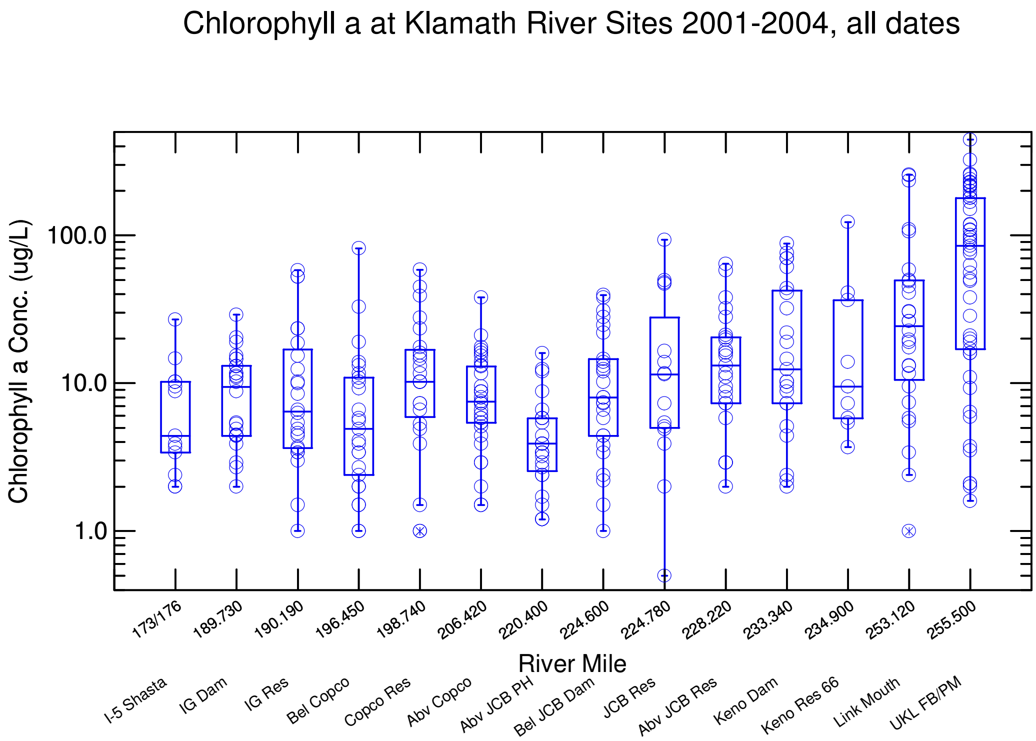
Table 2. Summary of biovolume data by site for surface samples* collected for the years 2001-2004. For each site, statistics include the number of samples (N), lower quartile, median, and upper quartile for total biovolume, nitrogen-fixing biovolume, and nitrogen-fixing biovolume as a percent of total biovolume.

			all surface samples			June 1 - Sept. 30 surface samples		
River Mile	Site Name	Metric	Total Biovolume (mm^3/L)	N-Fixer Biovolume (mm^3/L)	N-Fixer Biovolume (Percent)	Total Biovolume (mm^3/L)	N-Fixer Biovolume (mm^3/L)	N-Fixer Biovolume (Percent)
173/176	I-5 Shasta	N	13	13	13	7	7	7
173/176	I-5 Shasta	Lower Quartile	0.221	0.000	0.000	0.236	0.000	0.000
173/176	I-5 Shasta	Median	0.346	0.000	0.000	0.292	0.008	2.429
173/176	I-5 Shasta	Upper Quartile	0.509	0.026	7.243	0.356	0.047	13.917
189.73	IG Dam	N	27	27	27	15	15	15
189.73	IG Dam	Lower Quartile	0.202	0.000	0.000	0.456	0.003	0.202
189.73	IG Dam	Median	0.614	0.000	0.000	0.888	0.111	29.043
189.73	IG Dam	Upper Quartile	1.420	0.185	30.566	1.926	0.638	90.710
190.19	IG Res	N	24	24	24	15	15	15
190.19	IG Res	Lower Quartile	0.441	0.000	0.000	0.619	0.085	11.657
190.19	IG Res	Median	0.864	0.099	29.275	1.208	0.820	75.247
190.19	IG Res	Upper Quartile	1.738	1.102	80.106	1.931	1.478	89.426
196.45	Bel Copco	N	25	25	25	12	12	12
196.45	Bel Copco	Lower Quartile	0.126	0.000	0.000	0.159	0.006	2.869
196.45	Bel Copco	Median	0.286	0.009	3.187	0.319	0.041	7.535
196.45	Bel Copco	Upper Quartile	0.601	0.080	20.906	0.806	0.120	49.727
198.74	Copco Res	N	27	27	27	16	16	16
198.74	Copco Res	Lower Quartile	0.282	0.001	0.071	0.456	0.011	4.209
198.74	Copco Res	Median	0.618	0.041	5.847	0.885	0.054	11.459
198.74	Copco Res	Upper Quartile	4.700	4.118	89.460	6.184	5.286	97.613
206.42	Abv Copco	N	32	32	32	14	14	14
206.42	Abv Copco	Lower Quartile	0.197	0.000	0.000	0.196	0.000	0.000
206.42	Abv Copco	Median	0.285	0.002	0.733	0.258	0.005	2.020
206.42	Abv Copco	Upper Quartile	0.474	0.008	3.679	0.498	0.088	24.481
220.40	Abv JCB PH	N	26	26	26	13	13	13
220.40	Abv JCB PH	Lower Quartile	0.065	0.000	0.000	0.070	0.002	1.416
220.40	Abv JCB PH	Median	0.119	0.000	0.000	0.118	0.003	2.922
220.40	Abv JCB PH	Upper Quartile	0.192	0.004	4.007	0.174	0.008	4.477
224.60	Bel JCB Dam	N	26	26	26	12	12	12
224.60	Bel JCB Dam	Lower Quartile	0.194	0.000	0.000	0.183	0.016	5.363
224.60	Bel JCB Dam	Median	0.409	0.024	6.612	0.374	0.048	11.494
224.60	Bel JCB Dam	Upper Quartile	1.098	0.049	19.236	0.852	0.182	48.977

Table 2 (continued)

River Mile	Site Name	Metric	all surface samples: Total Biovolume (mm^3/L)	N-Fixer Biovolume (mm^3/L)	N-Fixer Biovolume (Percent)	June 1 - Sept. 30 surface samples: Total Biovolume (mm^3/L)	N-Fixer Biovolume (mm^3/L)	N-Fixer Biovolume (Percent)
224.78	JCB Res	N	15	15	15	9	9	9
224.78	JCB Res	Lower Quartile	0.239	0.000	0.000	0.213	0.026	0.768
224.78	JCB Res	Median	0.375	0.051	5.545	0.628	0.085	12.804
224.78	JCB Res	Upper Quartile	3.339	0.102	20.207	3.845	0.232	35.508
228.22	Abv JCB Res	N	24	24	24	12	12	12
228.22	Abv JCB Res	Lower Quartile	0.287	0.000	0.000	0.296	0.016	2.324
228.22	Abv JCB Res	Median	0.527	0.028	6.807	0.611	0.059	10.112
228.22	Abv JCB Res	Upper Quartile	1.479	0.126	22.953	1.636	0.730	86.204
233.34	Keno Dam	N	24	24	24	12	12	12
233.34	Keno Dam	Lower Quartile	0.518	0.015	3.471	1.464	0.490	49.946
233.34	Keno Dam	Median	1.464	0.285	31.349	2.402	1.308	78.168
233.34	Keno Dam	Upper Quartile	3.408	1.308	78.168	4.908	3.581	89.518
234.90	Keno Res 66	N	9	9	9	4	4	4
234.90	Keno Res 66	Lower Quartile	0.420	0.015	5.789	2.492	1.118	48.231
234.90	Keno Res 66	Median	1.187	0.341	29.975	5.539	2.820	71.461
234.90	Keno Res 66	Upper Quartile	8.350	2.189	65.302	9.797	8.383	91.863
253.12	Link Mouth	N	28	28	28	19	19	19
253.12	Link Mouth	Lower Quartile	0.579	0.312	72.419	0.631	0.502	93.071
253.12	Link Mouth	Median	1.786	1.604	96.280	2.139	2.116	98.922
253.12	Link Mouth	Upper Quartile	8.013	7.949	99.145	9.135	9.024	99.556
255.50	UKL Pel Mar*	N	11	11	11	8	8	8
255.50	UKL Pel Mar*	Lower Quartile	4.232	2.299	44.981	10.003	9.437	92.868
255.50	UKL Pel Mar*	Median	10.249	9.989	93.509	11.034	10.347	97.186
255.50	UKL Pel Mar*	Upper Quartile	14.887	14.638	99.693	20.414	20.392	99.842

*Note that although the Pelican Marina site in Upper Klamath Lake (river mile 255.50) is depth-integrated across the entire 1.5-2.5m water column, it is compared to surface samples at the other sites.



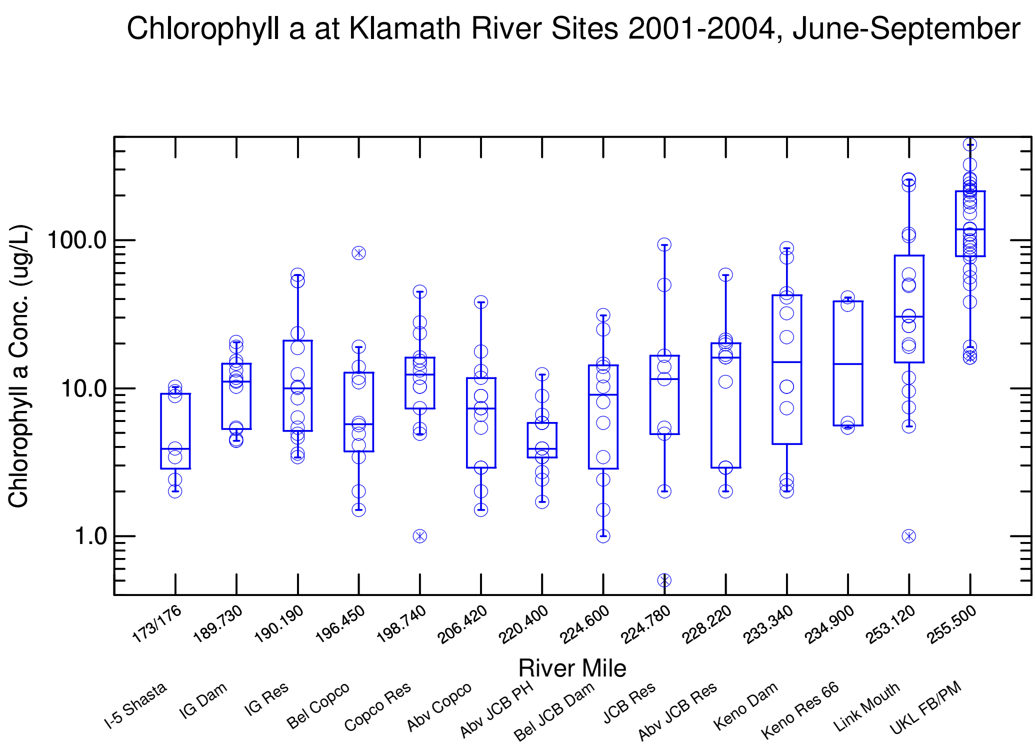


Figure 5. Chlorophyll *a* concentrations at Klamath River sites for all dates (top panel) and June-September (bottom panel), 2001-2004. Data are from samples collected by PacifiCorp and the Klamath Tribes.

Major Taxonomic Groups

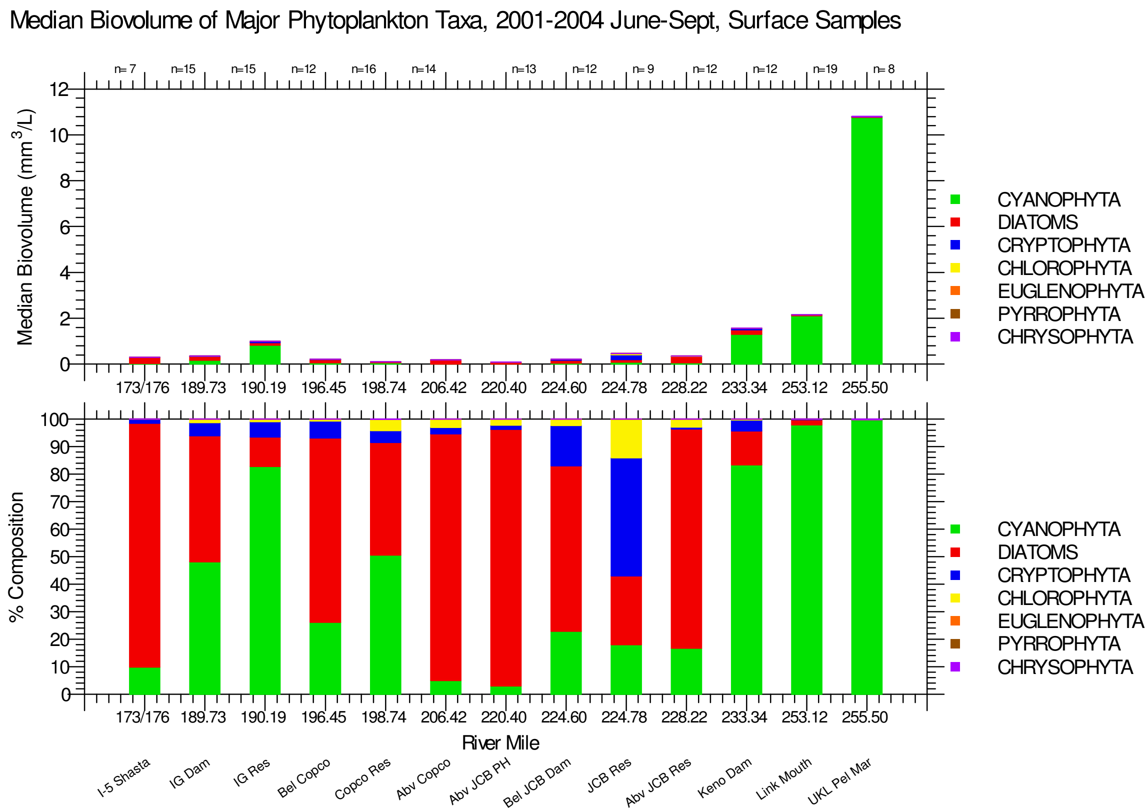
Cyanophyta
As expected, based upon the longitudinal trend described above in NFP species, which are comprised of algae from the taxonomic group Cyanophyta (blue-green algae), the longitudinal trend in both total biovolume and percent biovolume of the Cyanophyta (Figure 6) was similar to that of NFP shown above. UKL, dominated by the blue-green algal species *Aphanizomenon flos-aquae,* showed high median and UQ biomass and percent biomass levels. Downstream values then drop substantially, with median values decreasing from 10.8 mm^3/L to less than 0.01 mm^3/L above Copco (RM 206.42). However, although still low relative to UKL, median values were 5.8 and 86 times higher in Copco and Iron Gate Reservoirs than they were above Copco (Figure 6; top panel and Table 3). The trend in Cyanophyta percent composition is more pronounced through the reservoir complex than absolute biomass, with levels in Copco and Iron Gate increasing from 5% above Copco to 50% and 82% in Copco and Iron Gate Reservoirs, respectively.

As with total and NFP biomass, the upper distribution or UQ metric showed a more pronounced increase in the reservoir complex, especially for Copco Res (RM 198.74) which showed the overall increase to be 65 times higher than the above Copco station (Figure 6; bottom panel and Table 3). Moreover, percent Cyanophyta composition increased to 90% and 78% in Copco and Iron Gate, respectively. These trends in the upper distribution indicate that periodic high values of both biovolume and percent biovolume of Cyanophyta occurred in the reservoir complex relative to stations directly upstream.

Other dominant groups
As expected as the system changed from the lacustrine environment of UKL to the riverine environment of the Klamath River, diatoms increased in prevalence downstream, before decreasing again in the Copco/Iron Gate Reservoir complex (Figure 6; red color) as the Cyanophyta again dominated. Other major taxonomic groups that increased in prevalence downstream were the Cryptophyta (cryptophytes) and Chlorophyta (green algae); with the highest percent composition for these groups occurring in JC Boyle Reservoir (JCB Res; RM 224.78). As with the Cyanophyta, the species in these groups (e.g., *Cryptomonas erosa* and *Actinastrum hantzschii*) tend to be more lacustrine. Relative to diatoms and the Cyanophyta, the Euglenophyta (euglena), Pyrrophyta (dinoflagellates), and Chrysophyta (golden algae) comprised a very minor portion of the overall biovolume at all stations.

Seasonal Trends

Phytoplankton can respond to changes in their environment with periods of rapid growth or decline. These changes usually occur at intervals substantially shorter than the monthly sampling frequency of the PacifiCorp dataset. Given these limitations, apparent differences in peak biomass between years may in fact be due to the timing of sample collection rather than to any real differences. As such, it is not the goal in the following sections to compare the specific magnitudes among years, but rather to determine the general consistency of seasonal trends among years and to determine general seasonal trajectories. Bi-weekly data, such as that collected by the Klamath Tribes at its Pelican Marina site in UKL, would provide much-improved resolution for identifying and interpreting seasonal and inter-annual trends.



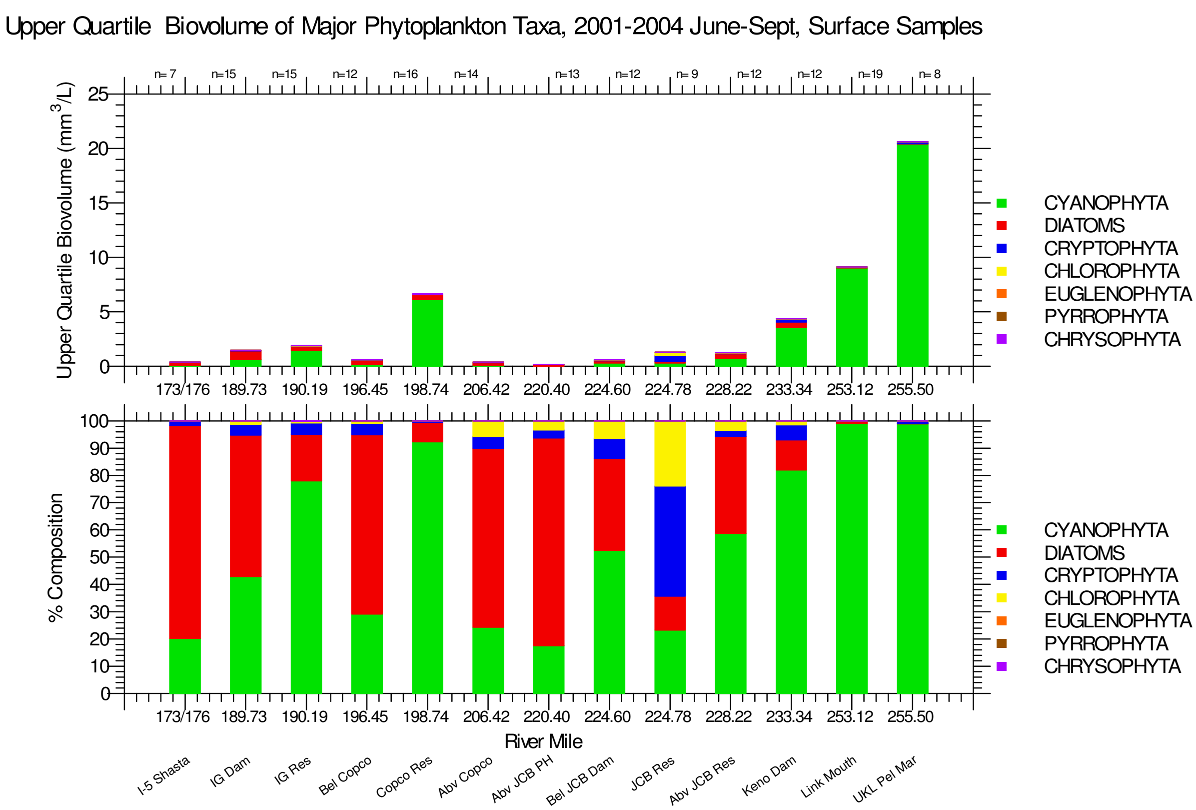


Figure 6. Median and upper quartile biovolume and percent composition of major phytoplankton taxonomic groups for surface samples collected June 1 – September 30, 2001-2004.

Table 3. Summary of biovolume data by site for surface samples* collected for the years 2001-2004 during the period June 1 – September 30. For each site, statistics include the number of samples (N) and the mean total biovolume for each major taxonomic group.

			Mean Biovolume (mm³/L) for June 1 - Sept. 30 surface samples						
River Mile	**Site Name**	**Metric**	**Chloro - phyta**	**Chryso-phyta**	**Crypto-phyta**	**Cyano-phyta**	**Diatoms**	**Eugleno-phyta**	**Pyrro-phyta**
173/176	I-5 Shasta	N	7	7	7	7	7	7	7
173/176	I-5 Shasta	Lower Quartile	0.0000	0.0000	0.0000	0.0000	0.2252	0.0000	0.0000
173/176	I-5 Shasta	Median	0.0000	0.0000	0.0045	0.0294	0.2646	0.0000	0.0000
173/176	I-5 Shasta	Upper Quartile	0.0003	0.0000	0.0061	0.0774	0.3003	0.0000	0.0000
189.73	IG Dam	N	15	15	15	15	15	15	15
189.73	IG Dam	Lower Quartile	0.0012	0.0000	0.0070	0.0070	0.0617	0.0000	0.0000
189.73	IG Dam	Median	0.0043	0.0000	0.0169	0.1707	0.1626	0.0000	0.0000
189.73	IG Dam	Upper Quartile	0.0188	0.0011	0.0574	0.6381	0.7728	0.0000	0.0000
190.19	IG Res	N	15	15	15	15	15	15	15
190.19	IG Res	Lower Quartile	0.0030	0.0000	0.0177	0.0846	0.0369	0.0000	0.0000
190.19	IG Res	Median	0.0091	0.0000	0.0554	0.8278	0.1072	0.0000	0.0000
190.19	IG Res	Upper Quartile	0.0115	0.0025	0.0793	1.4777	0.3245	0.0000	0.0000
196.45	Bel Copco	N	12	12	12	12	12	12	12
196.45	Bel Copco	Lower Quartile	0.0002	0.0000	0.0003	0.0161	0.0207	0.0000	0.0000
196.45	Bel Copco	Median	0.0015	0.0000	0.0129	0.0557	0.1425	0.0000	0.0000
196.45	Bel Copco	Upper Quartile	0.0060	0.0000	0.0247	0.1778	0.4024	0.0000	0.0000
198.74	Copco Res	N	16	16	16	16	16	16	16
198.74	Copco Res	Lower Quartile	0.0006	0.0000	0.0000	0.0262	0.0108	0.0000	0.0000
198.74	Copco Res	Median	0.0045	0.0000	0.0047	0.0550	0.0445	0.0000	0.0000
198.74	Copco Res	Upper Quartile	0.0120	0.0035	0.0205	6.1296	0.4748	0.0000	0.0000
206.42	Abv Copco	N	14	14	14	14	14	14	14
206.42	Abv Copco	Lower Quartile	0.0019	0.0000	0.0005	0.0000	0.1395	0.0000	0.0000
206.42	Abv Copco	Median	0.0057	0.0000	0.0044	0.0096	0.1709	0.0000	0.0000
206.42	Abv Copco	Upper Quartile	0.0221	0.0003	0.0166	0.0946	0.2550	0.0000	0.0000
220.40	Abv JCB PH	N	13	13	13	13	13	13	13
220.40	Abv JCB PH	Lower Quartile	0.0012	0.0000	0.0000	0.0017	0.0588	0.0000	0.0000
220.40	Abv JCB PH	Median	0.0020	0.0000	0.0013	0.0027	0.0827	0.0000	0.0000
220.40	Abv JCB PH	Upper Quartile	0.0054	0.0000	0.0048	0.0288	0.1251	0.0000	0.0000
224.60	Bel JCB Dam	N	12	12	12	12	12	12	12
224.60	Bel JCB Dam	Lower Quartile	0.0025	0.0000	0.0033	0.0168	0.0678	0.0000	0.0000
224.60	Bel JCB Dam	Median	0.0049	0.0000	0.0314	0.0487	0.1284	0.0000	0.0000
224.60	Bel JCB Dam	Upper Quartile	0.0395	0.0003	0.0445	0.3209	0.2060	0.0000	0.0000
224.78	JCB Res	N	9	9	9	9	9	9	9
224.78	JCB Res	Lower Quartile	0.0229	0.0000	0.0503	0.0260	0.0616	0.0000	0.0000
224.78	JCB Res	Median	0.0662	0.0000	0.2022	0.0849	0.1176	0.0000	0.0000
224.78	JCB Res	Upper Quartile	0.3117	0.0003	0.5285	0.3038	0.1631	0.0000	0.0000
228.22	Abv JCB Res	N	12	12	12	12	12	12	12
228.22	Abv JCB Res	Lower Quartile	0.0005	0.0000	0.0000	0.0158	0.1281	0.0000	0.0000
228.22	Abv JCB Res	Median	0.0104	0.0000	0.0022	0.0593	0.2820	0.0000	0.0000
228.22	Abv JCB Res	Upper Quartile	0.0438	0.0003	0.0262	0.7299	0.4419	0.0000	0.0000

Table 3 (continued)

River Mile	Site Name	Metric	Mean Biovolume (mm³/L) for June 1 - Sept. 30 surface samples Chloro-phyta	Chryso - phyta	Crypto-phyta	Cyano-phyta	Diatoms	Eugleno-phyta	Pyrro-phyta
233.34	Keno Dam	N	12	12	12	12	12	12	12
233.34	Keno Dam	Lower Quartile	0.0004	0.0000	0.0256	0.4902	0.0666	0.0000	0.0000
233.34	Keno Dam	Median	0.0057	0.0000	0.0620	1.3081	0.1928	0.0000	0.0000
233.34	Keno Dam	Upper Quartile	0.0610	0.0022	0.2381	3.5811	0.4824	0.0000	0.0000
234.90	Keno Res 66	N	4	4	4	4	4	4	4
234.90	Keno Res 66	Lower Quartile	0.0007	0.0000	0.0244	1.1177	0.0439	0.0000	0.0000
234.90	Keno Res 66	Median	0.0226	0.0000	1.0991	2.8241	0.1459	0.0000	0.0000
234.90	Keno Res 66	Upper Quartile	0.0532	0.0000	2.3557	8.3872	0.3057	0.0000	0.0000
253.12	Link Mouth	N	19	19	19	19	19	19	19
253.12	Link Mouth	Lower Quartile	0.0000	0.0000	0.0003	0.5019	0.0252	0.0000	0.0000
253.12	Link Mouth	Median	0.0004	0.0000	0.0039	2.1158	0.0392	0.0000	0.0000
253.12	Link Mouth	Upper Quartile	0.0007	0.0000	0.0091	9.0240	0.0774	0.0000	0.0000
255.50	UKL Pel Mar	N	8	8	8	8	8	8	8
255.50	UKL Pel Mar	Lower Quartile	0.0010	0.0040	0.0040	9.8190	0.0000	0.0000	0.0000
255.50	UKL Pel Mar	Median	0.0110	0.0060	0.0190	10.7720	0.0020	0.0000	0.0000
255.50	UKL Pel Mar	Upper Quartile	0.0370	0.0150	0.1440	20.3920	0.0270	0.0000	0.0000

*Note that although the Pelican Marina site in Upper Klamath Lake (river mile 255.50) is depth-integrated across the entire 1.5-2.5m water column, it is compared to surface samples at the other sites.

Major Taxonomic Groups

Seasonal trends for major taxonomic groups are shown for each station ordered longitudinally from UKL to the Klamath River above the Shasta River confluence in Figures 7-11. Similar to the above analyses, Cyanophyta biomass and composition dominated the June-September period at up-river stations (Figure 7), with diatoms, cryptophytes, and chlorophytes dominating during the spring months. Although the summer Cyanophyta dominance persists downstream to Below JCB Dam (RM 224.6), the period of dominance becomes seasonally restricted at sites downstream (Figures 8 and 9).

The importance of diatoms, cryptophytes, and chlorophytes begins to increase in importance below Keno Dam (RM 233.34) with diatoms dominating for much of the summer growing season by the time the river reaches the above Copco station (Figure 9; RM 206.42). Only restricted peaks in Cyanophyta dominance were observed at this station, occurring in July-August of 2003 and June-July of 2004. In contrast, peak Cyanophyta in Copco and Iron Gate Reservoirs (Figure 10) was substantially higher (note scale change from Figure 9 showing the Abv Copco station), with an overall decrease in diatom dominance during the summer months. Given that Cyanophyta tend to be buoyant and concentrate near the surface, and that releases from Iron Gate Reservoir are drawn from a depth ~30-40 feet, it is not surprising that the Iron Gate Dam station (RM 189.73 showed reduced composition of Cyanophyta, although relative to Abv. Copco, levels were higher and the period of dominance was protracted (Figure 11). Sampling frequency was insufficient (stations at RM's 173 and 176 were each only sampled in one year) to thoroughly evaluate stations below Iron Gate dam (Figure 11); however there is an indication of continued but diminished blue-green peaks, with increasing diatom dominance.

The overall seasonal pattern observed at most stations consists of spring diatom dominance, followed by increasing chlorophytes and cryptophytes, followed by a period of Cyanophyta (blue-green algae) dominance, and finally a return to diatoms during the fall. The magnitude and period of Cyanophyta dominance was dependant upon whether the station is a reservoir or river station.

Reservoir samples at various depths

Periodic multiple depth sampling occurred in JC Boyle, Copco, and Iron Gate Reservoirs from 2001-2004 (Figures 12-14). The grab samples shown as 0-1m are the same as the surface samples depicted in all above graphs; other sample depths consist of either a depth integrated sample of the top 8-10 m of the water column (thus is inclusive of the 0-1 m grab sample), and a depth-specific sample taken between the 7 and 10 m depths.

Depth-specific samples were limited but tend to indicate that in JC Boyle and Copco Reservoirs, the composition of diatoms increases relative to the surface samples that showed higher predominance of chlorophytes and cryptophytes in JC Boyle (Figure 12) and higher Cyanophyta in Copco (Figure 13). The depth integrated sampling was more consistent, and as expected based on dilution of surface water where algae tend to be more concentrated, overall water column biovolume was substantially lower (again note scale change from surface to depth-integrated graphs) than surface samples in all three reservoirs. Although overall biovolume was lower in the depth-integrated samples, they showed a similar seasonal pattern of blue-green dominance as the surface samples. This may be partially due to the inclusion of surface material in the integrated sample. Copco and Iron Gate depth-integrated samples during summer months also showed greater dominance by cryptophytes and chlorophytes than did surface samples (Figures 13 and 14).

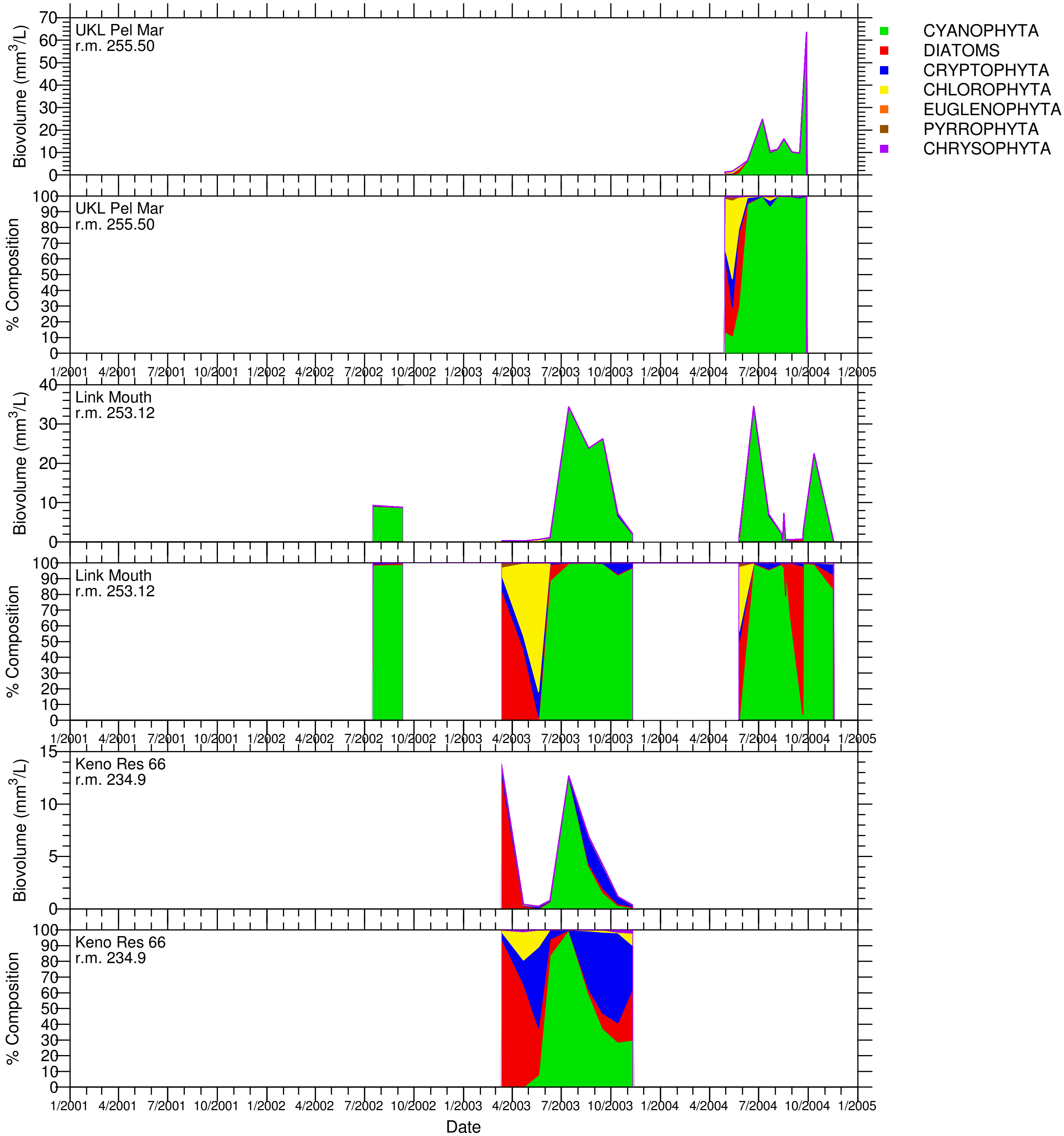


Figure 7. Biovolume and percent biovolume of major taxonomic groups of phytoplankton for surface samples collected in the years 2001-2004. Sites are listed in downstream order: Upper Klamath Lake at Pelican Marina, Link River at its mouth, and Keno Reservoir at the Highway 66 Bridge.

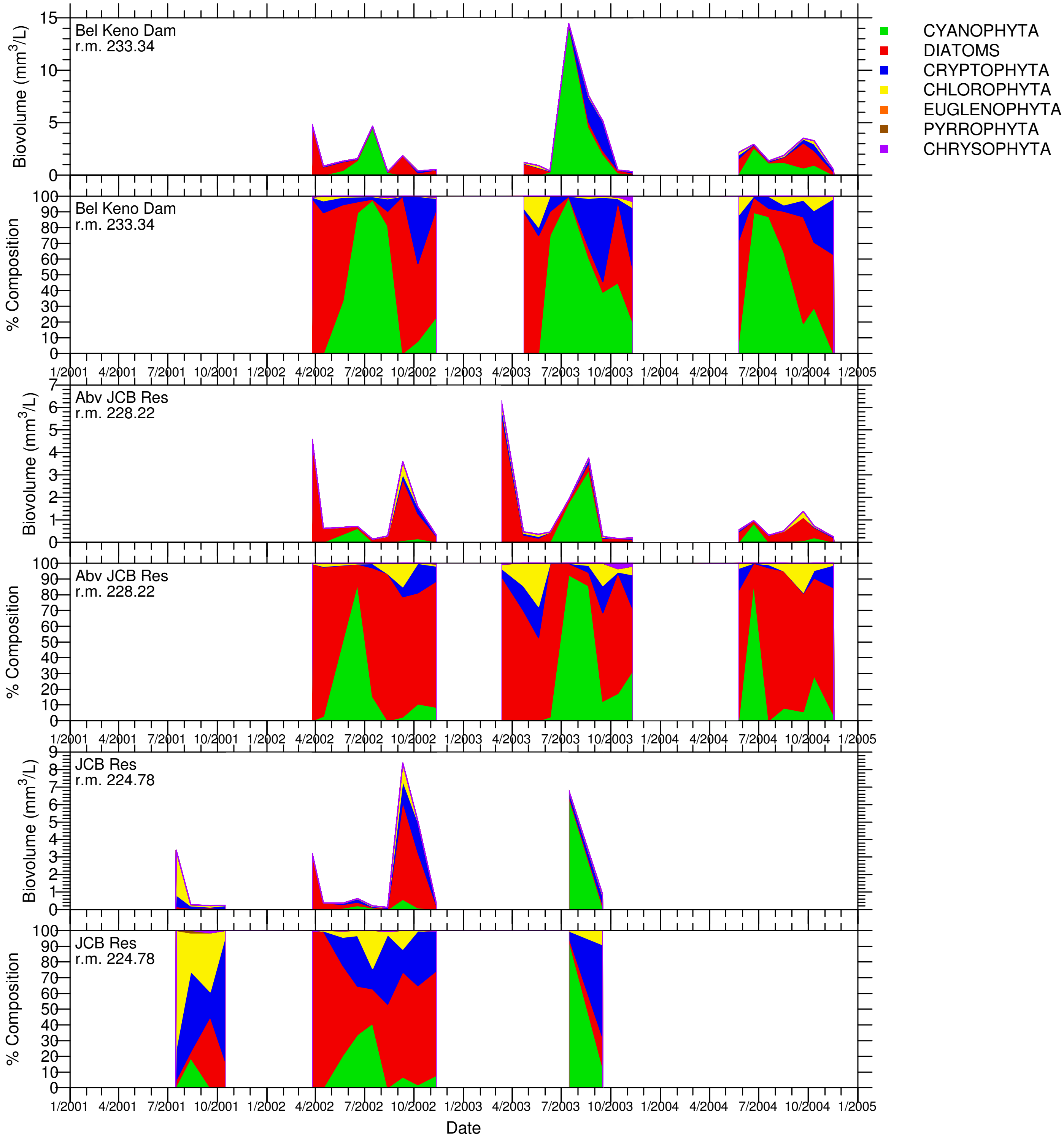


Figure 8. Biovolume and percent biovolume of major taxonomic groups of phytoplankton for surface samples collected in the years 2001-2004. Sites are listed in downstream order: Keno Dam, Above J.C. Boyle Reservoir, and J.C. Boyle Reservoir.

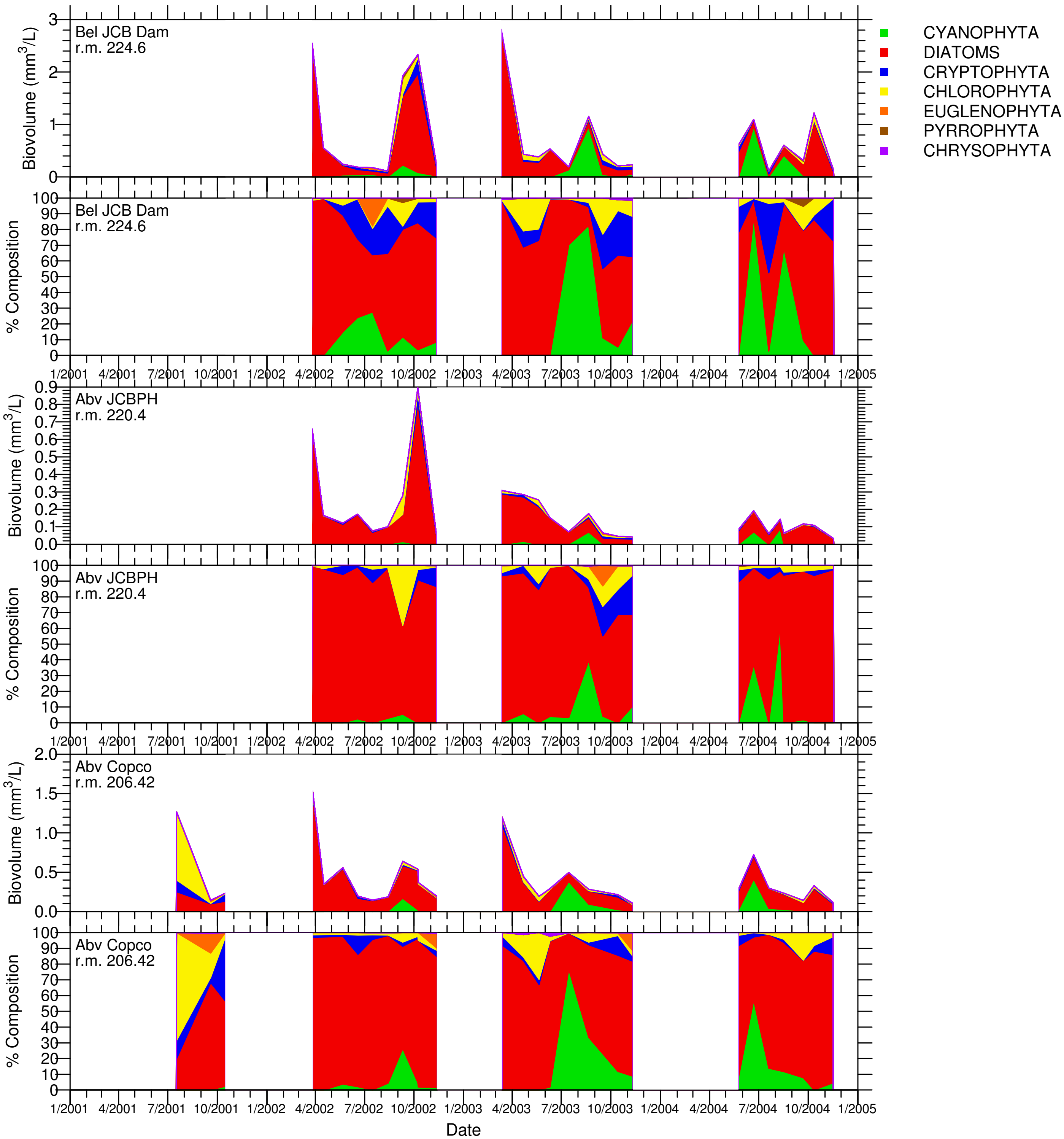


Figure 9. Biovolume and percent biovolume of major taxonomic groups of phytoplankton for surface samples collected in the years 2001-2004. Sites are listed in downstream order: Below J.C. Boyle Dam, Above J.C. Boyle Powerhouse, and Above Copco Reservoir.

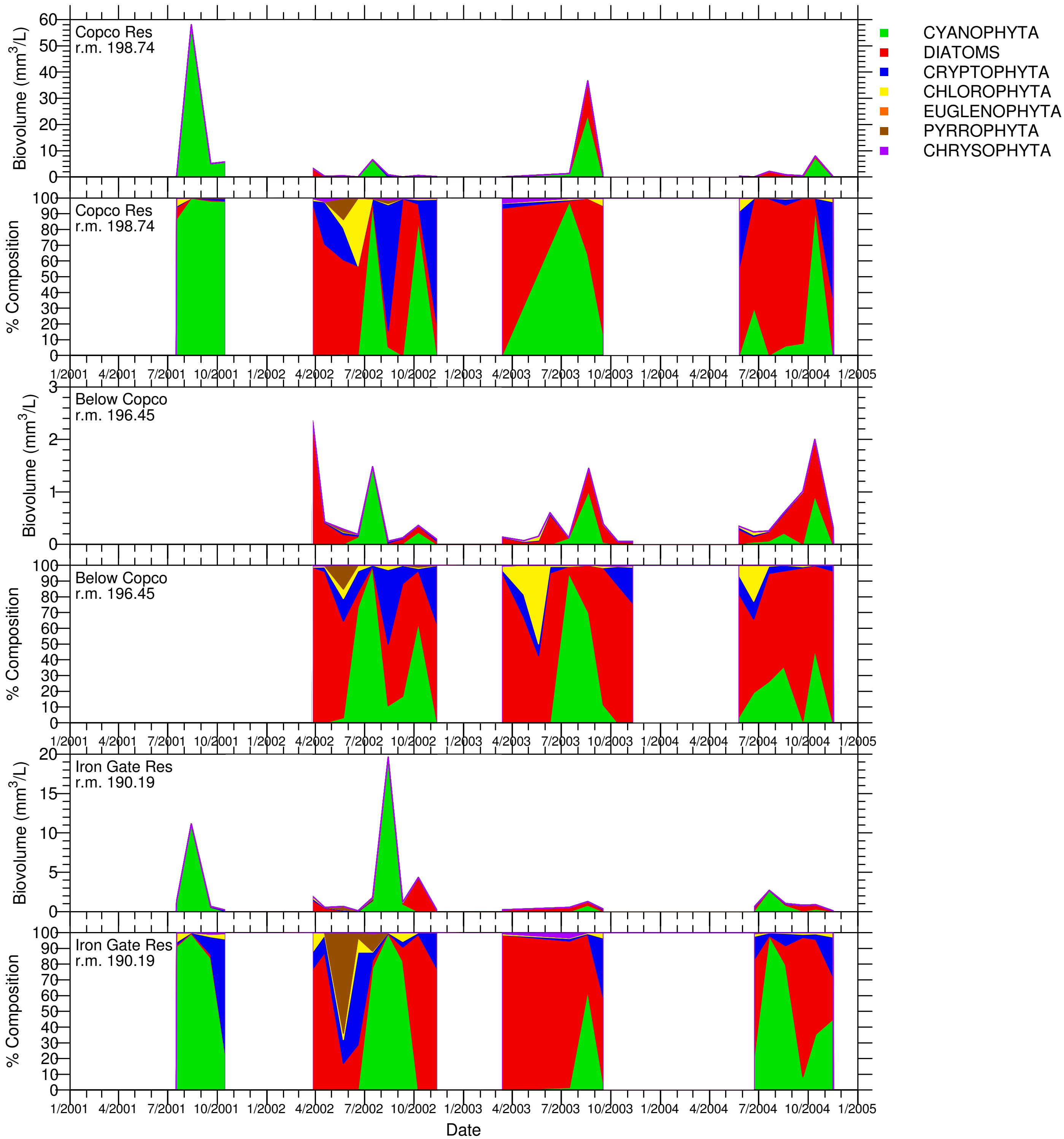


Figure 10. Biovolume and percent biovolume of major taxonomic groups of phytoplankton for surface samples collected in the years 2001-2004. Sites are listed in downstream order: Copco Reservoir, Below Copco Dam, and Iron Gate Reservoir.

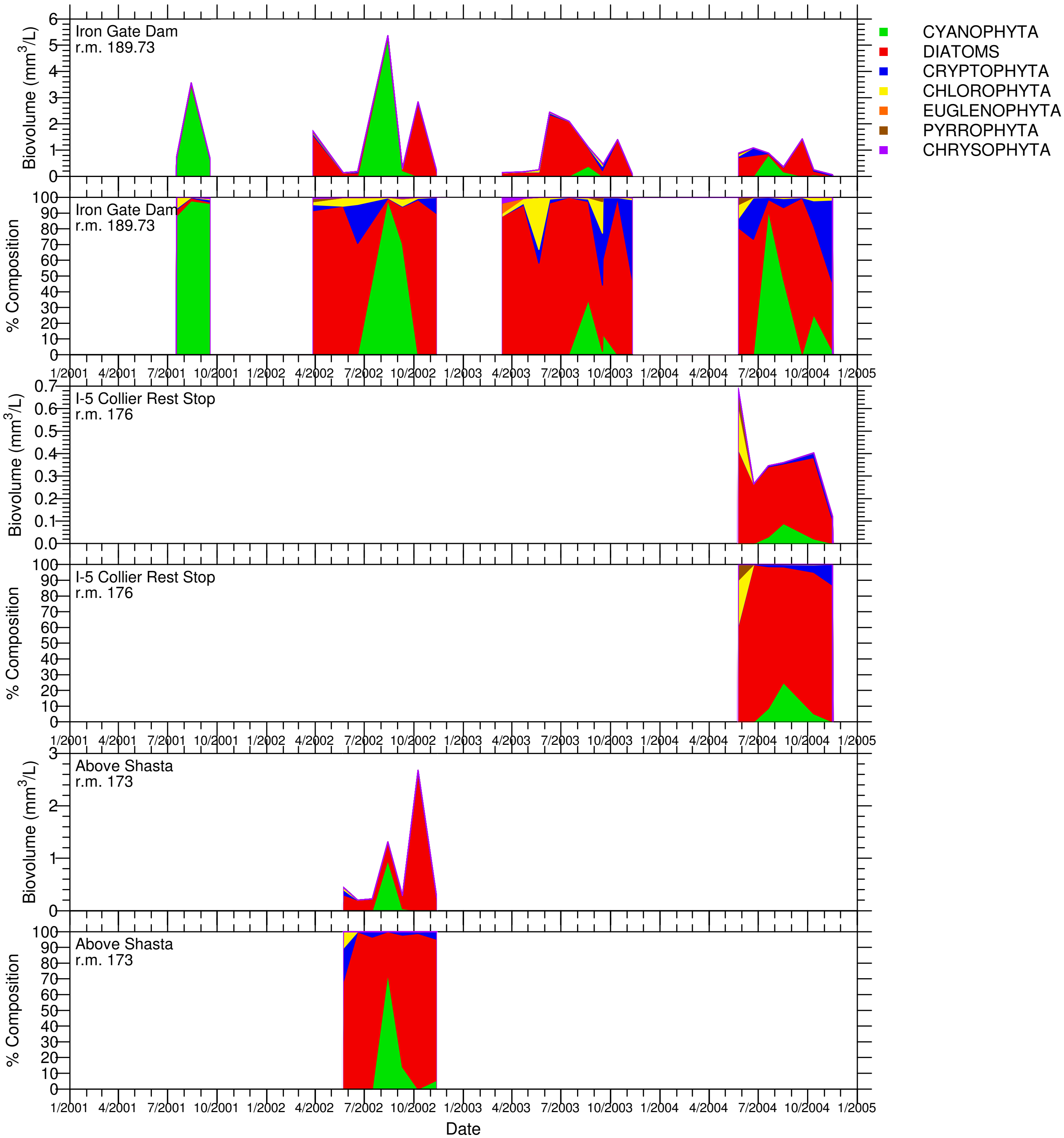


Figure 11. Biovolume and percent biovolume of major taxonomic groups of phytoplankton for surface samples collected in the years 2001-2004. Sites are listed in downstream order: Iron Gate Dam, Above the Shasta River, at the Interstate 5 Collier Rest Area.

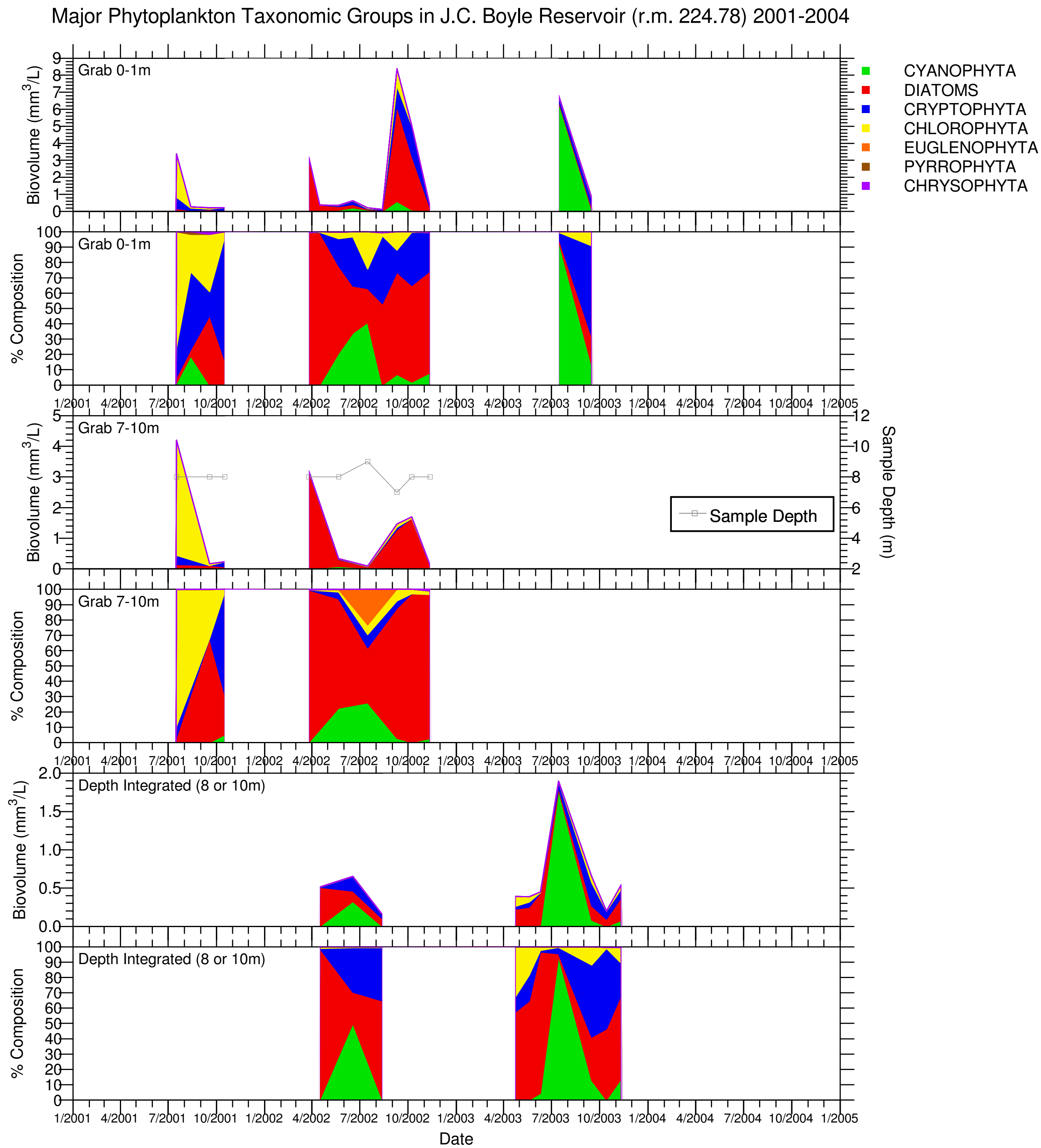


Figure 12. Biovolume and percent biovolume of major taxonomic groups of phytoplankton for samples collected in J.C. Boyle Reservoir in the years 2001-2003 (no samples collected in 2004). Each sampling depth is shown is a separate panel.

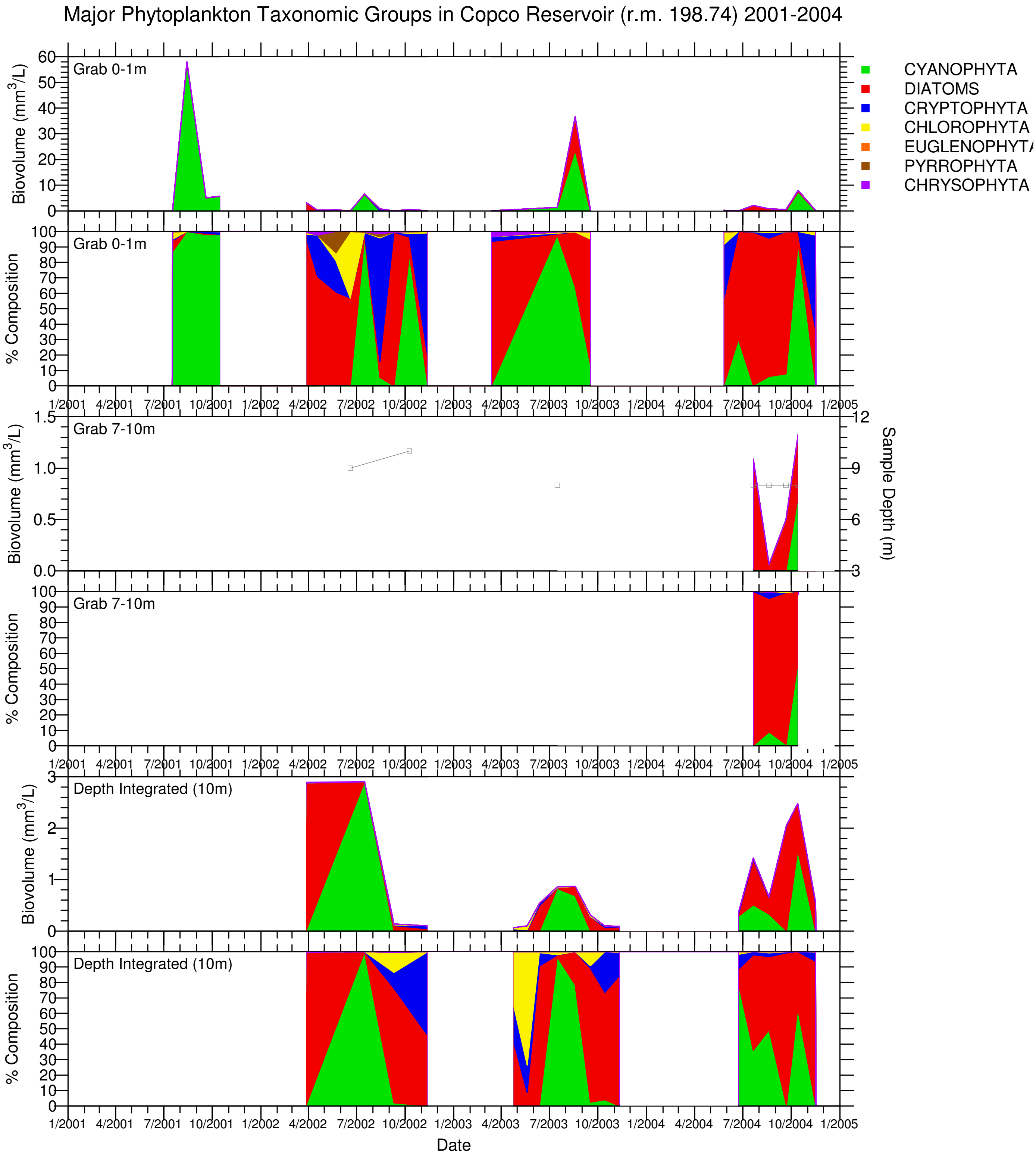


Figure 13. Biovolume and percent biovolume of major taxonomic groups of phytoplankton for samples collected in Copco Reservoir in the years 2001-2003 (no samples collected in 2004). Each sampling depth is shown is a separate panel. A few samples were also collected at depth greater than 10m, but those samples are not shown here.

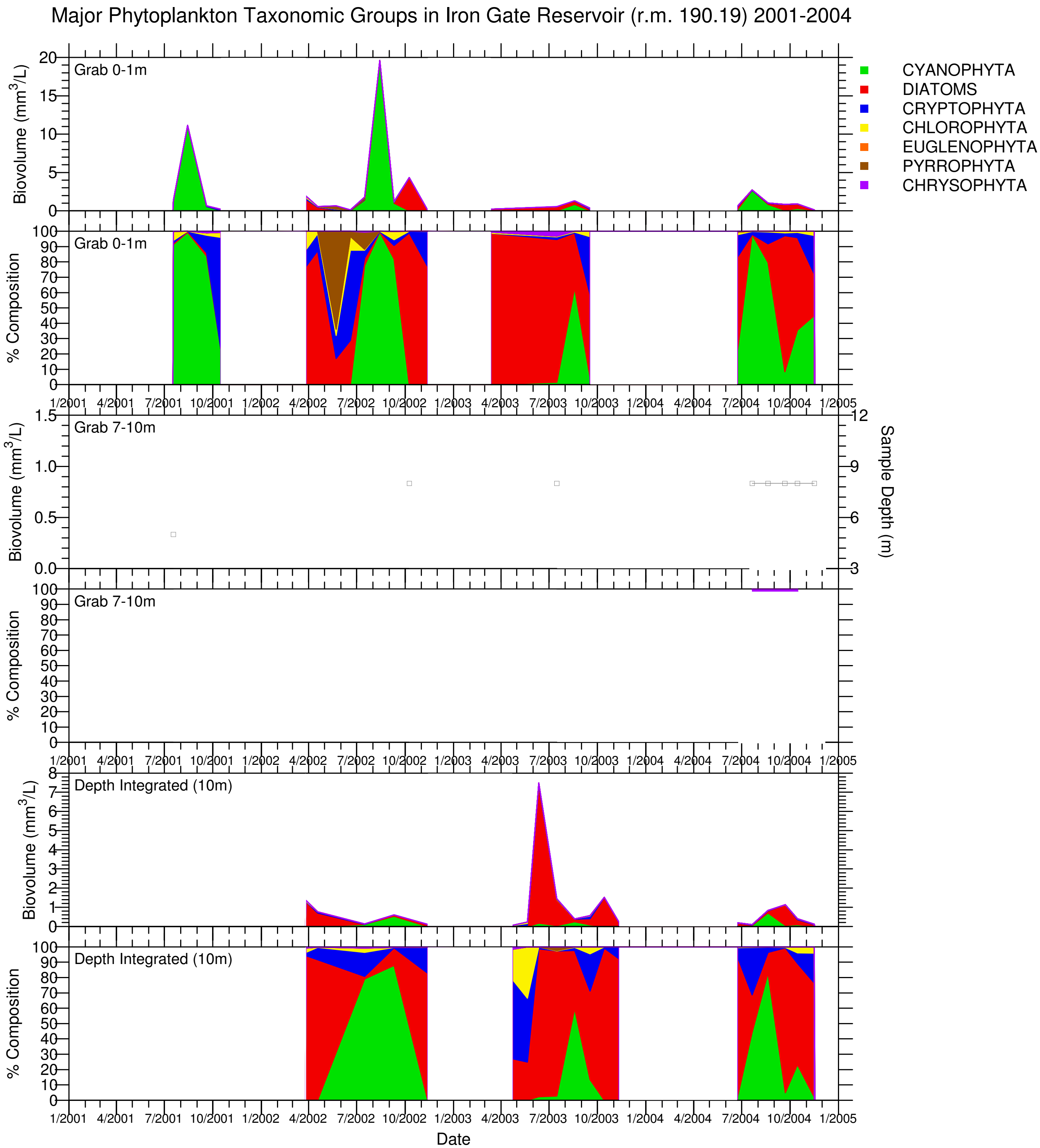


Figure 14. Biovolume and percent biovolume of major taxonomic groups of phytoplankton for samples collected in Iron Gate Reservoir in the years 2001-2003 (no samples collected in 2004). Each sampling depth is shown is a separate panel. A few samples were also collected at depth greater than 10m, but those samples are not shown here.

Species Composition

Seasonal trends for dominant species are shown for each station ordered longitudinally from UKL to the Klamath River above the Shasta River confluence in Figures 15-19. The intent of this section is not to provide detailed information on individual species, but rather to determine those species that comprise the major taxonomic groups described above in Figures 7-11. To improve graphical presentation, genera with more than one species observed were combined.

As discussed above, *Aphanizomenon* (APFA) is the major cyanophyte in water exiting UKL, often comprising >90% of the total Cyanophyta (Figure 15). There were also several incidences when *Microcystis aeruginosa* (MSAE) accounted for a small portion (<10%) of the cyanophyte biovolume leaving UKL. Moving downstream, APFA continues to dominate the Cyanophyta and MSAE is not noted again at considerable levels until Bel JC Boyle Dam (Figure 17). The seasonal APHA peak becomes more restricted as the river continues to the Keno and JC Boyle reaches (Figure 16), with increased summer dominance by *Cryptomonas* (e.g., CXER), *Cyclotella* , and *Melosira.* Spring and early-summer genera in this reach included the diatoms *Fragilaria*, *Stephanodiscus*, and *Asterionella.*

In the bypass reach Abv JCBPH (RM 220.4; Figure 17) where water is comprised mainly of spring inflow rather than reservoir or lake releases, the community was more diverse, and tended to be dominated by periphytic or attached diatom genera such as *Diatoma*, *Cocconeis*, *Gomphonema*, *Navicula*, and *Nitzschia*. Although this trend in increased periphytic diatoms continued to the Above Copco station (Abv Copco; RM 206.42), APFA again increased as water released from the JC Boyle Powerhouse mixed with water from the bypass reach.

Periphytic species then declined substantially and were replaced by more planktonic species in the Copco Iron Gate Reservoir complex (Figure 18). For example, APFA increased from 20.1% of the June-September biovolume above Copco to 70.8% of the biovolume in Copco Reservoir (Tables 4 and 5). Likewise, the second most dominant species in Copco reservoir for this period was MSAE (14.3%), a species that did not rank in the top ten dominant species above Copco, and was present at levels≤5% at upstream stations. Other planktonic genera that were periodically important in Copco Reservoir include the cyanophyte *Anabaena,* and the diatoms *Fragilaria* and *Stephanodiscus* (Figure 18). Below Copco, APFA decreased to 30.4% (RM 196.45; Table 4) and the period of APFA dominance was more restricted (Figure 18). In addition, diatoms increased in importance with *Nitzschia* and *Fragilaria* accounting for 32.4% of the biovolume on a seasonal basis (Table 4). In Iron Gate Reservoir, APFA again increased to 83% of the biovolume, with *Gloeotrichia* (GTEC)*,* another nitrogen-fixing blue-green, ranking second at 5.7% (Table 4). MSAE decreased in importance in Iron Gate Reservoir, but did show annual peaks in most years at the site below Iron Gate Dam (RM 189.73) where MSAE comprised 16.8% of biovolume in August 2004 and 6.7% in September 2004.

Seasonal patterns in the reservoirs generally included spring dominance by diatoms (e.g., *Stephanodiscus* and *Melosira*), summer dominance by the Cyanophyta (e.g., *Aphanizomenon*, *Microcystis,* and *Gloeotrichia*), and fall dominance by *Cryptomonas* and *Fragilaria* (Figure 18). Although limited by sampling frequency, there is an indication that 14-17 miles below Iron Gate Dam at both RM 176 and RM 173 that the periphytic diatom *Cocconeis* increases substantially in importance (Figure 18; Table 4).

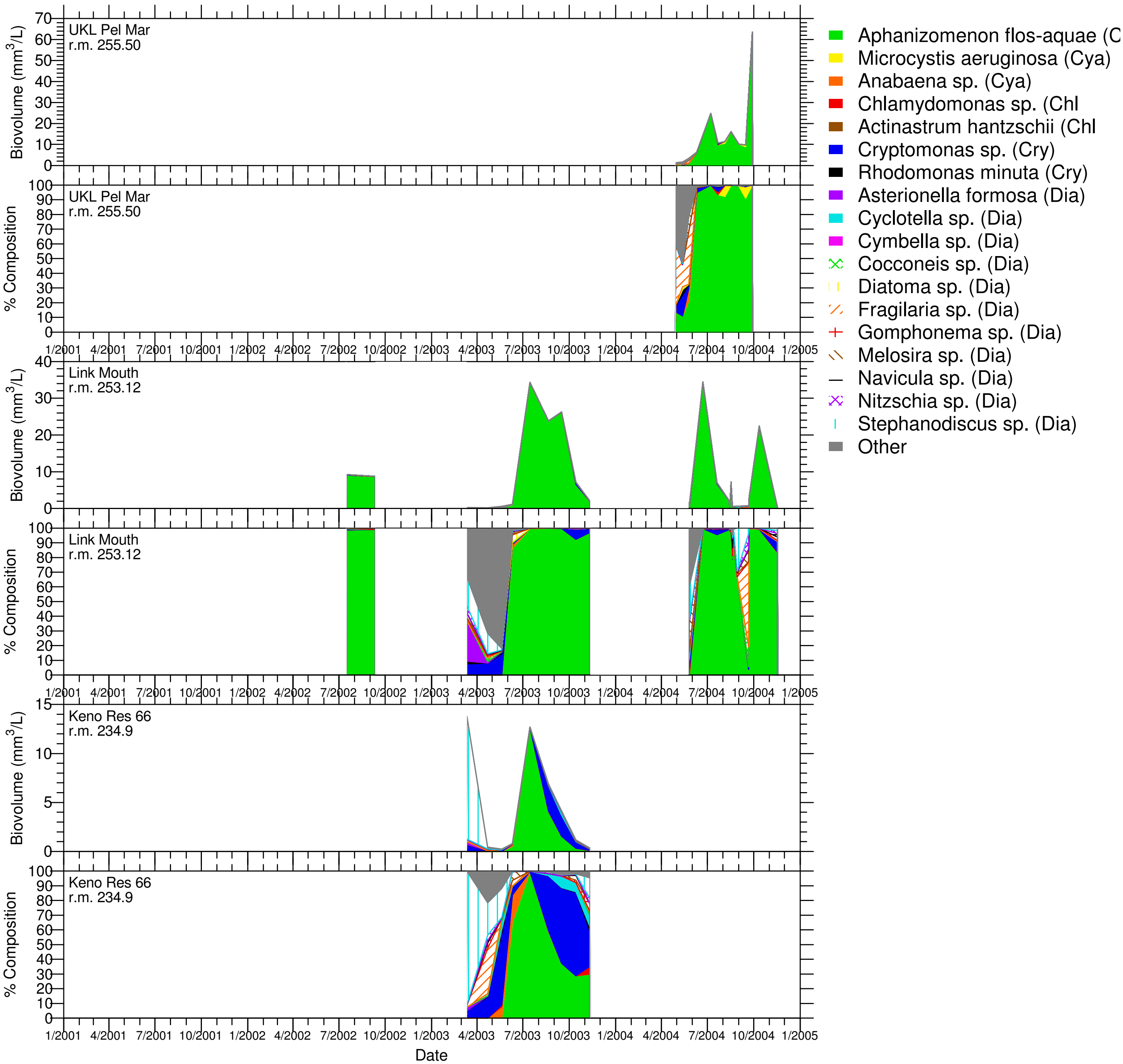


Figure 15. Biovolume and percent biovolume of dominant species of phytoplankton for surface samples collected in the years 2001-2004. Sites are listed in downstream order: Upper Klamath Lake at Pelican Marina, Link River at its mouth, and Keno Reservoir at the Highway 66 Bridge.

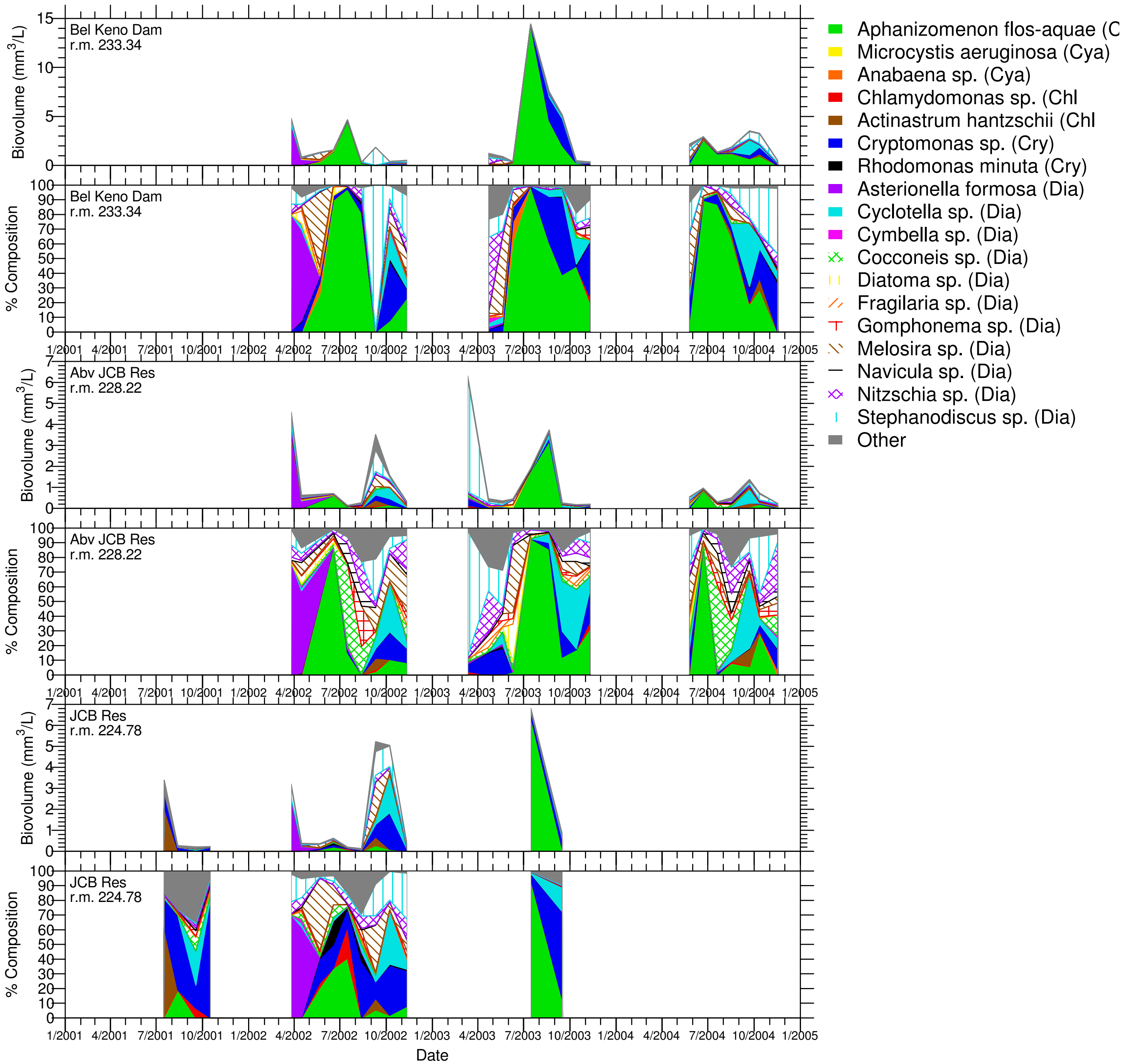


Figure 16. Biovolume and percent biovolume of dominant species of phytoplankton for surface samples collected in the years 2001-2004. Sites are listed in downstream order: Keno Dam, Above J.C. Boyle Reservoir, and J.C. Boyle Reservoir.

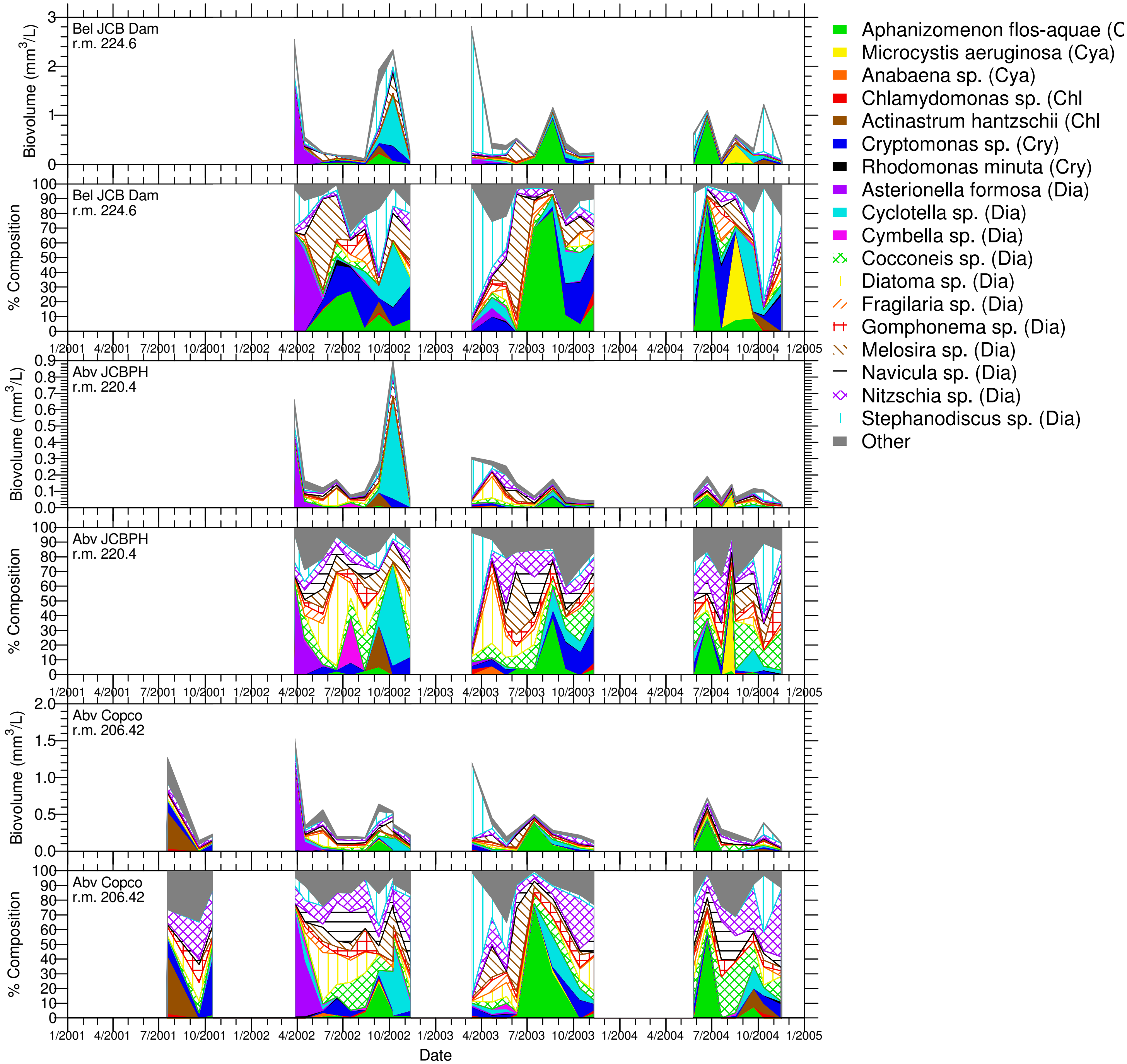


Figure 17. Biovolume and percent biovolume of dominant species of phytoplankton for surface samples collected in the years 2001-2004. Sites are listed in downstream order: Below J.C. Boyle Dam, Above J.C. Boyle Powerhouse, and Above Copco Reservoir.

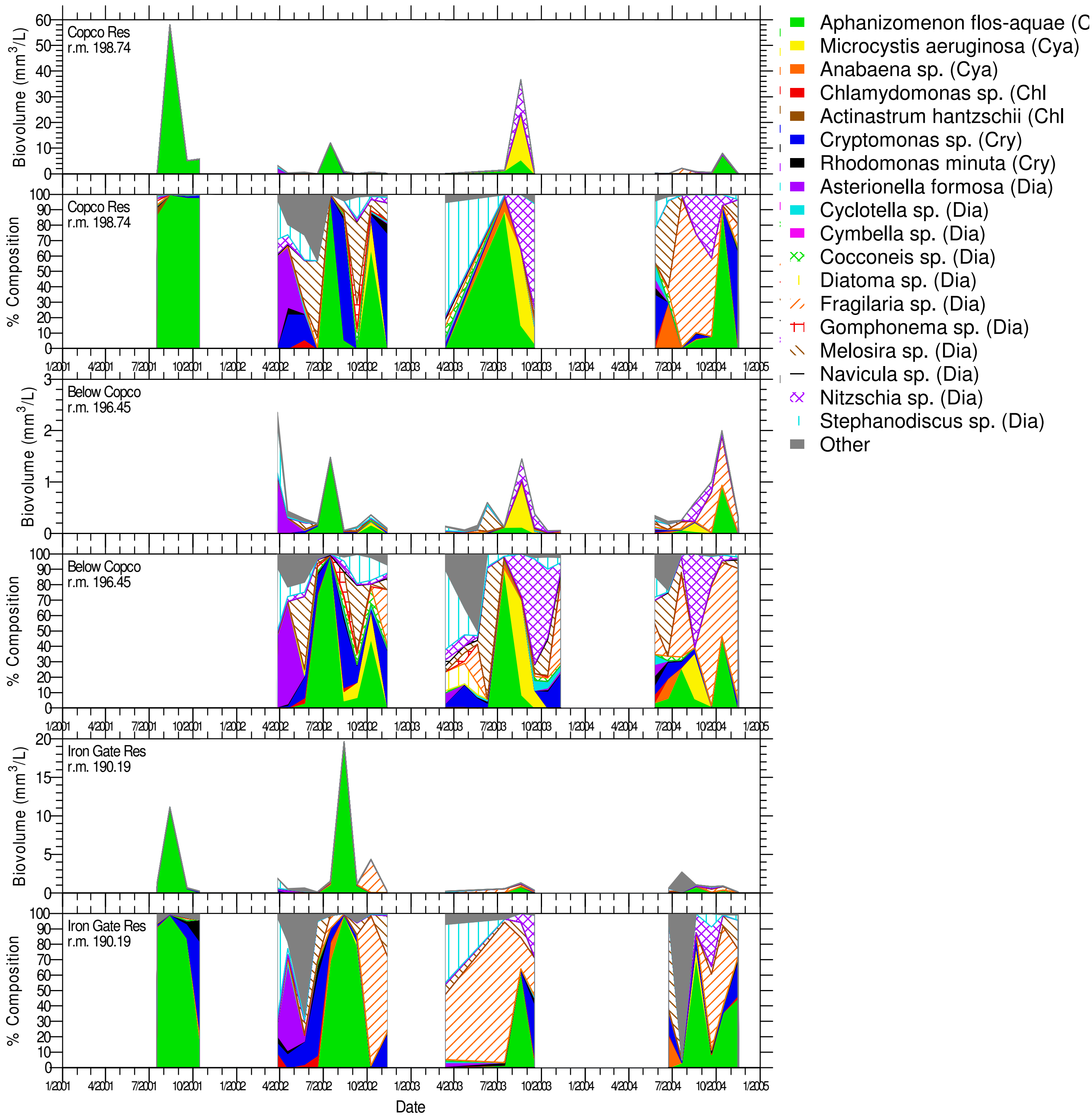


Figure 18. Biovolume and percent biovolume of dominant species of phytoplankton for surface samples collected in the years 2001-2004. Sites are listed in downstream order: Copco Reservoir, Below Copco Dam, and Iron Gate Reservoir.

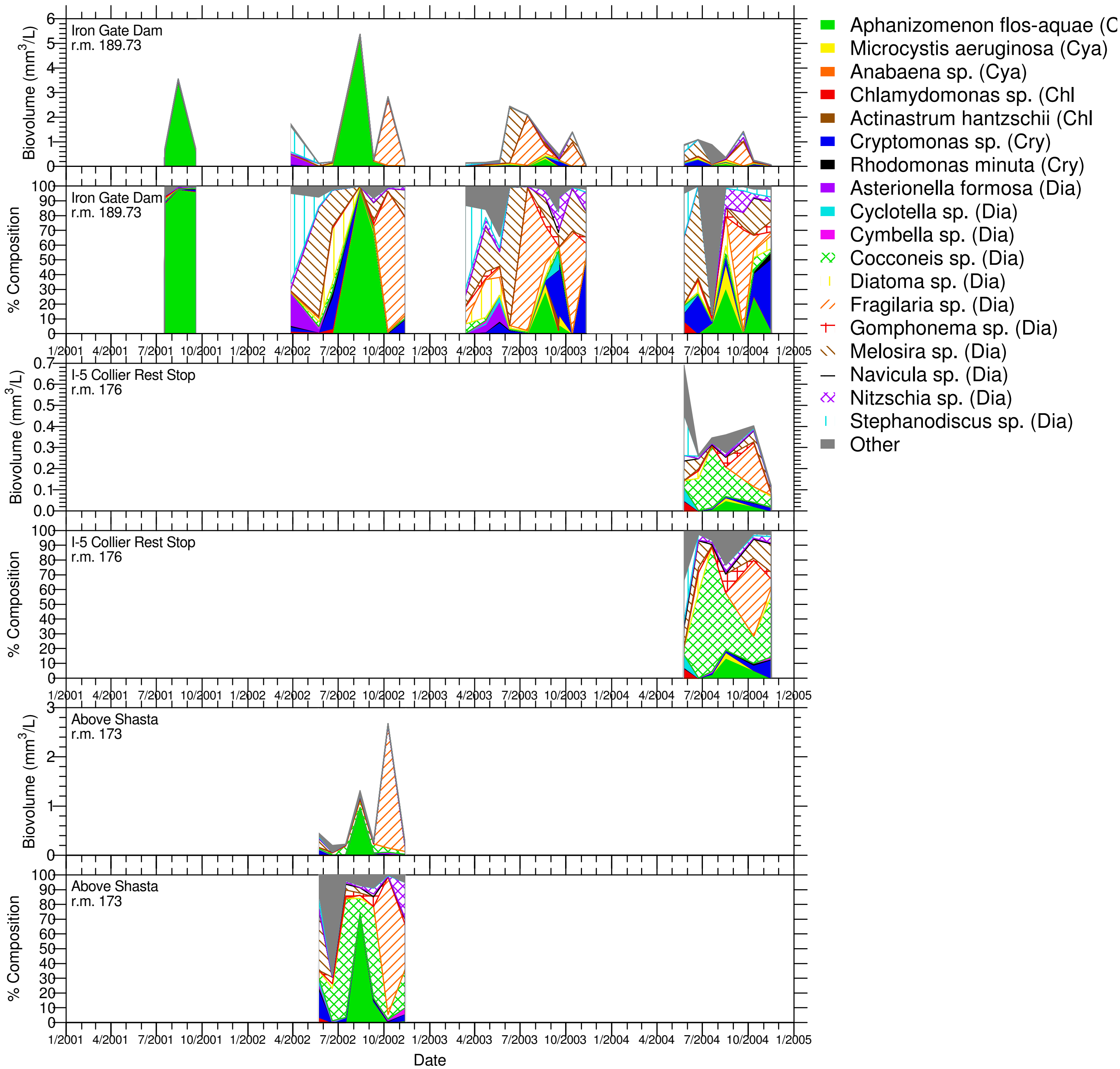


Figure 19. Biovolume and percent biovolume of dominant species of phytoplankton for surface samples collected in the years 2001-2004. Sites are listed in downstream order: Iron Gate Dam, Above the Shasta River, at the Interstate 5 Collier Rest Area.

Table 4. Biovolume for 10 most dominant species at each site, for surface samples collected in the years 2001-2004, June 1 – Sept 30. See Table 5 for a key to four-letter species codes.

				Species ranked by mean biovolume (mm³/L) for samples June 1 - Sept. 30										
River Mile	**Site Name**	**N**		**All**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
173/ 176	I-5 Shasta	7	Species		COPC	APFA	SNUL	EPSX	GFSB	DTVL	MLVR	OSXX	MLGR	RHCU
			Mean	0.4	0.1578	0.1519	0.0220	0.0188	0.0110	0.0101	0.0080	0.0068	0.0058	0.0048
			Percent		36.8%	35.4%	5.1%	4.4%	2.6%	2.4%	1.9%	1.6%	1.4%	1.1%
189.73	IG Dam	15	Species		APFA	FRCR	MLGR	GTEC	CXER	DTVL	NZPL	MLGA	COPC	MSAE
			Mean	1.4	0.7154	0.2200	0.2059	0.0501	0.0426	0.0248	0.0237	0.0185	0.0171	0.0112
			Percent		50.8%	15.6%	14.6%	3.6%	3.0%	1.8%	1.7%	1.3%	1.2%	0.8%
190.19	IG Res	15	Species		APFA	GTEC	FRCR	CXER	MLGR	NZPL	CJHR	MSAE	RDMN	MLGA
			Mean	3.0	2.4966	0.1724	0.0918	0.0456	0.0391	0.0322	0.0270	0.0080	0.0072	0.0049
			Percent		83.0%	5.7%	3.0%	1.5%	1.3%	1.1%	0.9%	0.3%	0.2%	0.2%
196.45	Bel Copco	12	Species		APFA	NZPL	MSAE	FRCR	MLAM	MLGR	MLGA	CXER	EDEL	STBI
			Mean	0.5	0.1653	0.0994	0.0941	0.0767	0.0261	0.0193	0.0144	0.0109	0.0044	0.0040
			Percent		30.4%	18.3%	17.3%	14.1%	4.8%	3.6%	2.7%	2.0%	0.8%	0.7%
198.74	Copco Res	16	Species		APFA	MSAE	NZPL	FRCR	CXER	CHXX	MLGR	CJHR	RDMN	COPC
			Mean	7.9	5.6065	1.1307	0.8561	0.2084	0.0538	0.0083	0.0069	0.0047	0.0040	0.0035
			Percent		70.8%	14.3%	10.8%	2.6%	0.7%	0.1%	0.1%	0.1%	0.1%	0.0%
206.42	Abv Copco	14	Species		APFA	ATHN	COPC	NVTP	DTVL	NZDS	CXER	RHCU	NZFR	STHN
			Mean	0.4	0.0763	0.0373	0.0320	0.0223	0.0207	0.0168	0.0166	0.0116	0.0105	0.0104
			Percent		20.1%	9.8%	8.4%	5.9%	5.5%	4.4%	4.4%	3.1%	2.8%	2.7%
220.40	Abv JCB PH	13	Species		DTVL	APFA	COPC	MLAM	MSAE	ATHN	NVTP	RHCU	CCMG	SNUL
			Mean	0.1	0.0146	0.0138	0.0112	0.0074	0.0065	0.0062	0.0059	0.0058	0.0054	0.0043
			Percent		11.4%	10.7%	8.7%	5.8%	5.0%	4.8%	4.6%	4.5%	4.2%	3.3%
224.60	Bel JCB Dam	12	Species		APFA	STHN	CCMG	MLAM	MSAE	CXER	MLGR	SNUL	SCQD	ATHN
			Mean	0.6	0.2092	0.0713	0.0402	0.0359	0.0307	0.0273	0.0217	0.0162	0.0154	0.0136
			Percent		36.6%	12.5%	7.0%	6.3%	5.4%	4.8%	3.8%	2.8%	2.7%	2.4%
224.78	JCB Res	9	Species		APFA	ATHN	CXER	STHN	MLAM	MLGR	CCMG	SCQD	SCAC	SFSR
			Mean	2.0	0.8004	0.2681	0.2570	0.1205	0.1138	0.0814	0.0619	0.0283	0.0257	0.0231
			Percent		40.7%	13.6%	13.1%	6.1%	5.8%	4.1%	3.2%	1.4%	1.3%	1.2%
228.22	Abv JCB Res	12	Species		APFA	CCMG	STHN	SNUL	MLAM	COPC	CXER	ATHN	MLGR	NVCV
			Mean	1.2	0.5575	0.1097	0.0922	0.0568	0.0452	0.0437	0.0369	0.0366	0.0277	0.0148
			Percent		47.2%	9.3%	7.8%	4.8%	3.8%	3.7%	3.1%	3.1%	2.3%	1.3%
233.34	Keno Dam	12	Species		APFA	CXER	STHN	CCMG	STBI	MLGR	NZPL	MLGA	RDMN	NZAC
			Mean	3.8	2.7610	0.4814	0.1934	0.1771	0.0258	0.0200	0.0163	0.0146	0.0102	0.0096
			Percent		72.5%	12.6%	5.1%	4.7%	0.7%	0.5%	0.4%	0.4%	0.3%	0.3%
253.12	Link Mouth	19	Species		APFA	FRCR	CXER	COPC	STAS	NZPL	GFSB	MLGR	STAM	DTVL
			Mean	8.6	8.5183	0.0224	0.0206	0.0091	0.0089	0.0086	0.0075	0.0057	0.0037	0.0029
			Percent		98.7%	0.3%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%
255.50	UKL Pel Mar	8	Species		APFA	MSAE	CXER	CHXX	CXOV	RDMN	KMXX	GDXX	MLGR	MGXX
			Mean	19.1	18.7380	0.2018	0.0580	0.0303	0.0182	0.0129	0.0120	0.0069	0.0058	0.0056
			Percent		98.1%	1.1%	0.3%	0.2%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%

Table 5. Key to four-letter species codes for most dominant phytoplankton species at sites listed in Table 4 for surface samples in years 2001-2004, with species listed in alphabetical order.

Species Code	Species Name	Major Taxonomic Group
APFA	*Aphanizomenon flos-aquae*	Cyanophyta
ATHN	*Actinastrum hantzschii*	Chlorophyta
CCMG	*Cyclotella meneghiniana*	Diatoms
CHXX	*Chlamydomonas sp*	Chlorophyta
CJHR	*Ceratium hirundinella*	Pyrrophyta
COPC	*Cocconeis placentula*	Diatoms
CXER	*Cryptomonas erosa*	Cryptophyta
CXOV	*Cryptomonas ovata*	Cryptophyta
DTVL	*Diatoma vulgare*	Diatoms
EDEL	*Eudorina elegans*	Chlorophyta
EPSX	*Epithemia sorex*	Diatoms
FRCR	*Fragilaria crotonensis*	Diatoms
GDXX	*Glenodinium sp*	Pyrrophyta
GFSB	*Gomphonema subclavatum*	Diatoms
GTEC	*Gloeotrichia echinulata*	Cyanophyta
KMXX	*Chromulina sp*	Chrysophyta
MGXX	*Mougeotia sp*	Chlorophyta
MLAM	*Melosira ambigua*	Diatoms
MLGA	*Melosira granulata angustissima*	Diatoms
MLGR	*Melosira granulata*	Diatoms
MLVR	*Melosira varians*	Diatoms
MSAE	*Microcystis aeruginosa*	Cyanophyta
NVCV	*Navicula cryptocephala veneta*	Diatoms
NVTP	*Navicula tripunctata*	Diatoms
NZAC	*Nitzschia acicularis*	Diatoms
NZDS	*Nitzschia dissipata*	Diatoms
NZFR	*Nitzschia frustulum*	Diatoms
NZPL	*Nitzschia palea*	Diatoms
OSXX	*Oscillatoria sp*	Cyanophyta
RDMN	*Rhodomonas minuta*	Cryptophyta
RHCU	*Rhoicosphenia curvata*	Diatoms
SCAC	*Scenedesmus acuminatus*	Chlorophyta
SCQD	*Scenedesmus quadricauda*	Chlorophyta
SFSR	*Sphaerocystis schroeteri*	Chlorophyta
SNUL	*Synedra ulna*	Diatoms
STAM	*Stephanodiscus astraea minutula*	Diatoms
STAS	*Stephanodiscus astraea*	Diatoms
STBI	*Stephanodiscus binderanus*	Diatoms
STHN	*Stephanodiscus hantzschii*	Diatoms

The overall longitudinal trend for individual species for the June-September period showed a declining trend in APFA from UKL to above Copco and a subsequent increase in Copco and Iron Gate Reservoirs (Table 4). As expected based on the trend in both nitrogen-fixing phytoplankton (NFP) and Cyanophyta described above, 85.1% of the biovolume in Copco reservoir surface stations was comprised of APFA and MSAE, and 88.7% was comprised of APFA and GTEC in Iron Gate Reservoir.

SUMMARY AND CONCLUSIONS

The purpose of this report was to provide an analysis of PacifiCorp's 2001-2004 phytoplankton dataset for the Klamath River from Upper Klamath Lake to above the Shasta River's confluence with the Klamath. Due to the importance of Upper Klamath Lake (UKL) to the Klamath River's nutrient and algal dynamics, phytoplankton data collected by the Klamath Tribes near the outlet of UKL were also used to provide a context for comparison.

Longitudinal trends for two time periods (all available sample dates and, then, June-September) showed the same basic trend of decreasing total phytoplankton biovolume, decreasing nitrogen-fixing phytoplankton (NFP) biovolume, and decreasing NFP percent composition from UKL to the station above Copco Reservoir. Downstream from this station these trends reverse as the river continues through the impounded areas of Copco and Iron Gate reservoirs, with total biovolume, NFP biovolume, and percent NFP all then increasing substantially, especially during the June-September period. The most pronounced change occurred in the upper 25th percentile (upper quartile) of the distribution, where compared to an NFP composition of 24.5% above Copco, reservoir NFP percent composition values returned to levels closer to those of UKL, exceeding 90% in both reservoirs. Thus, despite a decline in the downstream magnitude along the longitudinal profile between UKL and above Copco Reservoir, all parameters (total biovolume, NFP biovolume, and NFP percent biovolume) showed clear increases (by tens to hundreds of times) in the Copco/Iron Gate Reservoir complex during the June-September period.

Although not as pronounced as for the analyses of phytoplankton biovolume, the longitudinal trend in chlorophyll *a*, which provides an approximation of algal biomass, showed the same basic decreasing trend between UKL and above Copco Reservoir, and then increased (both median and upper quartile values) as the river traveled through the reservoir complex.

As expected as the system changed from the lacustrine environment of UKL to the riverine environment of the Klamath River, diatoms increased in prevalence downstream before decreasing again in the Copco/Iron Gate Reservoir complex as the Cyanophyta again dominated. Moreover, because Cyanophyta (blue-green algae) are comprised chiefly of algae from the NFP group, the longitudinal trend in both total biovolume and percent biovolume of the Cyanophyta was similar to that of NFP. The trend in Cyanophyta percent composition was more pronounced through the reservoir complex than absolute biomass, with levels in Copco and Iron Gate increasing from 5% above Copco to 50% and 82% in Copco and Iron Gate Reservoirs, respectively. Earlier analyses by Kann (2006) showed this same trend for *Microcystis aeruginosa,* a species that does not fix nitrogen, but that is a member of the Cyanophyta.

Consistently more pronounced trends in the upper quartile (UQ) relative to the median indicate that periodic high values or bloom events of NFP and Cyanophyta occurred in the reservoir complex relative to stations directly upstream.

Periodic multiple depth sampling in JC Boyle, Copco, and Iron Gate Reservoirs from 2001-2004 tend to indicate that the composition of diatoms increases relative to the surface samples, and as expected, based on the dilution of surface water where algae tend to be more concentrated, overall water column biovolume was substantially lower than surface samples in all three reservoirs. Although overall biovolume was lower in the depth-integrated samples, they showed a seasonal pattern of blue-green dominance similar to the surface samples. These samples indicate the buoyant nature of most Cyanophyta which tend to be concentrated near the surface. Thus, the Iron Gate Dam station (RM 189.73) which consists of water drawn from ~30-40 ft at the outlet of Iron Gate Reservoir, showed reduced composition of Cyanophyta, although relative to Abv. Copco, the levels were higher and the period of dominance was prolonged.

Aphanizomenon (APFA) was the major cyanophyte leaving UKL, decreasing in importance downstream to the bypass reach where the community was more diverse and tended to be dominated by periphytic or attached diatom genera such as *Diatoma*, *Cocconeis*, *Gomphonema*, *Navicula*, and *Nitzschia*. Periphytic species then declined substantially and were replaced by more planktonic species in the Copco/Iron Gate Reservoir complex with APFA increasing from 20.1% of the June-September biovolume above Copco to 70.8% of the biovolume in Copco Reservoir. The second most dominant species in Copco reservoir for this period was *Microcystis aeruginosa* (MSAE, 14.3%), a species that did not rank in the top ten dominant species above Copco, and was present at levels ≤5% at stations directly upstream. In Iron Gate Reservoir, APFA again increased to 83% of the biovolume, with *Gloeotrichia* (GTEC), another nitrogen-fixing blue-green, ranking second at 5.7%. MSAE decreased in importance in Iron Gate Reservoir, but did show annual peaks in most years at the site below Iron Gate Dam (RM 189.73) where MSAE comprised 16.8% of biovolume in August 2004 and 6.7% in September 2004.

The overall longitudinal trend for phytoplankton biovolume and important nitrogen-fixing and bloom forming species all confirm the same declining trend from UKL to above Copco Reservoir, with a subsequent increase in the Copco/Iron Gate Reservoir complex.

These results are similar to the analysis of the PacifiCorp dataset for MSAE only (Kann 2006), where analyses showed increased incidence and magnitude of MSAE in Copco and Iron Gate Reservoirs relative to stations upstream. Although MSAE is not a nitrogen–fixing species, it is an important member of the Cyanophyta. As stated in Kann (2006) and Kann and Corum (2006) this trend of increasing Cyanophyta is consistent with literature showing that MSAE and other buoyant cyanobacteria such as APFA do not dominate in river conditions of turbulent mixing such as that known to occur in the Klamath River above Copco and Iron Gate Reservoirs. Because cyanophytes tend to thrive at low turbulent diffusivity (calm-stable conditions) when their flotation velocity exceeds the rate of turbulent mixing, they are favored in lake and reservoir environments that tend to be warmer and less turbulent than riverine ones (Reynolds 1986).

In conclusion, these analyses show that although the Klamath River receives a large loading of algal biomass (made up largely of the cyanophyte, APHA) from UKL, the analyzed data provide clear evidence that Copco and Iron Gate Reservoirs are providing habitat conditions that foster increased overall phytoplankton biovolume comprised largely of nitrogen-fixing cyanophyte species as well as toxigenic MSAE. The relative increase in nitrogen-fixing species is important ecologically because these species have the potential to introduce additional nitrogen into the Klamath River system. Although nitrogen increases from algal fixation are not separable from reservoir sediment loading of nitrogen, nutrient budgets in Copco and Iron Gate Reservoirs for the year 2002 indicated that the reservoirs can act as both sources and sinks for nitrogen during the algal growing season (Kann and Asarian 2005).

Thus, this analysis underscores the need to account for reservoir hydrologic and nutrient alterations that foster increased phytoplankton growth in the Klamath River. Evaluation of impaired water quality due to hydrologic alterations attributable to the Klamath Hydroelectric Project should include such reservoir alterations as increased water retention time, higher water column stability, and internal sediment loading of nutrients. Although upstream loading of nutrients and algae are important, alterations to the river such as these can contribute to a further increase in algal production, especially of blue-green algal blooms.

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ELECTRONIC APPENDICES ON CD

A. Spreadsheet of PacifiCorp 2001-2004 phytoplankton data.