1998 ANNUAL REPORT, PART B.
LAKE ROOSEVELT FISHERIES EVALUATION PROGRAM LIMNOLOGY, PRIMARY PRODUCTION, AND ZOOPLANKTON IN LAKE ROOSEVELT, WASHINGTON.

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EXECUTIVE SUMMARY

The Lake Roosevelt Fisheries Evaluation Program is the result of a merger between two projects, the Lake Roosevelt Monitoring Program (BPA No. 8806300) and the Lake Roosevelt Data Collection Project (BPA No. 9404300). These projects were merged in 1996 to continue work historically completed under the separate projects, and is now referred to as the Lake Roosevelt Fisheries Evaluation Program.

The 1998 Annual Report, Part B. Limnology, Primary Production, and Zooplankton in Lake Roosevelt, Washington examined the limnology, primary production, and zooplankton at eleven locations throughout the reservoir. The 1998 research protocol required a continuation of the more complete examination of limnological parameters in Lake Roosevelt that began in 1997. Phytoplankton and periphyton speciation, phytoplankton and periphyton chlorophyll *a* analysis, complete zooplankton biomass analysis by taxonomic group, and an increased number of limnologic parameters (TDG, TDS, etc.) were examined and compared with 1997 results.

Total dissolved gas levels were greatly reduced in 1998, compared with 1997, likely resulting from the relatively normal water year experienced in 1998. Mean water temperatures were similar to what was observed in past years, with a maximum of 22.7 °C and a minimum of 2.6 °C. Oxygen concentrations were also relatively normal, with a maximum of 16.6 mg/L, and a minimum of 0.9 mg/L.

Phytoplankton in Lake Roosevelt was primarily composed of microplankton (29.6 %), Cryptophyceae (21.7 %), and Bacillriophyceae (17.0 %). Mean total phytoplankton chlorophyll *a* maximum concentration occurred in May (3.53 mg/m^3), and the minimum in January (0.39 mg/m^3). Phytoplankton chlorophyll *a* concentrations appear to be influenced by hydro-operations and temperature. Trophic status as indicated by phytoplankton chlorophyll *a* concentrations place Lake Roosevelt in the oligo-mesotrophic range. Periphyton colonization rates and biovolume were significantly greater at a depth of 1.5 m (5 ft) when compared with a 4.6 m (15 ft) depth, and during the shorter incubation periods (two and four weeks).

Mean zooplankton densities were greatest for Copepoda (88 %), then *Daphnia* spp. (10 %) and other Cladocera (2.1 %), while the zooplankton biomass assessment indicated *Daphnia* spp. had the greatest biomass (53.6 %), then Copepoda (44.0 %) and other Cladocera (2.5 %). Mean total zooplankton densities were the lowest observed since 1991. The cause was unclear, but may have been an artifact of human error. It seems unlikely that hydro-operations played a significant part in the reduction of zooplankton in light of the relatively friendly water year of 1998.

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1.0 INTRODUCTION

The Lake Roosevelt Monitoring / Data Collection Program (LRMP) is the result of a merger between the Lake Roosevelt Monitoring Program (BPA No. 8806300) and the Lake Roosevelt Data Collection Project (BPA No. 9404300). These projects were merged in 1996 due to overlapping support staff and data requirements. The LRMP continues work historically completed under the separate projects and will develop a biological rule curve for Lake Roosevelt.

1.1 Project and Data Collection History

Prior to the completion of the Grand Coulee Dam project in 1941, the portion of the Columbia River that is now Lake Roosevelt was once a major spawning area for anadromous fish, principally steelhead (*Onchorhynchus mykiss*) and Chinook salmon (*Onchorhynchus twshwastica*). Now, anadromous fish have been eliminated from the region, but resident game fish populations have been established and are now responsible for attracting a large percentage of the recreational visits to the reservoir. This increase in popularity has placed Lake Roosevelt fifth amongst the most visited State and Federal parks in Washington (Washington State Data Book, 1991). Increased use of the reservoir spawned efforts to enhance the resident sport fishery by hatchery supplementation of rainbow trout (*Oncorhynchus mykiss*) and kokanee salmon (*Oncorhynchus nerka*) which began in 1984. This was followed by the formation of the Spokane Tribal Lake Roosevelt Monitoring Project (LRMP) in 1988 and later by formation of the Lake Roosevelt Data Collection Project in 1991.

The LRMP has two main goals. The first is to collect baseline data to model biological responses to varying reservoir operation strategies. The biological model seeks to identify lake operations that minimize impacts to lake biota while addressing the needs of other interests (e.g. flood control, power generations, and anadromous fisheries). Major components of the model will include: 1) quantification of entrainment and other impacts to phytoplankton, zooplankton and fish caused by reservoir drawdowns and low water retention times; 2) quantification of seasonal distributions and standing crop of fish food organisms in the reservoir; and 3) examination of variations in fish growth in relation to reservoir operations, prey abundance and prey utilization.

The second goal of the LRMP is to evaluate the impacts of hatchery kokanee salmon (*Oncorhynchus nerka*) and rainbow trout (*Oncorhynchus mykiss*) on the ecosystem as well as determine stocking strategies that maximize angler harvest and return of adult kokanee salmon to egg collection facilities. Major tasks of the hatchery evaluation portion of the project include conducting a year round reservoir wide creel survey, sampling the fishery during spring, summer and fall via electro-fishing and gillnet surveys, and collecting information on diet, growth, and age composition of various fish species in Lake Roosevelt. Data was also collected to determine food availability and utilization by fish, and angler use information.

Long term monitoring by the LRMP and others has underlined the importance of zooplankton communities in supporting viable populations of resident sport fish within the reservoir (Beckman et al. 1985; Peone et al. 1990; Underwood et al. 1997; Cichosz et al. 1999). The zooplankton community of Lake Roosevelt forms a critical link between phytoplankton and secondary consumers. In particular, cladoceran zooplankton comprise a substantial portion of the diets of many Lake Roosevelt fishes including: kokanee salmon, rainbow trout, mountain whitefish (*Prosopium williamsoni*), lake whitefish (*Coregonus clupeaformis*), largescale sucker (*Catostomus macrocheilus*), smallmouth bass (*Micropterus dolomieui*), walleye (*Stizostedion vitreum*) and yellow perch (*Perca flavescens*; Beckman et al. 1985; Cichosz et al. 1999). Zooplankton populations in Lake Roosevelt are monitored to determine available biomass for fish food and to assist with modeling efforts.

Crustacean zooplankton abundance in Lake Roosevelt is comparable to other regional lakes of similar trophic status (Jagielo 1974). Extensive sampling of the zooplankton community in the reservoir since 1988 indicates that peak zooplankton densities occur during periods of highest water temperature and longest water retention times (Stober et al. 1981; Nigro et al. 1982, 1983; Cichosz, 1999). Studies suggest that zooplankton productivity in Lake Roosevelt is influenced by drastic and frequent reservoir drawdowns, which increase current velocities and reduce water retention times (Cooper and Black, 1999). Low water retention times have been associated with decreased zooplankton abundance (Beckman et al. 1985) leading to the recommendation that a 30 day minimum water retention time be established to maintain adequate zooplankton standing crops (Griffith and Scholz 1991).

1.2 Description of Study Area

Lake Roosevelt is a mainstem Columbia River impoundment formed by the completion of Grand Coulee Dam in 1941 (Figure 1.1). The reservoir at full pool elevation of 393 m inundates 33,490 hectares with a storage capacity of 1.16 x 10^{10} m^3, and a maximum depth of 122 meters (Nigro et al. 1981). Lake Roosevelt is the largest lake in Washington, the sixth largest reservoir in the U.S., and one of the largest artificial lakes in the world (Johnson et al. 1991). Grand Coulee Dam is the largest producer of hydropower in the United States and the third largest in the world, generating $462 million in power in 1994 (Grand Coulee Dam Information Center 1998). Grand Coulee Dam is a Bureau of Reclamation storage project operated primarily for power, flood control, and irrigation with secondary operations for recreation, fish, and wildlife. The Lake Roosevelt watershed drains a wide range of ecological habitat types including the steppe-shrub desert of central Washington; the agricultural/urban areas of the Spokane and Colville River valleys; the ponderosa pine (*Pinus ponderosa*) forests of the inter-mountain plateau; and the western snow pack of the Rocky Mountains (Wilson 1996). Major tributaries to Lake Roosevelt include the Columbia, Spokane, and Kettle Rivers, which contribute an average of 89, 7, and 3 percent of the inflow volumes to the lake respectively (Stober et al. 1981).

Flood control operations at Grand Coulee Dam annually reduce reservoir water levels by up to 24 m between January and June to create room for peak spring flows. Spring drawdown events decrease the volume of the reservoir by an average of 55 % and its surface area by 45 % annually (Beckman et al. 1985). Full pool elevation (393 m) is usually achieved by early July coinciding with the Fourth of July weekend (Nigro et al. 1981).

More recently, Lake Roosevelt has experienced an August drawdown of three-meters to facilitate anadramous fish migration through the lower Columbia and Snake Rivers.
In 1980, primary production values revealed the trophic status of the reservoir to be mesotrophic to slightly eutrophic (Stober et al. 1981). However, data obtained in 1997 indicated Lake Roosevelt maybe more oligotrophic than previously determined (Wierenga et al. 1997). A reduction in reservoir nutrient loading is thought to have caused the changes in trophic status through declines in phytoplankton abundance. Recent reductions in industrial effluents into the Columbia River, mainly from the British Columbia based Cominco, Ltd. lead-zinc smelter and fertilizer plant, along with the Celgar Pulp Co. mill, are believed to have significantly reduced reservoir nutrient loading (Sheehan and Lamb 1987, Johnson et al. 1988, Kenyon and Glover 1994).

Previous annual reports for the Lake Roosevelt Data Collection Project include Griffith et al. (1995), Griffith and McDowell (1996), Voeller (1996), Shields and Underwood (1996 and 1997), and Cichosz et al. (1998). Previous reports for the Lake Roosevelt Monitoring Program include Peone et al. (1990), Griffith and Scholz (1991), Griffith et al. (1995), Underwood and Shields (1996), Underwood et al. (1996 and 1997) and Cichosz et al (1998 and 1999).

1.3 1998 Study Objectives

Objectives of the Lake Roosevelt Fisheries Evaluation Project in regards to the limnology of Lake Roosevelt were to:

1) Collect hydrology data for Lake Roosevelt.

2) Collect zooplankton biomass, density, and length data at eleven locations throughout Lake Roosevelt.

3) Collect limnological data at eleven locations throughout Lake Roosevelt including temperature, dissolved oxygen (mg/L and percent), conductivity, turbidity, pH, oxidation – reduction potential, and total dissolved gas.

4) Collect primary production data, including speciation and chlorophyll *a* for phytoplankton and periphyton throughout Lake Roosevelt.

5) Maintain complete databases to be used in the development and validation of the Lake Roosevelt water quality model.

6) Examine interactions between parameters to improve the overall understanding of the reservoir within 1998, and between years to monitor changes in the reservoir over time.

7) Participate in management decisions for the Lake Roosevelt fishery.

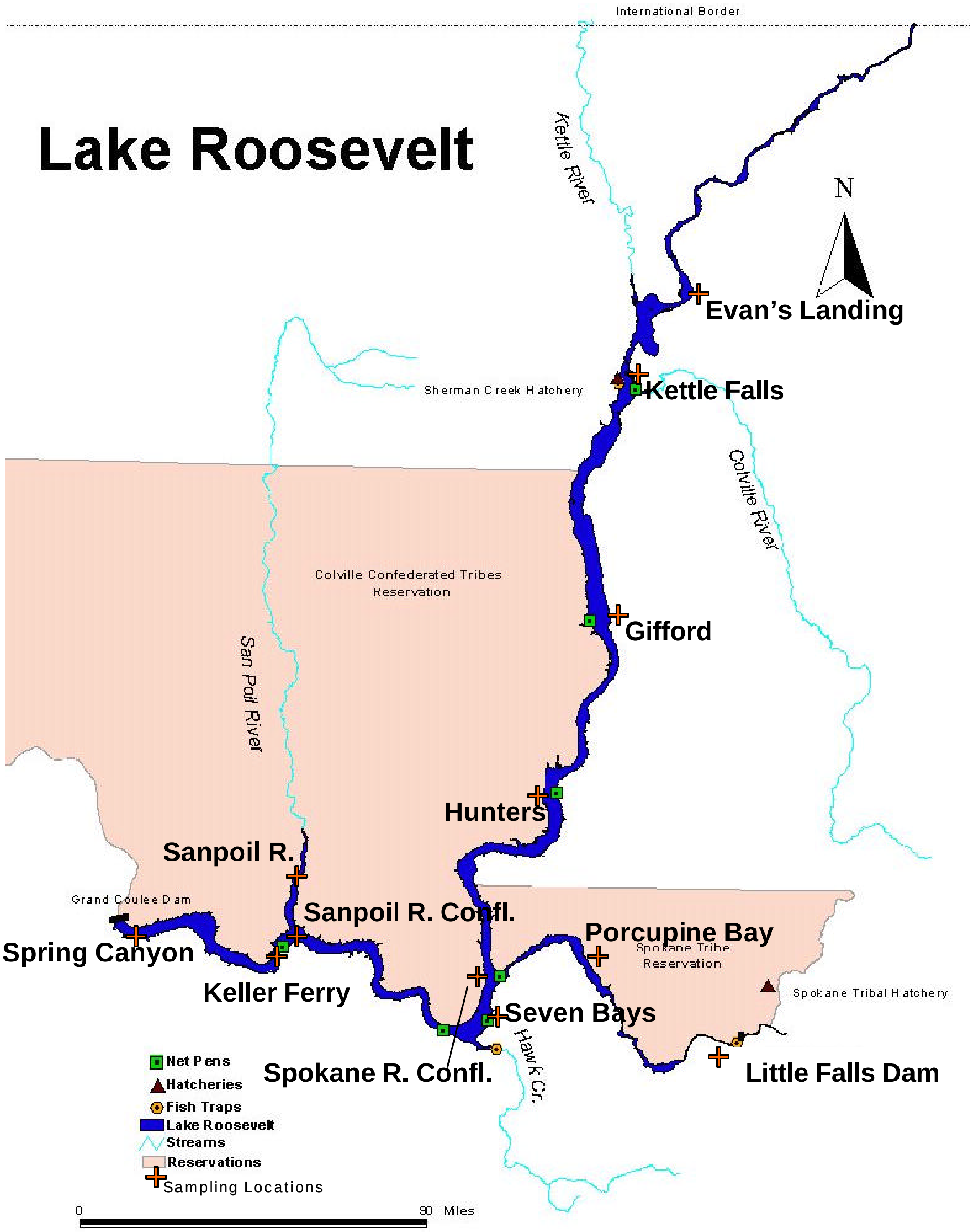

Figure 1.1 Map of Lake Roosevelt, Washington showing 1998 sampling locations.

MATERIALS AND METHODS

2.1 Reservoir Operations

Water retention time data were calculated from daily midnight reservoir elevations (ft) and total outflows in thousand cubic feet per second per day (kcfs). Reservoir elevation and total outflow values were obtained from the internet at the web site DART River Environment (address: *http://www.cqs.washington.edu./dart/river.html.*). Reservoir elevation was converted to volume of water stored (kcfsd) using a reservoir water storage table (USACE 1981), and daily water retention time was then calculated as reservoir volume divided by outflow.

2.2 Reservoir Water Quality

Physical measurements of water temperature, dissolved oxygen, conductivity, pH, oxidation – reduction potential, turbidity, total dissolved solids, percent oxygen saturation, and total dissolved gas were recorded from the pelagic zone using a Hydrolab Surveyor 4 at twelve sites throughout Lake Roosevelt in 1998. Hydrolab measurements were collected once per month in January, February, November and December and twice per month during March and May through October. Water quality sampling was not conducted in April. Hydrolab data were collected from the surface to a depth of 33 m in 3 m intervals at Evan's Landing (Location 0), Kettle Falls (Location 1), Gifford (Location 2), Hunters (Location 3), Porcupine Bay (Location 4), the confluence of the Spokane and Columbia Rivers (Location 5.5), Seven Bays (Location 6), Keller Ferry (Location 7), above the confluence of the Sanpoil and Columbia Rivers (Location 8.5), Sanpoil River (Location 8), and Spring Canyon (Location 9; Figure 1.1). Additional Hydrolab measurements were taken from 33 m to 90 m at Keller Ferry and Spring Canyon to characterize deep areas of the lower reservoir.

Water samples for laboratory analyses were collected from the euphotic zone at each site using an integrated sampling tube. Euphotic zone depths were estimated using a Kahl Scientific Instruments Model 268WD305 underwater irradiameter. Euphotic zone depths were defined as the portion of the water column extending from the surface to a depth where one percent of ambient surface light penetrates (Goldman and Horne 1983).

2.3 Primary Production

Spatial and temporal trends in primary production within Lake Roosevelt were investigated by conducting phytoplankton and chlorophyll *a* analyses of the euphotic zone. Phytoplankton samples were collected at eleven sites (Figure 1.1) twice per month during March and May through October. During the months of January, February, November and December, samples were collected once per month. Phytoplankton samples were not collected in April. Phytoplankton samples were collected using an integrated sampling tube to collect a column of water from the surface to the bottom of the euphotic zone. Phytoplankton samples were preserved with Lugol's solution and shipped to the Water Research Center at Eastern Washington University for speciation, enumeration, and estimation of biovolumes.

Chlorophyll *a* measurements were conducted at eleven standardized locations twice per month from March through October and once per month in January, February, November and December. Chlorophyll *a* samples were not collected in April. Chlorophyll *a* concentrations were calculated using a Turner Designs Model 10-AU field fluorometer calibrated monthly to known chlorophyll *a* concentrations. Chlorophyll *a* values at each site / date were determined for three depths within the euphotic zone; 0.5 m below the surface, the mid point of the euphotic zone and 0.5 m above the bottom of the euphotic zone.

Periphyton colonization rates were monitored from mid July through mid September 1999 in embayment habitats near Gifford, Porcupine Bay, Seven Bays and Spring Canyon. Periphyton was allowed to colonize glass microscope slides suspended at depths of 1.5 m (5 ft) and 4.6 m (15 ft) below the surface. Four colonization periods were examined including three of 2 week duration, one of 4 week duration (mid-July through mid-August), one of 6 week duration (mid-July through late August) and one of 8 week duration (mid-July through mid-September). Slides were collected and frozen following each colonization period and sent to the Water Research Center at Eastern Washington University for speciation, enumeration, biovolume estimation, and chlorophyll *a* concentration determination.

2.4 Zooplankton

Consistent with previous years, zooplankton samples were collected from the pelagic zone of each sampling location twice per month during March and May through October and once per month in January, February, November and December (Figure 1.1). Samples were not collected in April. From January through August, three vertical Wisconsin zooplankton tows were taken in the pelagic zone of each sampling location from a depth of 33 m to surface (when possible). In cases where sampling location depths were less than 33 m, zooplankton tows were taken from 1 m above the bottom to the lake surface. All zooplankton samples collected in 1998 were obtained using a 20 cm diameter, 80 µm mesh Wisconsin plankton net fitted with a high efficiency sampling collar (Aquatic Resource Incorporated).

Assuming 100 % filtering efficiency, each 33 m tow filtered approximately 1,036 liters of reservoir water. Zooplankton collected from each tow were rinsed onto a 63 µm mesh screen (to remove excess water) and flash killed for one minute in 95 % ethanol to ensure maximum egg retention. Collected organisms were then rinsed into a 60 ml polyethylene sample bottle using 70 % ethanol for preservation and analysis.

In the laboratory, zooplankton samples were sorted, counted, and identified to species or lowest practical taxon using taxonomic keys by Brooks (1957), Edmondson (1959), Pennak (1989), and Thorp and Covitch (1991). In cases where organism densities were too high to count directly, sub-samples were taken using a Motodo 1.5 liter plankton splitter. High-density zooplankton samples were split until approximately 100 organisms of the most prevalent species remained in the sub-sample. Organism lengths were taken from the first 20 individuals of a particular species and from all egg carrying females using a Leica MZ-8 dissecting microscope fitted with an optical micrometer. Upon obtaining 20 length measurements by species, all remaining non-gravid individuals were counted. Organism lengths for Branchiopoda (i.e. *Daphnia* and other cladocera) were taken from the anterior most region of the head to the posterior base of the carapace. Organism lengths for copepod taxa were taken from the anterior most region of the head to the base of the caudal ramus.

Zooplankton length, density, and biomass were calculated for individual tows and the results of replicate tows were combined to derive average values by location and date. Zooplankton densities were calculated through the incorporation of two equations. First, the volume of water sampled by the plankton net was calculated according to the equation:

$$V = \pi r^2 h$$

Where:

V = volume of water sampled (liters);
π = pi (3.14);
r = radius of the sample net (cm); and
h = depth of the sample (m).

Second, the number of zooplankton per cubic meter of water sampled was calculated using the equation:

$$D = ((TC*SF)/V)*1000$$

Where:

D = organism density (#/m^3);
TC = total organisms measured and counted;
SF = the split fraction of original sample analyzed; and
V = volume of water sampled (liters).

Zooplankton biomass was determined for each species using the length to dry weight regressions of Dumont et al. (1975) and Bottrell et al. (1976) as summarized by Downing and Rigler (1984; Table 2.1). Dry weight estimates for observed zooplankton species were calculated using the equation:

$$W = e^{a + b \ln (L)}$$

Where:

W = dry weight estimate (µg) for each species;
a = the slope intercept constant;
b = the slope constant of the regression line; and
L = length measurement (µm) for each individual.

Table 2.1 **Slope (b) and intercept (ln a) values used to estimate dry weights for 1998 Lake Roosevelt zooplankton samples.**

ZOOPLANKTON SPECIES	ln *a*	*b*
CLADOCERA		
Daphnia schødleri [a]	**2.30**	**3.10**
Daphnia pulex [a]	**1.59**	**2.77**
Daphnia retrocurva [a]	**1.4322**	**3.129**
Daphnia galeata mendotae [a]	**1.51**	**2.56**
Daphnia thorata [a]	**1.51**	**2.56**
Juvenile *Daphnia* [b]	**2.45**	**2.67**
Ceriodaphnia quadrangula [a]	**2.5623**	**3.338**
Bosmina longirostris [a]	**3.28**	**3.13**
Sida crystalina [a]	**2.0539**	**2.189**
Alona quadrangularis [a]	**2.8713**	**3.079**
Diaphanosoma brachyrum [a]	**1.6242**	**3.0468**
Diaphanosoma birgei [a]	**1.6242**	**3.0468**
Leptodora kindtii [a]	**-0.822**	**2.670**
Polyphemus pediculus [a]	**2.7792**	**2.152**
Chydorus sphaericus [a]	**4.543**	**3.636**
COPEPODA		
Epischura nevadensis [c]	**0.0077**	**2.33**
Leptodiaptomus ashlandi [c]	**0.0077**	**2.33**
Diacyclops bicuspidatus thomasi [c]	**1.10**	**2.59**
Mesocyclops edax [c]	**1.10**	**2.59**
Harpacticoid spp. [c]	**12.51**	**4.40**
Unknown Cyclopoid copepodids [c]	**1.10**	**1.89**
Calanoid/cyclopoid nauplii [c]	**1.10**	**1.89**

References: [a] = Downing and Rigler, 1984; [b] = Bottrell et al., 1976 and [c] = Dumont et al., 1975.

3.0 RESULTS AND DISCUSSION

3.1 Reservoir Operations and Hydrology

Grand Coulee Dam is a Bureau of Reclamation storage project commissioned by congress to operate primarily for power generation, flood control, and irrigation with secondary operations for recreation, fisheries, wildlife and navigation. Reservoir operations differ across years and seasons in order to accommodate the needs of a variety of stakeholders (Table 4.1). Slightly below normal annual precipitation forecasts resulted in less severe spring flood control operations than in recent years (Blue Book 1998). Mean monthly inflow ranged from a minimum of 69.8 kcfs in October to a maximum of 150.0 kcfs in June. Mean monthly outflow ranged from a minimum of 65.5 kcfs in October to a maximum of 142.6 in June (Table 3.1). Minimum reservoir elevation (1,52.3 feet) for 1998 occurred on March 4 (1,52.3 feet) and the maximum reservoir elevation (1,289 feet) occurred on June 21 (Figure 3.2). Monthly mean water retention time ranged from 26.7 days in February to 68.3 days in October (Table 3.3). Water retention time averaged more than 30 days in every month of 1998 except February (26.7 days; Table 3.3). Annual mean inflow (105.3 kcfs), outflow (101.8 kcfs), water retention time (45.1 days), and water elevation (1276.3 ft.) for 1998 were very near the eight-year means (1991-1998) of 111.7 kcfs, 107.4 kcfs, 44.1 days, and 1,275.5 ft. respectively (Table 3.3).

Reservoir operations in January and February were predominantly controlled by power production and flood control resulting in a steady decrease in elevation. Reservoir operations aimed at meeting refill objectives for Lake Roosevelt and flow targets defined by the National Marine Fisheries Service Biological Opinion in concert with near average spring runoff had Lake Roosevelt refilled to near full pool elevation (1,290 ft.) by mid-June. From mid-July through early September, Lake Roosevelt was drawn down approximately 10 ft to augment flows for anadromous fish migrations in the lower Columbia basin. Elevations were maintained above 1,280 ft from early September through mid-November to facilitate kokanee spawning and adult kokanee collection. Reservoir operations were again controlled by power generation in December, marked by increased mean outflow, decreased mean water retention time, and a decrease in mean elevation (Table 3.1).

Reservoir operations have a magnitude of effects on the biota within Lake Roosevelt. Outflow was found to account for 80 percent of the variance in estimated water retention time(s) in Lake Roosevelt (Cichosz et al. 1999). Water retention times have previously been linked to entrainment of fishes from Lake Roosevelt (Griffith et al. 1995). Extensive manipulation of outflow influences the water retention time as well as reservoir elevation, affecting all trophic levels through littoral habitat destruction and entrainment of fish, zooplankton, and nutrients from Lake Roosevelt.

Table 3.1 **Monthly and annual mean reservoir inflow, outflow, spill, elevation, storage capacity, and water retention time for Lake Roosevelt, WA (1998).**

Month	Inflow (kcfs)	Outflow (kcfs)	Spill (kcfsd)	Reservoir Elevation (Ft)	Storage Capacity (kcfsd)	Water Retention Time (Days)
January	99.1	107.2	0.02	1,268.8	3,777.0	37.3
February	112.9	129.6	0.00	1,258.1	3,404.9	26.7
March	112.2	107.4	0.51	1,255.0	3,297.2	32.9
April	93.6	67.8	0.00	1,269.5	3,804.3	61.6
May	148.3	132.8	1.39	1,281.6	4,254.7	33.8
June	150.0	142.6	2.53	1,287.6	4,492.0	33.3
July	117.9	116.3	0.10	1,286.6	4,454.2	39.0
August	107.6	105.3	0.10	1,282.4	4,285.0	42.6
September	85.6	76.2	0.10	1,281.0	4,231.8	57.2
October	69.8	65.5	0.00	1,283.1	4,312.8	68.3
November	74.9	76.0	0.00	1,281.3	4,242.8	61.1
December	91.8	95.6	0.00	1,279.1	4,161.2	47.0
Mean	**105.3**	**101.8**	**0.40**	**1,276.3**	**4,063.8**	**45.1**

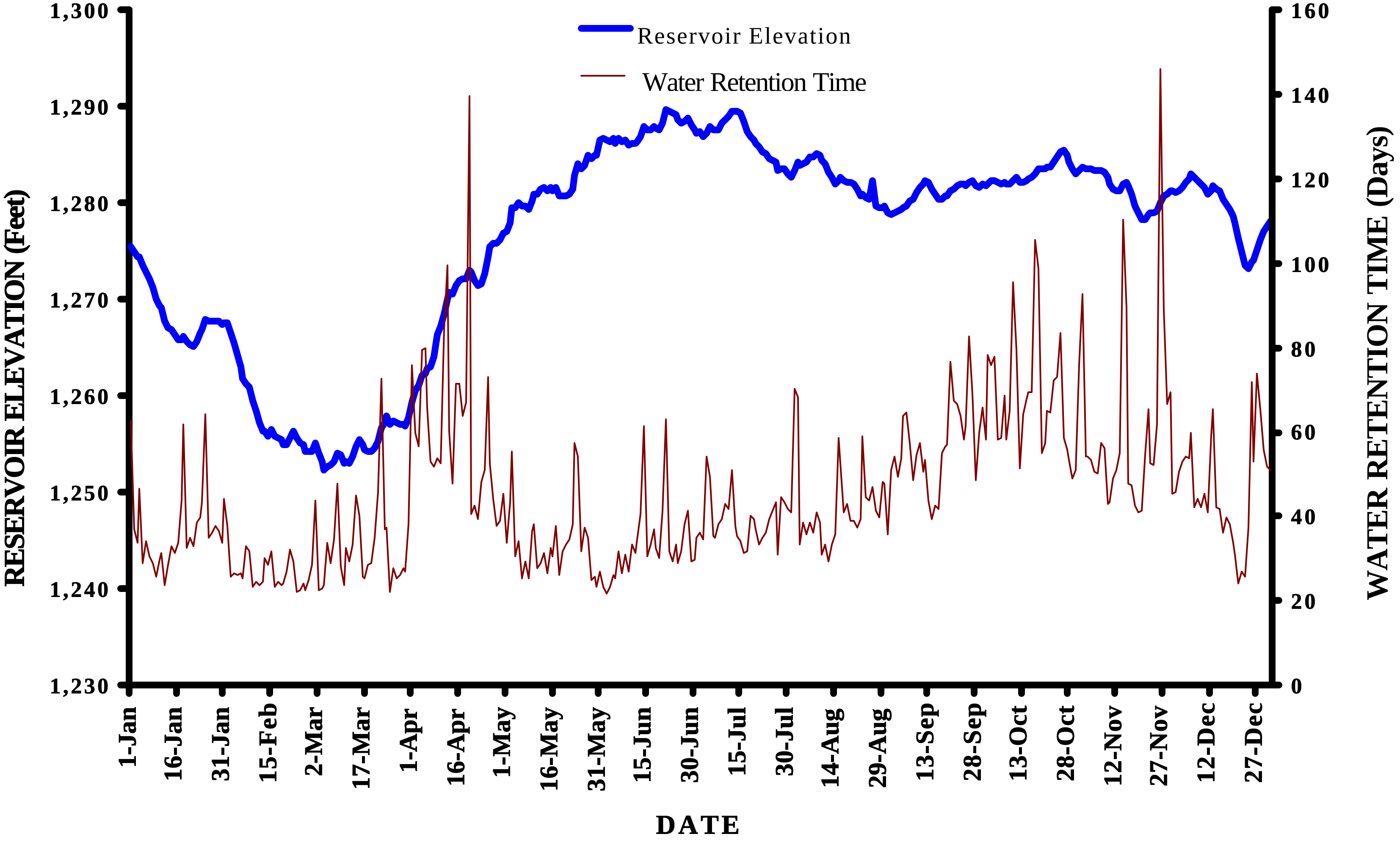

Figure 3.1 Daily water retention times and daily lake elevations for Lake Roosevelt, WA (1998).

Table 3.2 Monthly mean outflow, water retention time, and elevation for Lake Roosevelt, WA (1991-1998).

Year	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
Mean Outflow (kcfs)								
January	142	101.5	100.5	77.2	88.3	154.9	141.6	107.2
February	131.3	77.7	85.9	103.6	94	154.9	142.4	129.6
March	151	92.6	53.9	77.7	90.1	144.4	129.2	107.4
April	153.4	79.3	48.4	73	84.5	147.7	152.7	67.8
May	146.4	112.1	119	99.6	93.5	167.8	218.4	132.8
June	145.7	131.7	95.7	135.9	117.8	173.1	258.1	142.6
July	129.6	80.6	97.2	95.8	110.5	157.9	169.2	116.3
August	125.7	81.7	81.7	73.3	91.9	131.2	135.3	105.3
September	78	73	73	55.9	65.9	90.8	97.5	76.2
October	84.7	65.9	62.5	64	80.6	90.7	106.6	65.5
November	87.9	81.9	84.2	75.7	91.9	93.9	95.1	76.0
December	87.9	109.9	109.9	83.5	141.6	110.7	127.8	95.6
Mean WRT (days)								
January	32.2	45.1	40.2	61.8	49.3	28.4	30.3	37.3
February	34.1	59	44	42.5	42.6	31.7	23.3	26.7
March	25	48.4	67.1	54.9	42.4	23.9	23.4	32.9
April	17.7	51.2	87.1	55	47.5	18.6	15.9	61.6
May	18.5	34.4	39.4	44	39.4	15.7	10.8	33.8
June	29.2	33.7	49.6	30.1	40.1	21.8	16.1	33.3
July	35.8	62.1	46.9	43.5	41.4	29.4	27.1	39.0
August	37	56.8	56.8	58.7	47.2	34.3	33.2	42.6
September	59.1	61	61	78.4	69	47.9	46.5	57.2
October	55.8	69	73.5	72.6	56.7	49.2	42.8	68.3
November	53.2	56.3	51.4	60.1	50.4	48.3	47.7	61.1
December	53.2	37.5	37.5	56.3	32.4	38.9	33.5	47.0
Mean Elevation (ft)								
January	1283.9	1287.1	1267.5	1285.4	1278.3	1281.6	1273	1268.8
February	1285.1	1287.8	1263.5	1281.8	1266.3	1280.7	1253.7	1258.1
March	1267.5	1281.4	1256	1276.5	1259	1258.5	1239.4	1255.0
April	1235.4	1267.9	1271.8	1268.1	1265.8	1235.1	1220.8	1269.5
May	1234.9	1266.4	1284.7	1280.5	1259.8	1232.3	1223.4	1281.6
June	1275.2	1281.1	1287.5	1276	1283.6	1267.8	1275.3	1287.6
July	1288.3	1286.6	1286.4	1274.9	1286.9	1287.9	1287.7	1286.6
August	1288.5	1285.9	1285.9	1277.1	1280.9	1284.9	1285.8	1282.4
September	1287	1281.3	1281.3	1281.3	1285.1	1280.7	1284.4	1281.0
October	1287	1284.1	1281.9	1287.2	1285.8	1284.1	1283.9	1283.1
November	1286.7	1284.2	1278.8	1284.7	1286.5	1284.2	1286.5	1281.3
December	1286	1273	1279	1284.2	1287	1278.5	1280.3	1279.1

Table 3.3 Mean inflow, outflow, elevation and water retention times (WRT) for Lake Roosevelt, WA (1991-1998).

Year	Inflow (kcfs)	Outflow (kcfs)	Elevation (feet)	WRT (days)
1991	126.6	122.2	1275.4	37.5
1992	109.9	90.7	1280.6	51.2
1993	85.6	81.9	1277.1	56.0
1994	87.8	84.4	1279.8	54.9
1995	100.0	90.2	1277.1	46.2
1996	143.5	134.8	1271.4	32.4
1997	151.6	147.8	1266.8	29.2
1998	105.3	101.8	1276.3	45.1
Grand Means	**111.7**	**107.4**	**1275.5**	**44.1**

3.2 Water Quality

3.2.1 Total Dissolved Gas

Total dissolved gas (TDG) saturation levels in Lake Roosevelt ranged from 99.2 to 121.9 % with a mean saturation level of 105.3 % during 1998 (Figure 3.2 and Table 3.4). Surface TDG levels in Lake Roosevelt ranged from 99.2 to 110.7% saturation with an annual average of 105.1 % (Figure 3.2). Overall, TDG levels throughout the reservoir were lower in 1998 compared with 1997 (Table 3.5). Only 3.9 % of the TDG readings observed in 1998 exceeded maximum state and federal guidelines for surface water quality (110 % saturation), compared with 100 % observed readings exceeding 110 % in 1997 (Cichosz et. al. 1999). TDG saturation levels in 1998 did not appear to harm resident fish populations and little evidence of gas bubble trauma was observed among net pen reared kokanee salmon and rainbow trout. Reduced TDG levels and corresponding decreased incidences of gas bubble trauma were likely a result of the lower level of runoff and subsequent decreases in flow observed in 1998 compared with 1997 (Table 3.5). Water that is spilled over dams during high flow events has been identified as a primary cause of supersaturated TDG conditions in the Columbia River basin (Cichosz et. al. 1999). Comparatively, 1998 was a lower water year than 1997 and, as a result, Lake Roosevelt was not operated as aggressively to control flood conditions in the Columbia Basin in 1998. Decreased outflows and spill at upriver dams reduced TDG levels in Lake Roosevelt in 1998.

Table 3.4 Minimum, maximum and mean TDG saturation levels observed in Lake Roosevelt, WA by reach (1998).

Reach	Location(s) included*	Minimum TDG %	Maximum TDG %	Mean TDG %
Upper Mainstem	0, 1, 2	100.4	111.2	105.2
Middle Mainstem	3, 5.5, 6	99.8	110.7	105.5
Lower Mainstem	7, 8, 8a, 9	99.2	121.9	105.0
Spokane River	4	100.8	110.3	105.8
			Grand Mean	**105.3**

* See Figure 1.1 for location descriptions.

Analysis of log transformed TDG levels in Lake Roosevelt noted no significant differences between sample depths (ANOVA; $p > 0.10$; Figure 3.2) in 1998. However, TDG levels did vary significantly (ANOVA; $p < 0.001$) by sample location and reservoir reach. Overall, TDG concentrations during 1998 were significantly higher (ANOVA; $p < 0.001$) at Porcupine Bay and Seven Bays than at other locations. Additionally, TDG values in the Spokane River (Porcupine Bay) were significantly (ANOVA; $p < 0.001$) higher than those observed in the upper (Evans Landing, Kettle Falls, Gifford) and lower (Keller Ferry, Sanpoil River confluence, Sanpoil River and Spring Canyon) portions of Lake Roosevelt. TDG levels at middle (Hunters, Spokane River confluence and Seven Bays) mainstem Columbia River sites were also significantly higher (ANOVA; $p < 0.001$) than at lower mainstem sites (Table 3.4). This differs from last year, when TDG levels were greater in the mainstem than the Spokane River but the reasons behind the differences remain the same. The level of supersaturation is dependent upon a variety of factors; including the physical characteristics of the water, the structure of the dams and associated spillways, the proportion of water discharged as spill, and the morphology of the tailrace. Additionally, the rates at which excess dissolved gasses are released from a river or reservoir are affected by a number of factors, including reservoir morphology and limnology. Therefore, production of excess TDG may differ widely between river systems, and may be greater in the Spokane River relative to the Columbia River in normal or low water years compared with a high water years, as observed in 1997.

Monthly mean TDG saturation levels observed in Lake Roosevelt in 1998 generally declined or remained static from January through August, before increasing from September through November, followed by a slight decline in December. Significant differences in TDG levels were noted between months during 1998 (ANOVA; $p < 0.001$; Table 3.6).

Table 3.5 **Mean TDG saturation levels observed throughout Lake Roosevelt, WA by reach (1997-1998) and percent runoff calculated as a percentage of the 61 year average.**

Reach	Location(s) included*	Mean TDG % 1997	Mean TDG % 1998
Upper Mainstem	0, 1, 2	114.0	105.2
Middle Mainstem	3, 5.5, 6	112.4	105.5
Lower Mainstem	7, 8, 8a, 9	111.2	105.0
Spokane River	4	116.1	105.8
Overall		**112.3**	**105.3**
% Runoff		**142 %**	**95 %**

* See Figure 1.1 for location descriptions.

Monthly mean TDG levels in Lake Roosevelt were highest in February (110.0 %), followed by January (109.2 %; Table 3.6). Monthly mean TDG levels were significantly ($p < 0.001$) higher in February than in any other month, and January was significantly higher than any month except February (Table 3.6). Higher TDG levels observed in February in 1998 were likely a result of the late winter-early spring drawdown of the reservoir for spring flood control. Reduced water retention times suggest a greater potential for TDG production, because reducing time that the water stays pooled in the reservoir would allow excess gases to be lost from the water column into the atmosphere. Additionally, the reduction in TDG from March through August suggests the increase in surface area of the reservoir following re-fill may contribute to degassing of the water by increasing the area of the water-atmosphere interface, thus allowing a greater area for degassing. Highest individual TDG readings observed in Lake Roosevelt during 1998 (121.9 %) occurred at the Sanpoil River confluence (Location 8a) on March 26, 1998. Monthly mean TDG levels were significantly lower (ANOVA; $p < 0.001$) in August (103.3 %) and July (103.3 %) than in any other month (Table 3.6). Lowest individual TDG readings observed during 1998 (99.2 %) occurred in the Sanpoil River (Location 8) on August 12 (Table 3.6).

Table 3.6 **Differences in monthly mean TDG concentrations observed in Lake Roosevelt, WA (1998). Significance is based on Kruskal-Wallis statistics.**

Month	Mean % TDG Saturation	Significant ($p<0.001$) Differences
January (JA)	109.2	F,M,MY,J,JU,A,S,O,N,D
February (F)	110.0	J,M,MY,J,JU,A,S,O,N,D
March (M)	107.5	MY,J,JU,A,S,O,N,D
May (MY)	104.2	JU,A,S,O,N,D
June (J)	104.3	JU,A,S,O,N,D
July (JU)	103.3	S,O,N,D
August (A)	103.3	S,O,N,D
September (S)	105.7	O
October (O)	105.0	N
November (N)	106.1	
December (D)	105.5	

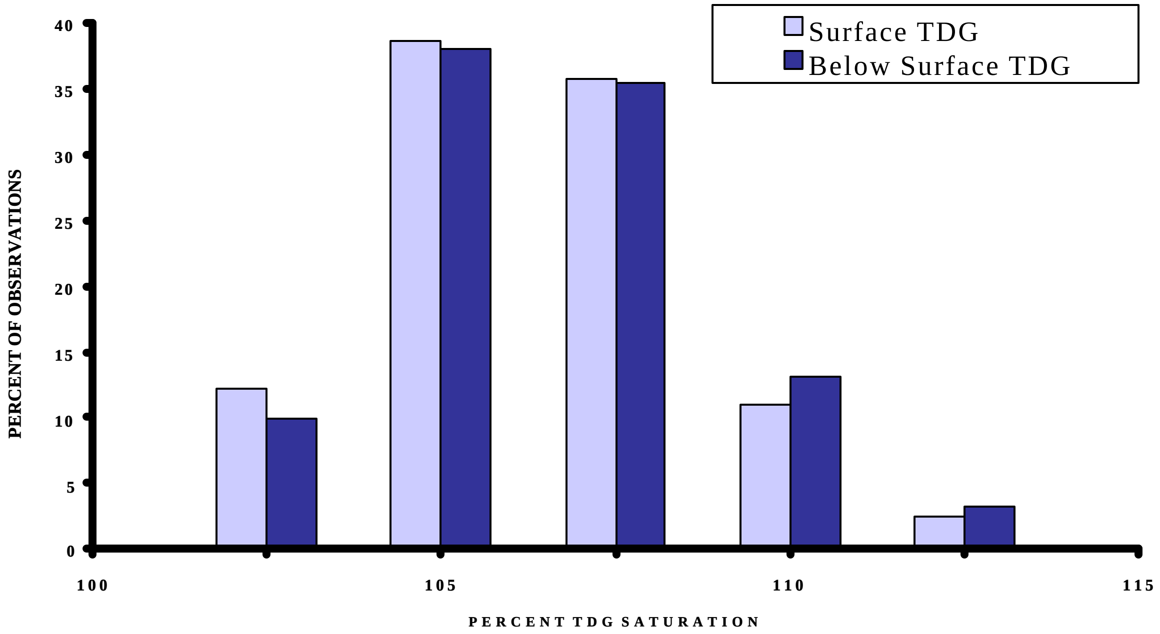

Figure 3.2 Distribution of total dissolved gas (TDG) observations in Lake Roosevelt, WA (1998).

3.2.2 Additional Limnological Parameters

Consistent with previous years, 12 m water temperatures were used for comparisons between locations and dates to help minimize surface variations and better represent vertical profile means. During 1998, 12 m water temperatures ranged from 2.6 ^{o} C at Keller Ferry on February 6 to 22.7 ^{o} C at Spring Canyon on July 30. Temperatures exceeded 10 ^{o} C by mid-May at all sample locations in Lake Roosevelt and remained above 10 ^{o} C through November at all locations, except Evan's Landing and Kettle Falls. In December, the water temperature at 12 m decreased to less than 10 ^{o} C at all locations. Analysis of vertical water temperature profiles in Lake Roosevelt found that thermal stratification is related to the water retention time. If water is held during the summer time, a weak stratification may be established. In 1998, the strongest thermal stratification was noted at Spring Canyon and had began to form in early May. The stratification was strongest in late July and had begun to mix by August. However, any thermal stratification that is subjected to increased flows and shorter retention times will likely break down quickly.

Dissolved oxygen concentrations recorded during 1998 ranged from 0.9 mg/L at Porcupine Bay on September 9 to 16.6 mg/L at Porcupine Bay on February 2. Dissolved oxygen exceeded 13 mg/L at all sampling stations in January and February and remained above 10 mg/L through May. Except for a brief period of anoxia at depth at Porcupine Bay, dissolved oxygen concentrations ranged between 5 and 12 mg/L at all locations from June through December 1998. Dissolved oxygen saturation levels (% DO) ranged from 7.3 % at Porcupine Bay on September 9 to 140 % at Spring Canyon on May 6, 1998. Dissolved oxygen was supersaturated (> 100%) at all locations in January and February, and below 100 % saturation at all locations from September through December 1998. Dissolved oxygen saturation levels from March through August ranged from 19.0 % at Porcupine Bay on August 11 to 140 % at Spring Canyon on May 9. Dissolved oxygen saturation levels between March and August averaged 87.9 % at Porcupine Bay and 89.3 % at the Spokane River confluence, and were significantly lower (ANOVA; $p < 0.0001$) than other reservoir locations.

Conductivity values in Lake Roosevelt in 1998 ranged from 0.074 mmhos/cm at Spring Canyon on July 14 to 0.687 mmhos/cm at Sanpoil River on May 6. Total dissolved solids (TDS) ranged from 48.0 mg/L at Spring Canyon on July 14 to 442.0 mg/L at Sanpoil River on May 6. Conductivity was highly correlated ($r^2 = 0.995$) with observed total dissolved solids levels (TDS). Turbidity values in Lake Roosevelt were highest at Kettle Falls (96.6 NTU) followed by Porcupine Bay (91.9 NTU) on February 3, 1998, and the Sanpoil River (35.4 NTU) on May 19. All other turbidity readings in Lake Roosevelt were low, only rarely exceeding 10 NTU.

Observed pH levels in Lake Roosevelt during 1998 ranged from 5.31 at Seven Bays on March 25 to 10.29 at Spring Canyon on July 1. Average pH values were highest in June and July (8.97 and 8.71 pH units respectively) and significantly lower ($p < 0.0001$) in March (6.51 pH units) than in all other months. Oxidation - reduction potential (ORP) ranged from –215 mV at Spring Canyon on November 18 to 802 mV at the Sanpoil River on May 19. Average oxidation - reduction potentials were lowest in November (-32.6 mV) and highest in March (281 mV). Oxidation - reduction potential values were negatively correlated ($r = -0.276$; $p < 0.0001$) with pH.

3.3 Primary Production

3.3.1 Phytoplankton Chlorophyll *a*

Lake Roosevelt euphotic zone chlorophyll *a* concentrations varied significantly between months in 1998 (ANOVA; $p < 0.001$). Overall, monthly mean chlorophyll *a* concentrations were low (< 0.62 mg/m^3) from January through March, and in December of 1998 (Table 3.7). High monthly mean chlorophyll *a* concentrations occurred in May (3.53 mg/m^3) and June (2.97 mg/m^3) at levels significantly higher (ANOVA; $p < 0.001$) than any other month sampled in 1998 (Figure 3.3). Lowest monthly mean chlorophyll *a* values occurred in January (0.39 mg/m^3), March (0.52 mg/m^3), February (0.58 mg/m^3), and December (0.61 mg/m^3) at levels significantly below ($p < 0.001$) the remaining months of the year (Table 3.7). A similar pattern was observed in 1997 in Lake Roosevelt, where planktonic chlorophyll *a* concentrations were significantly higher during May, June, and July when compared to other months (Cichosz et al. 1999).

Table 3.7 Differences in monthly mean phytoplankton chlorophyll *a* concentrations observed in Lake Roosevelt, WA (1998). Significance is based on Scheffe's S.

Month	Mean Chlorophyll *a* conc. (mg/m^3)	Significant ($p < 0.05$) Differences
January (J)	0.39	< MY, J, JU, A, S, O, N
February (F)	0.58	< MY, J, JU, A, S, O, N
March (M)	0.52	< MY, J, JU, A, S, O, N
May (MY)	3.53	> J, F, M, J, JU, A, S, O, N, D
June (J)	2.97	< MY; > J, F, M, JU, A, S, O, N, D
July (JU)	2.18	< MY, J; > J, F, M, A, S, O, N, D
August (A)	1.92	< MY, J; > J, F, M, N, D
September (S)	1.63	< MY, J, JU; > D
October (O)	1.62	< MY, J, JU; > N, D
November (N)	1.31	< MY, J, JU, A; > D
December (D)	0.62	< MY, J, JU, A, S, O, N

Pairwise comparisons indicate that monthly mean chlorophyll *a* concentrations increased from January to February, then decreased slightly in March (not significant, $p = 0.758$), followed by a significant increase in May. The means decreased significantly later in the year, starting in June through to December (Scheffe's S, $p < 0.05$; Table 3.7).

In 1998, phytoplankton chlorophyll *a* concentrations appeared to be influenced by temperature and hydro-operations. When the reservoir elevation was raised in the spring of 1998 water temperatures increased from 4.7 ° C in March to 11.2 ° C in May. Lake Roosevelt elevation increased by 26.6 ft (8.1 m) from 1255.0 ft (382.5 m) in March to 1281.6 ft (390.6 m) in May. During that time, phytoplankton chlorophyll *a* increased by nearly seven fold (Figure 3.4). During the same time period, Secchi depths decreased, as would be expected, with reduced transparencies from spring runoff. However, since all phytoplankton samples originate from the euphotic zone, overall light limitation was less of a factor (Figure 3.4). Phytoplankton growth and photosynthesis are directly related to temperature, light, and the interaction between the two (Wetzel 1983). Phytoplankton chlorophyll *a* concentrations peaked in May corresponding with the peak in phytoplankton cell densities (Figure 3.3 & 3.7).

Analysis of monthly mean chlorophyll *a* concentrations found significant differences between locations and depths in 1998. Chlorophyll *a* samples taken from the upper euphotic zone (1.50 mg/m^3) were significantly ($p < 0.001$) lower than in the middle (1.95 mg/m^3) and lower (1.95 mg/m^3) portions of the euphotic zone. This likely occurred in Lake Roosevelt during 1998 because of photosynthetic photoinhibition to phytoplankton cells that receive too much light (Cichosz et al. 1999). Photoinhibition is well documented and results from the harmful effects created by UV radiation (Wetzel 1983). Monthly mean chlorophyll *a* concentrations were significantly (ANOVA; $p < 0.001$) higher at Porcupine Bay than at Evan's Landing, Gifford, Hunters, Keller Ferry, Sanpoil River, and Spring Canyon. Seven Bays chlorophyll *a* concentrations were also significantly higher ($p < 0.001$) than the Sanpoil River and Spring Canyon. Trophic status associated with phytoplankton chlorophyll *a* concentrations indicate that Lake Roosevelt was in the oligotrophic to meso-oligotrophic range during 1998 across the entire reservoir (Wetzel 1983).

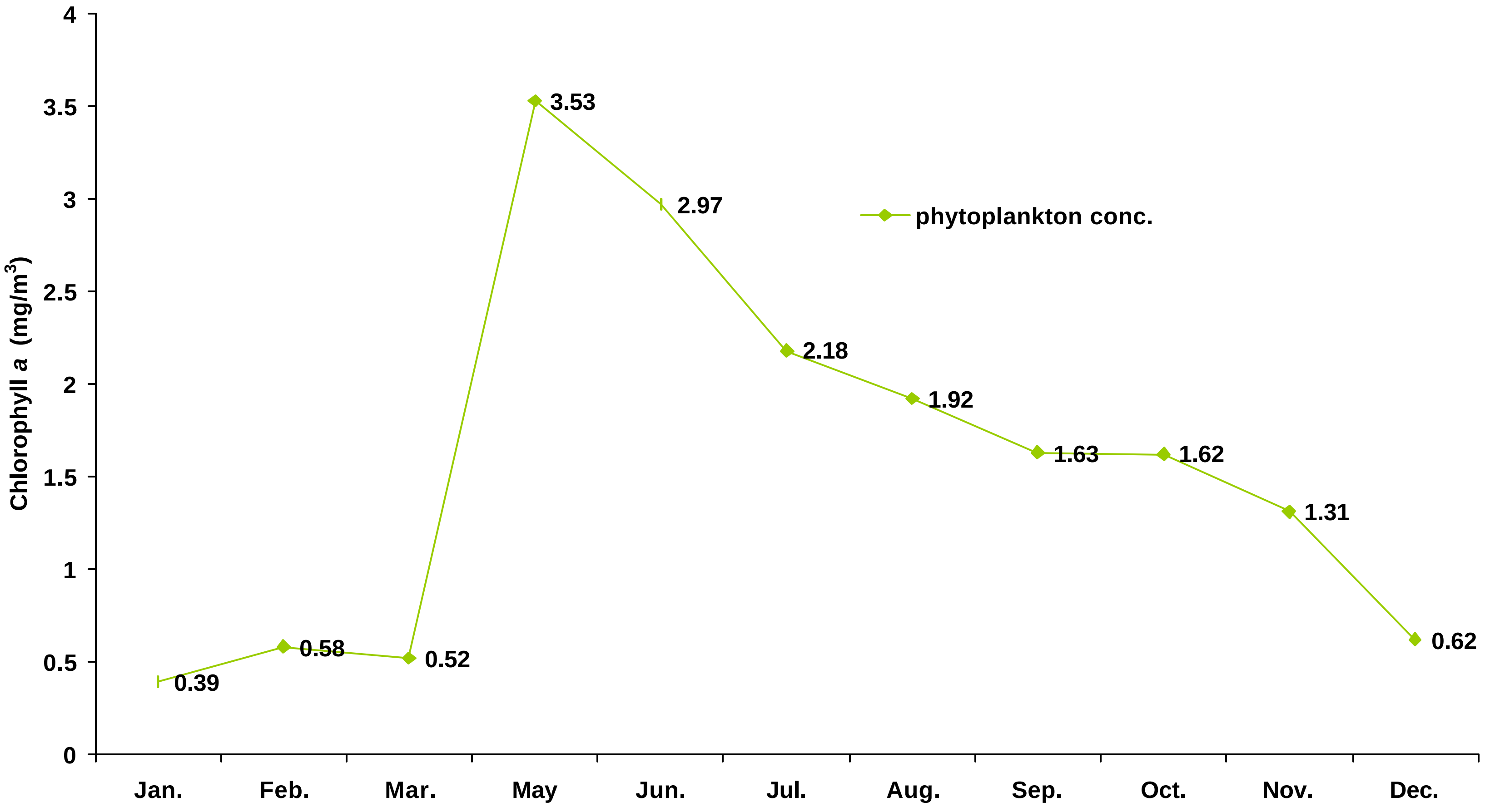

Figure 3.3 Mean monthly phytoplankton chlorophyll *a* concentrations in Lake Roosevelt, WA (1998).

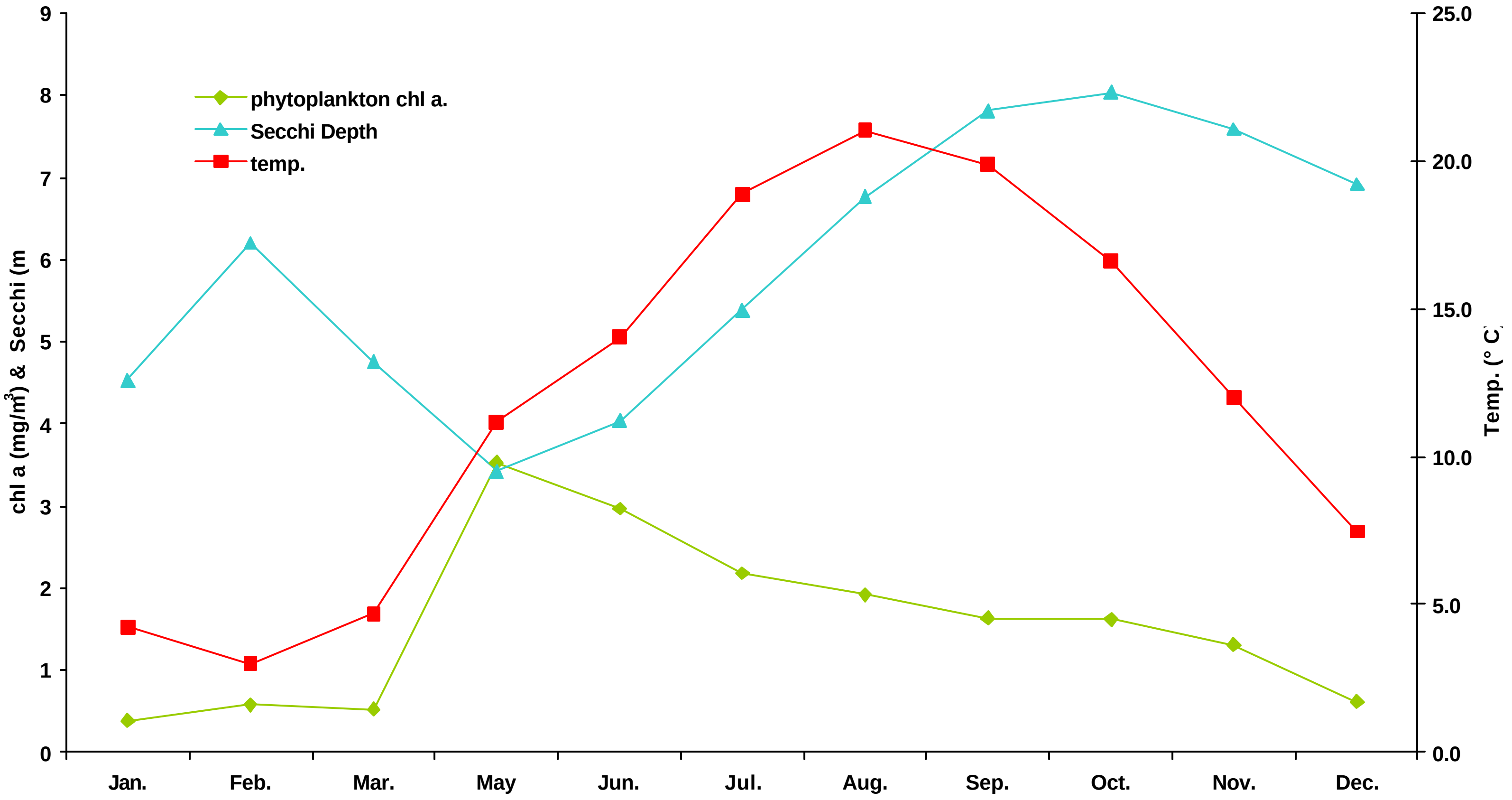

Figure 3.4 Mean monthly phytoplankton chlorophyll *a*, Secchi depths, and temperature in Lake Roosevelt, WA (1998).

3.3.2 Periphyton

Periphyton surveys were conducted in embayment habitats on Lake Roosevelt from mid-July through mid-September 1998 at Gifford, Porcupine Bay, Seven Bays and Spring Canyon. Twenty-five individual periphyton taxa were identified from Lake Roosevelt in 1998, representing three Divisions and three Classes (Table 3.8). During 1998, diatoms (Bacillariophyceae) dominated the periphyton community of Lake Roosevelt, accounting for 87.1 % of total density and 58.0 % of total biovolume, respectively (Table 3.5). *Achnanthes* sp. (Bacillariophyceae) had the highest overall density by taxa, accounting for 64.1 % of total periphyton density followed by *Mougeotia* sp. (Chlorophyceae; 12.4 %), *Amphora* sp. (Bacillariophyceae; 8.5 %) and *Synedra* sp. (Bacillariophyceae; 5.7 %; Table 3.8). Periphyton biovolumes were dominated by *Mougeotia* sp. (41.7 %), *Amphora* sp. (20.5 %), *Achnanthes* sp. (10.3 %) and *Gomphonema* sp. (Bacillariophyceae; 6.2 %; Table 3.8).

Periphyton colonization rates (mean number of organisms/cm^2/day) differed significantly between sampling depths, locations, and colonization periods during 1998 (ANOVA; $p < 0.05$). Mean periphyton colonization rates at 1.5 m (0.010 organisms/cm^2/day), were nearly double those observed at 4.6 m (0.006 organisms/cm^2/day). Periphyton production measured by biovolume was also significantly different by depth (ANOVA; $p=0.025$), where the 1.5 m depth accumulated roughly twice as much periphyton as the 4.6 m depth (Figure 3.5). However, periphyton production measured by chlorophyll *a* was not significantly different by depth (ANOVA; $p<0.05$; Figure 3.6). Periphyton production as measured by chlorophyll *a* is often more variable than when measured by biovolume (Wetzel 1983). A larger sample size may have been necessary to have adequate power to test for measurable differences.

Colonization time affected periphyton biovolume and chlorophyll *a* production. Biovolume production was significantly different for all colonization periods with the exception of differences between two and four weeks and differences between six and eight weeks (Fisher's PLSD; $\alpha=0.05$).

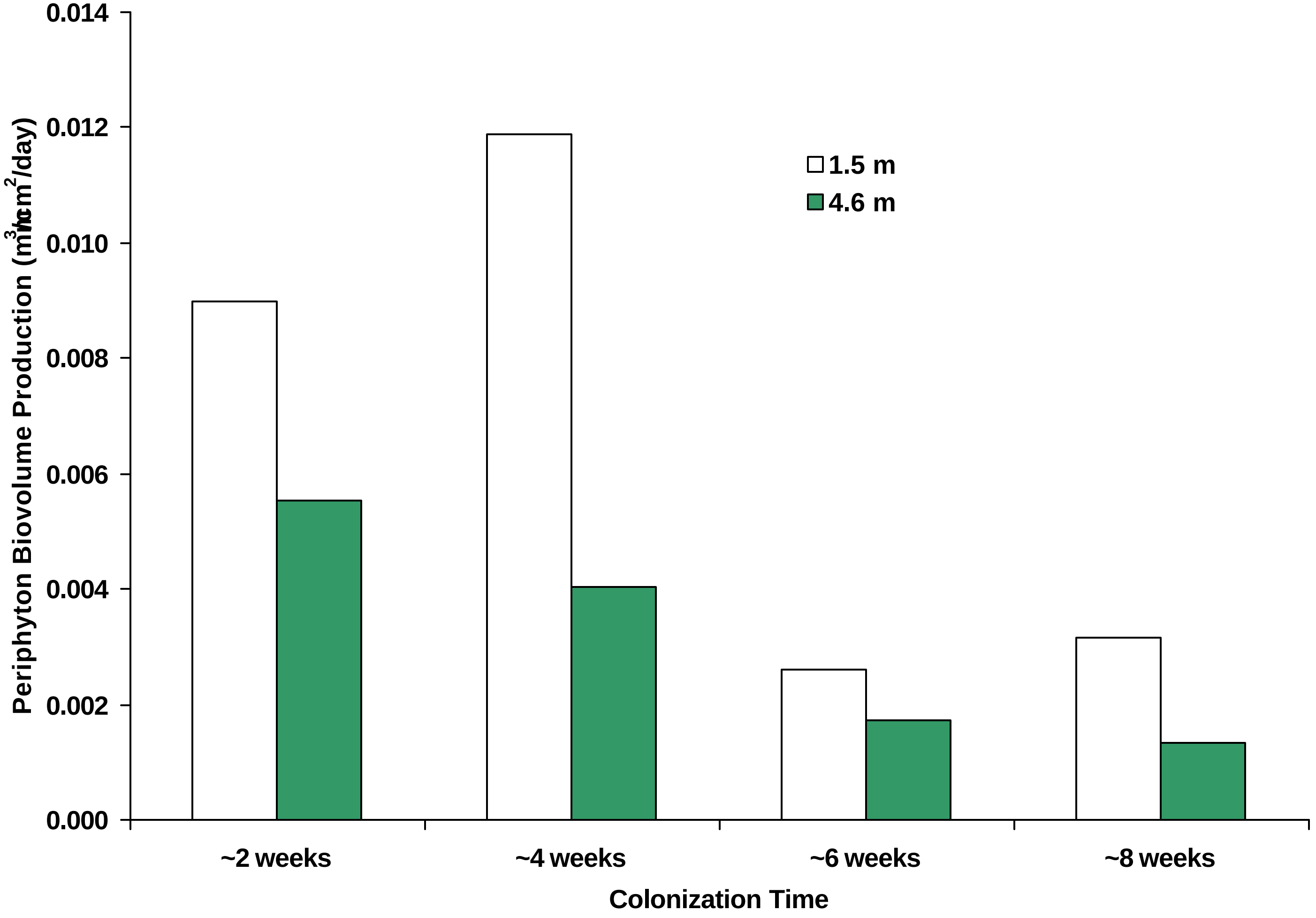

Figure 3.5 **Periphyton biovolume at 1.5 m and 4.6 m during four colonization times examined in Lake Roosevelt, WA (1998).**

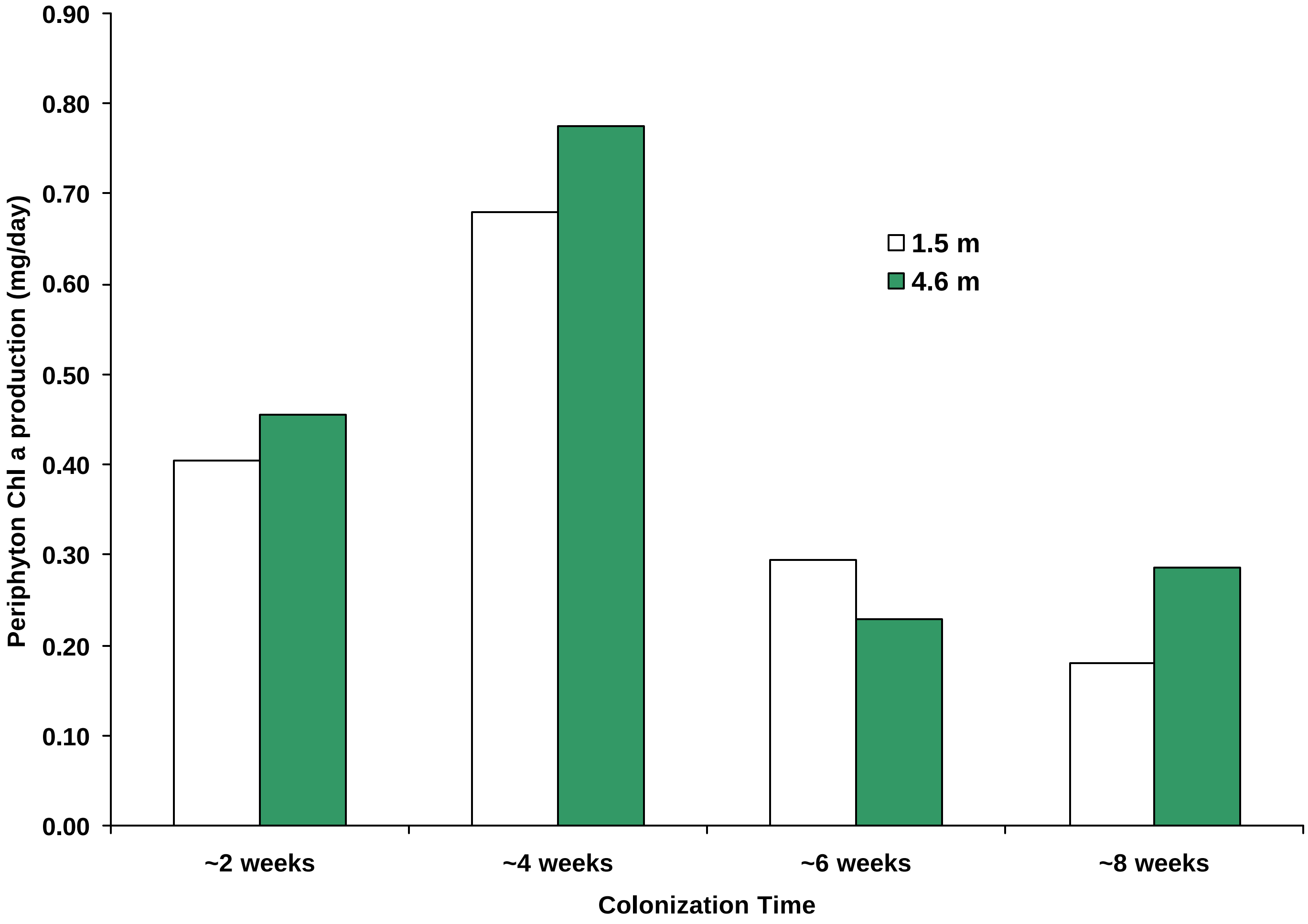

Figure 3.6 **Periphyton chlorophyll *a* at 1.5 m and 4.6 m during four colonization times examined in Lake Roosevelt, WA (1998).**

Chlorophyll *a* production during the four-week colonization was significantly higher than all other colonization times. Periphyton production, as measured by chlorophyll *a* and biovolume, was elevated in the early colonization times and highest during the four-week incubation. Cichosz et al. (1999) suggested that, in Lake Roosevelt, periphyton colonization would be elevated at a two-week incubation period. In 1998, the two-week incubation was elevated but the four-week incubation was even higher. Mean colonization rates were significantly less at Porcupine Bay (0.004 organisms/cm^2/day) than at Gifford (0.008 organisms/cm^2/day), Seven Bays (0.011 organisms/cm^2/day), or Spring Canyon (0.009 organisms/cm^2/day) in 1998 (Scheffe's S, $p < 0.05$). Mean periphyton colonization rates were consistent (0.010 organisms/cm^2/day) over the first three colonization periods of 1998 (July 15 – July 27, July 27 – August 10, and August 10 – August 24), but declined to 0.007 organisms/cm^2/day during the final colonization period (August 24 – September 9).

Table 3.8 **Relative abundance of periphyton species observed in Lake Roosevelt, WA surveys (1998).**

	% of Total Density	% of Total Biovolume
Division Chlorophyta		
Class Chlorophyceae	12.6	41.9
Ankistrodesmus falcatus	<1.0	<1.0
Cosmarium sp.	<1.0	<1.0
Mougeotia sp.	12.4	41.7
Scenedesmus bijuga	<1.0	<1.0
Scenedesmus dimorphus	<1.0	<1.0
Scenedesmus quadricauda	<1.0	<1.0
Division Chrysophyta		
Class Bacillariophyceae	87.1	58.0
Achnanthes sp.	64.1	10.3
Amphipleura sp.	<1.0	<1.0
Amphora sp.	8.5	20.5
Cocconeis sp.	<1.0	<1.0
Cyclotella sp.	<1.0	<1.0
Cymbella sp.	<1.0	<1.0
Fragilaria crotonensis	<1.0	<1.0
Fragilaria sp.	3.2	3.1
Gomphonema sp.	2.2	6.2
Gyrosigma sp.	<1.0	<1.0
Melosira herzogii	<1.0	<1.0
Melosira varians	<1.0	4.2
Navicula sp.	1.3	1.3
Pinnularia sp.	<1.0	4.4
Rhizosolenia sp.	<1.0	<1.0
Synedra sp.	5.7	1.3
Tabellaria sp.	<1.0	5.4
Division Cyanophyta		
Class Cyanophyceae	<1.0	<1.0
Merismopedia sp.	<1.0	<1.0
Oscillatoria sp.	<1.0	<1.0

3.3.3 Phytoplankton

Fifty species of phytoplankton representing five genera and six classes were identified from Lake Roosevelt in 1998 (Table 3.9). Overall, Chlorophyceae (green algae) was the most diverse group of phytoplankton observed, with 18 representative species, followed by Bacillariophyceae (diatoms) with 17, Cyanophyta (blue – green algae) with eight, Cryptophyceae (unicellular flagellates) with two, and Pyrrhophyta (dinoflagellates) with a single species represented. Lake Roosevelt total phytoplankton densities were highest in May (1,130 organisms/ml) and lowest in January (394 organisms/ml) (Figure 3.7). Total phytoplankton densities across all sites and dates in 1998 averaged 706 organisms/ml and exceeded 500 organisms/ml in every month except January and November (499 organisms/ml; Figure 3.7).

On an annual basis, microplankton accounted for the majority (29.6 %) of total phytoplankton densities observed in 1998, followed by Cryptophyceae (21.7 %), Bacillariophyceae (17.0 %), Cyanophyceae (14.8 %), Chlorophyceae (13.3 %), Chrysophyceae (3.2 %), and Pyrrhophyta (0.3 %; Figure 3.7). Zooplankton prefer to feed on Bacillariophycea (diatoms), small Chlorophyceae (green algae), and Cryptophyceeae (unicellular flagellates) because of their size and nutritional superiority (Wetzel 1983). Seasonal succession of various phytoplankton taxa was observed in Lake Roosevelt during 1998. Bacillariophyceae reached peak abundances in early May and declined in December. Chrysophyceae followed with a peak in July then a general decline through December (Figure 3.5). Cryptophyceae, Cyanophyceae, and Pyrrhophyta reached peak densities in July, followed by declines through December (Figure 3.7). Part of this succession in phytoplankton was likely due to selective predation by zooplankton (Wetzel 1983). Microplankton were most abundant in February (348 organisms/ml) and accounted for a substantial proportion (17 – 44 %) of total phytoplankton densities in each month sampled (Figure 3.3).

On a volumetric basis, members of the Phylum Pyrrhophyta had the highest mean cell volume recorded in 1998 (0.154 mm^3/l), accounting for 42.4 % of the annual total (Figure 3.8). Members of the Bacillariophyceae were second largest volumetrically (0.092 mm^3/l), accounting for 25.3 % of the annual total, followed by Cryptophyceae (0.051mm^3/l; 14.0 %), Chlorophyceae (0.018 mm^3/l; 5.0 %), Microplankton (0.018 mm^3/l; 4.9 %), Cyanophyceae (0.017 mm^3/l; 4.6 %), and Chrysophyceae (0.014 mm^3/l; 3.8 %; Figure 3.8). Highest observed cell volumes by taxonomic group occurred in August (0.205 mm^3/l) for Pyrrhophyta, in May for Bacillariophyceae (0.330 mm^3/l), Chlorophyceae (0.052 mm^3/l), Chrysophyceae (0.021 mm^3/l), and Cryptophyceae (0.101 mm^3/l), in September for Cyanophyceae (0.069 mm^3/l), and in February for microplankton (0.079 mm^3/l; Figure 3.8).

Table 3.9 Phytoplankton taxa identified from Lake Roosevelt, WA (1998).

Division Chlorophyta
- **Class Chlorophyceae**
  - *Ankistrodesmus falcatus*
  - *Carteria sp.*
  - *Chlamydomonas sp.*
  - *Closterium sp.*
  - *Cosmarium sp.*
  - *Eudorina elegans*
  - *Mougeotia sp.*
  - *Oocystis sp.*
  - *Pediastrum boryanum*
  - *Pediastrum duplex*
  - *Quadrigula chodatii*
  - *Scenedesmus bijuga*
  - *Scenedesmus quadricauda*
  - *Schroederia setigera*
  - *Spirogyra sp.*
  - *Spondylosium sp.*
  - *Staurastrum paradoxum*
  - *Tetraedion minimum*

Division Chrysophyta
- **Class Chrysophyceae**
  - *Dinobryon bavaricum*
  - *Dinobryon sertularia*
  - *Mallomonas pseudocoronata*
  - *Mallomonas sp.*

- **Class Bacillariophyceae**
  - *Achanthes sp.*
  - *Amphora sp.*
  - *Asterionella formosa*
  - *Cyclotella sp.*
  - *Cymbella sp.*
  - *Fragilaria crotonensis*
  - *Fragilaria sp.*
  - *Gomphonema sp.*

Division Chrysophyta
- **Class Bacillariophyceae (cont'd)**
  - *Melosira distans*
  - *Melosira granulata*
  - *Melosira herzogii*
  - *Melosira italica*
  - *Melosira varians*
  - *Navicula sp.*
  - *Rhizosolenia sp.*
  - *Synedra sp.*
  - *Tabellaria sp.*

Division Cryptophyta
- **Class Cryptophyceae**
  - *Cryptomonas sp.*
  - *Rhodomonas sp.*

Division Cyanophyta
- **Class Cyanophyceae**
  - *Anabaena sp.*
  - *Aphanizomenon flos-aquae*
  - *Aphanocapsa sp.*
  - *Chroococcus sp.*
  - *Gloeocapsa sp.*
  - *Microcystis aeruginosa*
  - *Oscillatoria limnetica*
  - *Oscillatoria sp.*

Division Pyrrhophyta
- **Class Dinophyceae**
  - *Ceratium hirundinella*

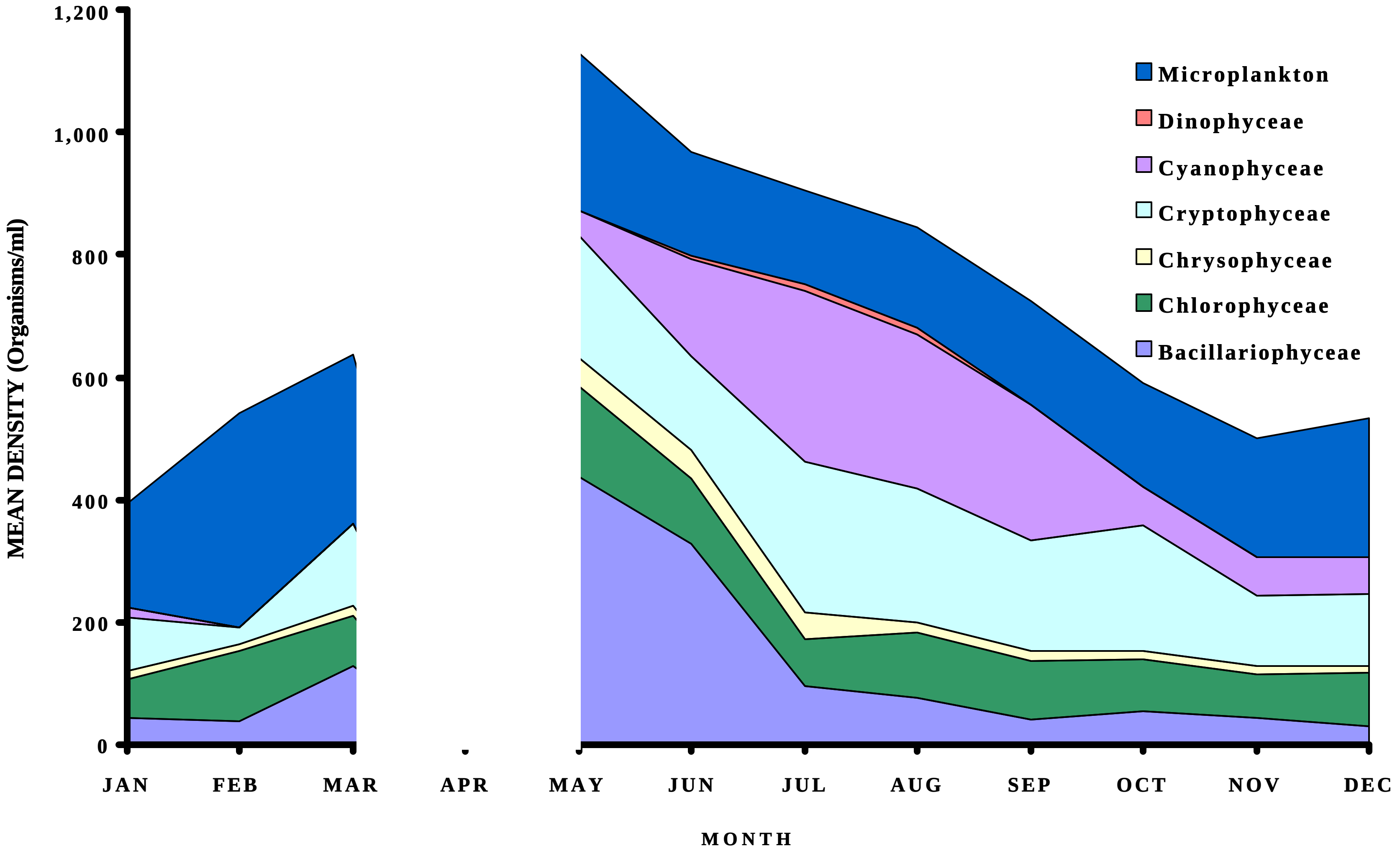

Figure 3.7 **Mean monthly density of major phytoplankton groups collected from Lake Roosevelt, WA (1998).**

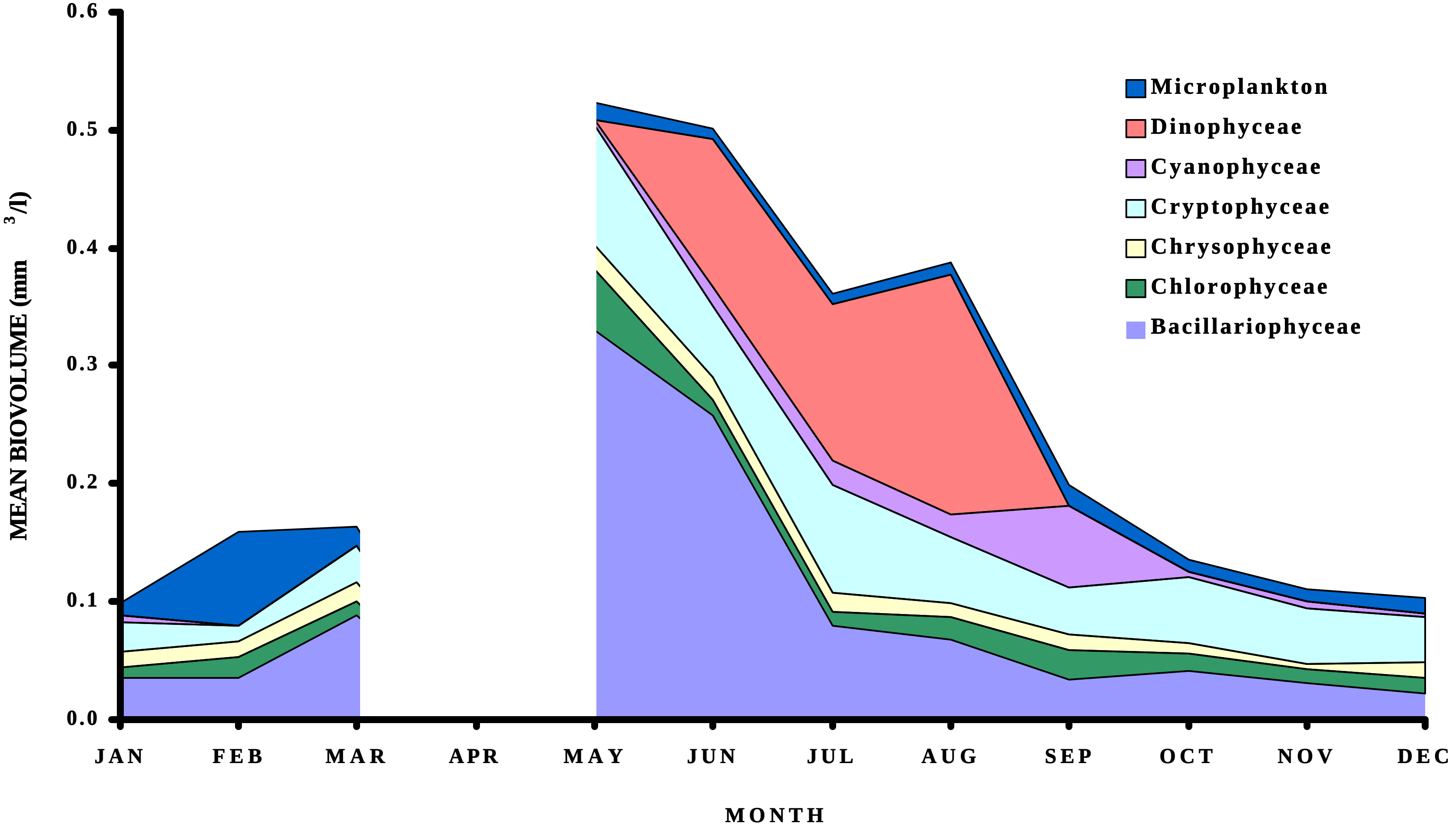

Figure 3.8 Seasonal variation in monthly mean phytoplankton biovolume by taxonomic group for Lake Roosevelt, WA (1998).

3.4 Zooplankton Density and Length Analysis

3.4.1 Species Identified

Twenty species of zooplankton (excluding rotifers) were identified from Lake Roosevelt in 1998, of which fourteen were from the order Branchiopoda and six were from the sub-order Copepoda (Table 3.10). Predominant families observed in 1998 included the Daphniidae, Sididae, Bosminidae, Diaptomidae, and Cyclopidae. Overall, Daphniidae was the most diverse family observed with six representative species collected (Table 3.10). Most Branchiopoda (commonly known as Cladocera) in Lake Roosevelt are herbivorous consumers of phytoplankton, except for two visual predators, *Leptodora kindtii* and *Polyphemus pediculus*, which prey on protozoa, rotifers, and crustaceans (Karabin 1974). Copepod zooplankton species commonly exhibit omnivorous or opportunistic feeding behavior and their diet may vary with developmental stage (Maly and Maly 1974). In Lake Roosevelt, the calanoid copepod *Epischura nevadensis* and the cyclopoids, *Mesocyclops edax* and *Diacyclops bicuspidatus thomasi* graze on phytoplankton in early life stages, but assume predatory roles in larger adult stages, generally feeding on rotifers and small crustacean zooplankton (Kerfoot 1987). *Leptodora kindtii* is the largest zooplankton species present in the reservoir and can attain sizes up to 12 mm. All other zooplankton species collected in 1998 were generally less than 3 mm in length.

Numerous studies have identified the importance of zooplankton in maintaining viable planktivorous fish populations in Lake Roosevelt (Beckman et al. 1985, Peone et al. 1990, Cichosz et al. 1999). Of the species identified in 1998, *Daphnia pulex* was the most important zooplankton prey item in Lake Roosevelt accounting for between 15.9 % and 48.9 % of the annual index of relative importance (IRI) values for walleye (15.9 %), smallmouth bass (20.8 %), rainbow trout (23.6 %), mountain whitefish (40.1 %), lake whitefish (25.0 %), large scale sucker (17.0 %), and kokanee salmon (48.9 %). *Daphnia schødleri, Daphnia galeata, Leptodora kindtii, Epischura nevadensis, Diacyclops bicuspidatus thomsi* and *Leptodiaptimus ashlandi* were also important zooplankton prey items in Lake Roosevelt accounting for between 0.4 % and 12.9 % of the annual IRI values for the above mentioned fish species (Spotts et al., 2002, Table 3.13).

Table 3.10 Zooplankton taxa identified in Lake Roosevelt, WA (1998).

- **Phylum Anthropoid**
  - **Sub-class Crustacea**
    - **Order Branchiopoda**
      - **Family Daphniidae**
        - *Ceriodaphnia quadrangula*
        - *Daphnia schødleri*
        - *Daphnia pulex*
        - *Daphnia retrocurva*
        - *Daphnia galeata mendotae*
        - *Daphnia thorata*
      - **Family Chydoridae**
        - *Alona quadrangularis*
        - *Chydorus sphaericus*
      - **Family Sididae**
        - *Diaphanosoma brachyurum*
        - *Diaphanosoma birgei*
        - *Sida crystallina*
      - **Family Bosminidae**
        - *Bosmina longirostris*
      - **Family Leptodoriidae**
        - *Leptodora kindtii*
      - **Family Polyphemidae**
        - *Polyphemus pediculus*

- **Phylum Anthropoid**
  - **Sub-class Copepoda**
    - **Sub-order Calanoida**
      - **Family Diaptomidae**
        - *Leptodiaptomus ashlandi*
      - **Family Temoridae**
        - *Epischura nevadensis*
    - **Sub-order Cyclopoida**
      - **Family Cyclopoidae**
        - *Diacyclops b. thomasi*
        - *Mesocyclops edax*
        - Unkown Cyclopoid spp.
    - **Sub-order Cyclopoida**
      - **Family Harpacticoidae**
        - *Bryocamptus* sp.

Consistent with previous years, taxonomically related zooplankton species were grouped into categories for certain analyses as follows: *Daphnia pulex, Daphnia retrocurva, Daphnia schødleri, Daphnia thorata* and juvenile *Daphnia* were grouped as "*Daphnia* spp.," while *Alona quadrangularis, Bosmina longirostris, Ceriodaphnia quadrangula, Diaphanosoma brachyurum, Diaphanosoma birgei, Leptodora kindtii, Chydorus sphaericus, Sida crystallina*, and *Polyphemus pediculus* were grouped as "other Cladocera." *Leptodiaptomus ashlandi*, *Diacyclops bicuspidatus thomasi*, *Mesocyclops edax*, *Epischura nevadensis,* Harpacticoid sp., unknown cyclopoid copepods, and nauplii (juvenile copepoda) were grouped as "copepod sp." Each of the above categories were examined separately to address differing levels of importance in the diets of managed fish species (Underwood et al. 1996 and 1997; Griffith and Scholz 1991).

3.4.2 Total Pelagic Zooplankton Densities

Copepods were the most abundant zooplankton taxon collected from Lake Roosevelt in 1998, accounting for 88.0 % of annual total pelagic zooplankton densities. *Daphnia* spp., accounted for 10.0 % of annual total pelagic zooplankton densities while other Cladocera accounted for 2.1 %. High copepod abundances in 1998 were driven primarily by high densities of two copepod spp. and nauplii. *Diacyclops bicuspidatus thomasi* comprised 36.1 %, *Leptodiaptomus ashlandi* comprised 20.4 %, and nauplii comprised 19.6 % of the total zooplankton densities in 1998.

Mean total pelagic zooplankton densities were low (<14.5 organisms/m^3) from January through March in 1998, but dramatically increased by early and late May (>420 organisms/m^3; Figure 3.9a; Table 3.11). Mean total pelagic zooplankton density declined to 527.5 organisms/m^3 in early June, then to 323.1 organisms/m^3 by mid-June, primarily due to lowered copepod abundance. In early July, total pelagic zooplankton density rebounded to 1,114.2 organisms/m^3, and reached maximum annual densities by mid-July (1,395.8 organisms/m^3; Figure 3.9a; Table 3.11). In late July, mean total pelagic zooplankton density began a fairly dramatic fall decline, decreasing from 905.5 to 504.9 organisms/m^3 by late August, and 225.7 organisms/m^3 by late September. Pelagic total zooplankton densities remained relatively constant from early October through the end of the year (Figure 3.9a; Table 3.11).

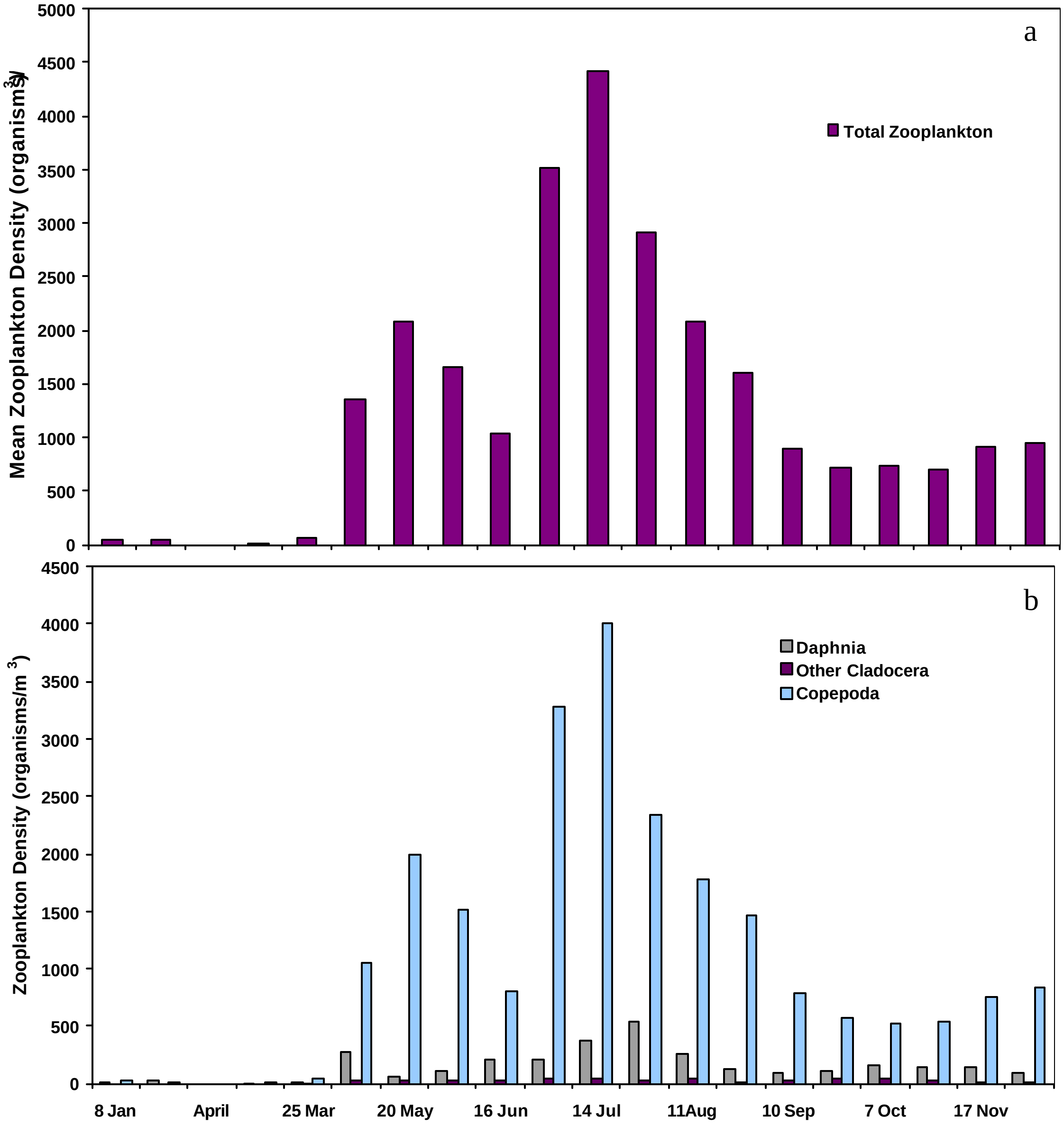

Figure 3.9 Mean total zooplankton densities (a) and mean zooplankton densities by taxonomic group (b) in Lake Roosevelt, WA. Includes all sites sampled in 1998. No data was collected in April.

Table 3.11 **Mean pelagic zooplankton densities (organisms/m^3) by taxonomic group and sample date collected from Lake Roosevelt, WA. Data includes all sites sampled in 1998.**

Approximate Sample Date	*Daphnia*	Other Cladocera	Copepoda	Total Zooplankton
8-Jan	11.14	0.4	35.4	14.5
3-Feb	33.12	0.1	17.1	14.5
10-Mar	2.8	0.4	14.4	5.5
25-Mar	10.6	1.1	48.7	18.8
7-May	278.3	26.2	1,056.60	422.8
20-May	55.9	23	1,995.90	659.7
3-Jun	113.2	36.4	1,514.10	527.5
17-Jun	216.3	23.2	800.2	323.1
2-Jul	204.8	38.7	3,276.40	1,114.20
15-Jul	369.6	45.4	4,011.60	1,395.80
29-Jul	543.9	25.6	2,346.90	905.5
11-Aug	254.7	38.9	1,783.50	652.9
25-Aug	124.1	11	1,466.50	504.9
10-Sep	91.7	24.8	783.3	284.4
23-Sep	104.7	39.1	569.5	225.7
7-Oct	167.4	46.3	517.1	229.1
27-Oct	141.3	28.6	531.4	219.3
17-Nov	142.5	9.7	760.2	284.7
15-Dec	101	4.3	839.8	296.5
MEAN	**157.7**	**22.6**	**1,192.10**	**431.6**

Timing of peak pelagic zooplankton densities were similar across taxonomic groups in 1998. Overall, copepod (4,011.6 organisms/m^3) and other Cladocera (45.8 organisms/m^3) densities peaked in mid-July, while *Daphnia* spp. (543.9 organisms/m^3) peaked in late-July (Figure 3.9b; Table 3.11). Other cladoceran peak mean densities were 12 times less than peak *Daphnia* spp. mean densities, and nearly 87 times less than peak copepod mean densities (Figure 3.9a; Table 3.11).

As expected, mean zooplankton densities increased dramatically with increasing proximity to Grand Coulee Dam (Figure 3.10). The northern sections of Lake Roosevelt (Evan's Landing, Kettle Falls, and Gifford) are the most riverine sections of the reservoir, usually characterized by greater flows that flush zooplankton downriver. The transitional zone of Lake Roosevelt (Hunters, Spokane River confluence, and Seven Bays) is characterized by slower water velocities and increasingly lacustrine conditions, which allow zooplankton populations to begin accumulating. The section of Lake Roosevelt nearest Grand Coulee Dam (Keller Ferry, Sanpoil River confluence, and Spring Canyon) had the greatest mean zooplankton densities, likely a result of the more lacustrine conditions found there. Mean zooplankton densities in the Sanpoil River arm had slightly greater mean densities compared with nearby locations, with the exception of Spring Canyon, which had the greatest mean density observed in 1998 (Figure 3.10). Porcupine Bay also had slightly greater mean density compared with nearby mainstem Columbia River locations (Figure 3.10). Cichosz et al. (1999) suggested the greater mean zooplankton densities found in the Sanpoil and Spokane River arms of Lake Roosevelt are a result of greater temperatures and phytoplankton biovolume observed there, compared with the mainstem locations. However, in 1998 phytoplankton chlorophyll *a* and temperature were found to not differ significantly by site (Scheffe's S; $p<0.05$). To detect a measurable difference, a more subtle technique may be necessary. Simple linear regression found the log transformation of mean zooplankton density significantly related to the log transformation of phytoplankton chlorophyll *a* (ANOVA, $p<0.0001$; $r^2=0.38$) and the log transformation of temperature (ANOVA $p<0.0001$; $r^2=0.58$). Relationships were similar

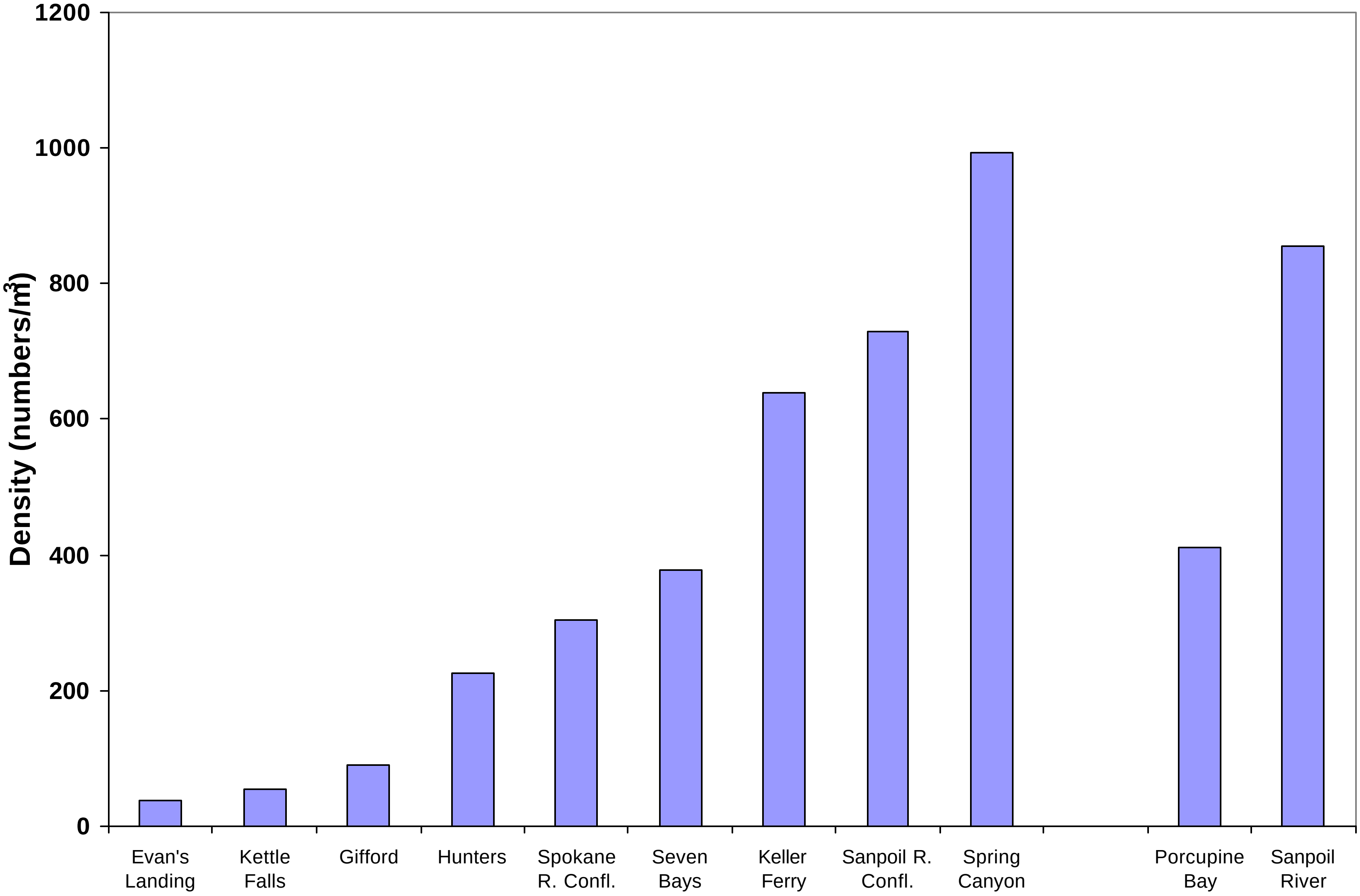

Figure 3.10 **Mean total pelagic zooplankton densities by location in Lake Roosevelt, WA (1998).**

between log transformed mean zooplankton biomass versus log transformed phytoplankton chlorophyll *a* (ANOVA $p<0.0001$; $r^2=0.21$) and log transformed temperature (ANOVA $p<0.0001$; $r^2=0.39$). Therefore, it appears that phytoplankton and temperature do affect zooplankton.

Beginning in 1991, reservoir mean zooplankton abundance was computed as an average of densities observed at five index stations (Gifford, Porcupine Bay, Seven Bays, Keller Ferry, and Spring Canyon). While additional zooplankton sampling stations have been added since 1995, between year comparisons of zooplankton density will continue using the five-site average in order to preserve comparability across years.

Predictably, in Lake Roosevelt total zooplankton abundance is low from January through April. Beginning in sometime around May, abundance generally begins to increase, coinciding with reservoir refill, increased availability of food resources in the form of algal abundance, and increases in temperature (Cichosz, et al., 1999). Densities remain high from June through October, before decreasing in November to near minimum levels, likely a result of decreased water temperatures. The increased densities observed in the summer months provide a large food base for planktivorous fish, facilitating greater growth (Cichosz, et al, 1997). In 1998, mean zooplankton densities for the traditional index stations followed a pattern similar to what has been observed in Lake Roosevelt in past years (Figure 3.11a, Table 3.12). Densities were low in January through March, but began to show increased numbers by May, which was followed by a moderate decline in early June. By late June, densities began to increase, reaching peak density in July (1,470 organisms/m^3). From peak density, total mean zooplankton densities declined steadily until September (Figure 3.11a, Table 3.12). Mean densities remained relatively stable from September through December.

Analysis of the taxonomic groups showed similar patterns as those observed for the total zooplankton (Figure 3.11b). *Daphnia* and other Cladocera densities were low in January through March, began increasing in May, reaching peak densities in July before declining in August (Figure 3.11b; Table 3.12). *Daphnia* densities remained relatively steady for the remainder of the year. Other Cladocera densities remained relatively stable through

October before exhibiting further declines in November and December. Of the three taxonomic groups examined, Copepoda density shifts most closely resembled those of the total zooplankton (Figure 11b; Table 3.12), indicating the importance of the Copepoda as a component of the total zooplankton. Copepod densities began low in January through March before increasing in May (Figure 11b; Table 3.12). There was a slight decline in June, before densities rebounded and peaked in July (4,143.1 organisms/m^3). Densities declined, beginning in August and continuing through October, before showing small increases in November and again in December (Figure 11b; Table 3.12).

Table 3.12 Monthly mean densities (organisms/m^3) of Copepoda, *Daphnia*, and other Cladocera for the five traditional Lake Roosevelt, WA index locations (1998).

Month	Copepoda	*Daphnia*	Other Cladocera	Total Zooplankton
Jan	34.6	7.4	0.2	13.1
Feb	11.1	2.3	0.1	4.2
Mar	33.4	2.3	0.9	11.6
May	1,906.6	48.1	30.3	632.2
Jun	1,252.2	137.9	33.3	449.7
Jul	4,143.1	515.3	34.7	1473.0
Aug	1,773.2	162.7	24.0	618.4
Sep	852.7	84.8	33.3	308.1
Oct	620.9	139.6	37.7	251.0
Nov	847.8	100.3	7.9	300.4
Dec	1,142.2	128.1	4.6	400.2

In 1998, as in the past, total zooplankton abundance in Lake Roosevelt has been dominated by copepods. Copepod densities composed 89.9 % (942,658 organisms/m^3) of the total zooplankton, compared with 8.2 % (86,280 organisms/m^3) for *Daphnia*, and 1.9 % (19,907 organisms/m^3) for other Cladocera. Lake Roosevelt has been characterized in the past as a mesotrophic system that has become increasingly oligotrophic in recent years. Copepods tend to be more successful than Cladocera in oligotrophic lakes due to selective feeding mechanisms and obligate sexuality (McNaught 1975 and Allan 1976).

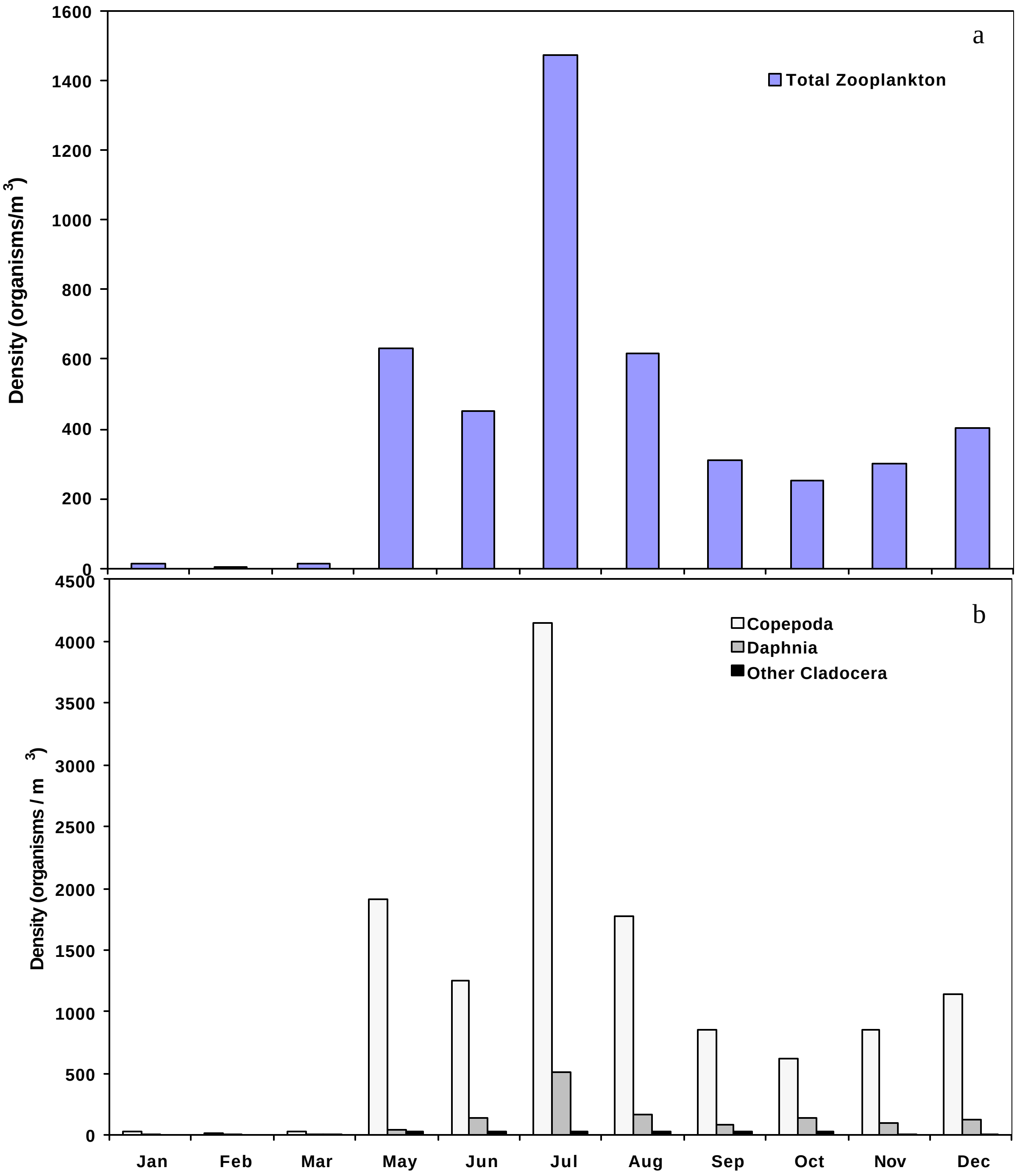

Figure 3.11 **Monthly mean total zooplankton densities (a) and zooplankton densities by taxonomic group (b) in Lake Roosevelt, WA (1998). Data from the traditional index stations (Gifford, Porcupine Bay, Seven Bays, Keller Ferry, and Spring Canyon) only have been included. No data was collected in April.**

Comparisons of past years' mean total zooplankton densities indicate zooplankton density in Lake Roosevelt ranged between 1,313 organisms/m^3 (1993) and 9,151 organisms/m^3 (1997) (Table 3.13). Mean total zooplankton density for 1998 was 501.8 organisms/m^3, a much lower mean density than observed at any other time in the historic database. All three taxonomic groups examined, Copepoda, other Cladocera, and *Daphnia*, exhibited decreased mean densities compared with previous data for Lake Roosevelt. Reasons for this remain unclear. Comparatively, 1998 was a normal water year with no unusual hydro-operations or weather events that may have caused such a drastic reduction in mean total zooplankton density. Phytoplankton biovolume and population structure also appear to be well within the norm, and are similar to what was found in 1997.

One possible explanation may be that zooplankton densities are decreasing in Lake Roosevelt as a result of a currently unidentified cause. Contaminants identified in Lake Roosevelt (Johnson et al 1991) or poor food quality may have the capacity to reduce fecundity or increase mortality rates in many species (Wetzel 1983). The long history of using *Daphnia* for chemical assays to identify which chemicals are harmful or persistent in the environment has been partially based on the sensitivity of the taxon to contaminants (APHA 1976). In 1998, *Daphnia* spp. had the greatest overall decline compared with previous years densities, suggesting that the decline was most strongly felt by that group.

Alternatively, the decline may be an artifact of human error. The protocol for counting zooplankton for biomass and density calculations requires that 100 of the most common individuals must be included for the numbers to be statistically viable. Samples that are split beyond the capacity to contain 100 individuals/m^3 will contain only a few of the most common individuals, likely to be nauplii or *D. b. thomasi*, and none of the less common species, such as *Daphnia*. This may potentially cause an artificial inflation of the very common species, while underestimating the number of less common species.

Examination of the data in relation to protocols suggests this may have factored into the differences in the total densities observed in 1998, but to what extent was unknown.

Table 3.13 Mean total zooplankton densities, and mean densities for the taxonomic groups, Copepoda, *Daphnia*, and other Cladocera, for the five traditional index locations in Lake Roosevelt, WA (1998).

Year	*Daphnia*	Other Cladocera	Copepoda	Total Zooplankton
1991	1,361	260	7,531	9,151
1992	1,020	76	6,957	8,054
1993	807	17	489	1,313
1994	891	13	575	1,478
1995	918	111	2,095	3,141
1996	995	43	1,885	2,933
1997	405	64	1,828	2,297
1998	151	23	1,417	502

3.4.3 Zooplankton Lengths

Twenty-one species of zooplankton were collected in Lake Roosevelt in 1998. Four species had annual mean lengths less than 0.5 mm, 12 species had annual mean lengths of 0.5 mm to 1.0 mm, and six species had annual mean lengths of 1.0 mm or greater, including the only species exceeding 2.0 mm in mean length, *Leptodora kindti.* Of the total number of zooplankton measured in 1998 (n = 37,832), 41.3 % were smaller than 0.5, 35.0 % were 0.5 to 1.0 mm in size, 19.6 % were 1.0 to 2.0 mm in length, and 4.1 % had an annual mean length of 2.0 mm or greater. As with previous years, *Daphnia* (1.3 mm) comprised the group with the greatest annual mean length, while the smallest group was composed of the copepods (0.56 mm). Other Cladocerans (0.63 mm) were, on average, only slightly larger than the copepods, despite the inclusion of *Leptodora kindtii* (mean length 3.29 mm), the largest zooplankter in Lake Roosevelt (Table 3.14).

Daphnia consistently maintained the greatest mean length over the year, while other Cladocera were the shortest group January through May (Figure 3.12). Copepods and other Cladocera interchanged as the shortest group for the remainder of the year (Figure 3.12). The spike in other Cladocera mean length observed in June, and much of the variation observed from June through December, was likely a result of shifts in *Leptodora kindtii* abundance in the population (Figure 3.12).

Zooplankton mean length was greatest in January and February in 1998 (0.84 mm and 0.82 mm, respectively), likely as a result of greater numbers of large, over-wintering adult *Daphnia*, combined with low numbers of small-bodied zooplankton such as nauplii (Figure 3.13). In March, mean length had decreased nearly 0.2 mm and continued to decrease until May, when the lowest mean length was observed (0.56 mm), coinciding with increased abundance of juvenile zooplankton, particularly nauplii. Mean length increased from June through September, when it peaked a second time (0.81 mm), which was followed by a second decline in annual mean length that extended through December (Figure 3.13). Increased body length, resulted primarily from a proportional increase in densities of large bodied *Daphnia* spp. combined with increased abundances of nauplii early in the season. The fall decrease in mean zooplankton length was more difficult to explain in light of greater *Daphnia* densities observed. However, while there were greater overall, numbers of large bodied *Daphnia*, in particular *D. pulex*, the mean length of the *Daphnia* decreased nearly 0.2 mm overall in the late fall (Figure 3.12 & 3.13).

Table 3.14 Annual mean lengths for all species of zooplankton observed in Lake Roosevelt, WA (1998).

Species	Mean Length (mm)	Standard Deviation	Number	Observed Range
Daphnia				
Daphnia galeata	1.16	0.505	1991	0.44 - 2.81
Daphnia pulex	1.47	0.642	3234	0.48 - 3.60
Daphnia retrocurva	1.09	0.47	1206	0.28 - 2.66
Daphnia schodleri	1.37	0.546	550	0.52 - 3.13
Daphnia thorata	1.75	0.494	142	0.60 - 3.06
Juvenile *Daphnia*	0.52	0.087	148	0.32 - 0.72
Other Cladocera				
Alona quadrangularis	0.49	0.169	93	0.20 - 0.94
Bosmina longirostris	0.34	0.081	1437	0.12 - 0.68
Ceriodaphnia quadrangula	0.48	0.265	34	0.24 - 1.40
Chydorus sphaericus	0.30	0.115	131	0.14 - 1.00
Diaphanosoma birgei	0.77	0.269	104	0.28 - 1.66
Diaphanosoma brachyurum	0.85	0.28	467	0.28 - 1.72
Leptodora kinditii	3.29	2.28	106	0.30 - 11.2
Polyphemus pediculus	0.53	0.326	8	0.32 - 1.18
Sida crystallina	0.98	0.397	245	0.20 - 2.38
Copepoda				
Diacyclops bicuspidatus thomasi	0.71	0.249	9231	0.10 - 1.60
Epischura nevadensis	0.88	0.613	2236	0.26 - 2.75
Leptodiaptomus ashlandi	0.83	0.272	5387	0.28 - 2.13
Mesocyclops edax	0.84	0.26	905	0.28 - 1.60
Harpacticoid	0.54	0.178	36	0.26 - 1.00
Unknown Cyclopoid	0.57	0.142	46	0.32 - 1.00
Nauplii	0.17	0.058	10095	0.08 - 0.46

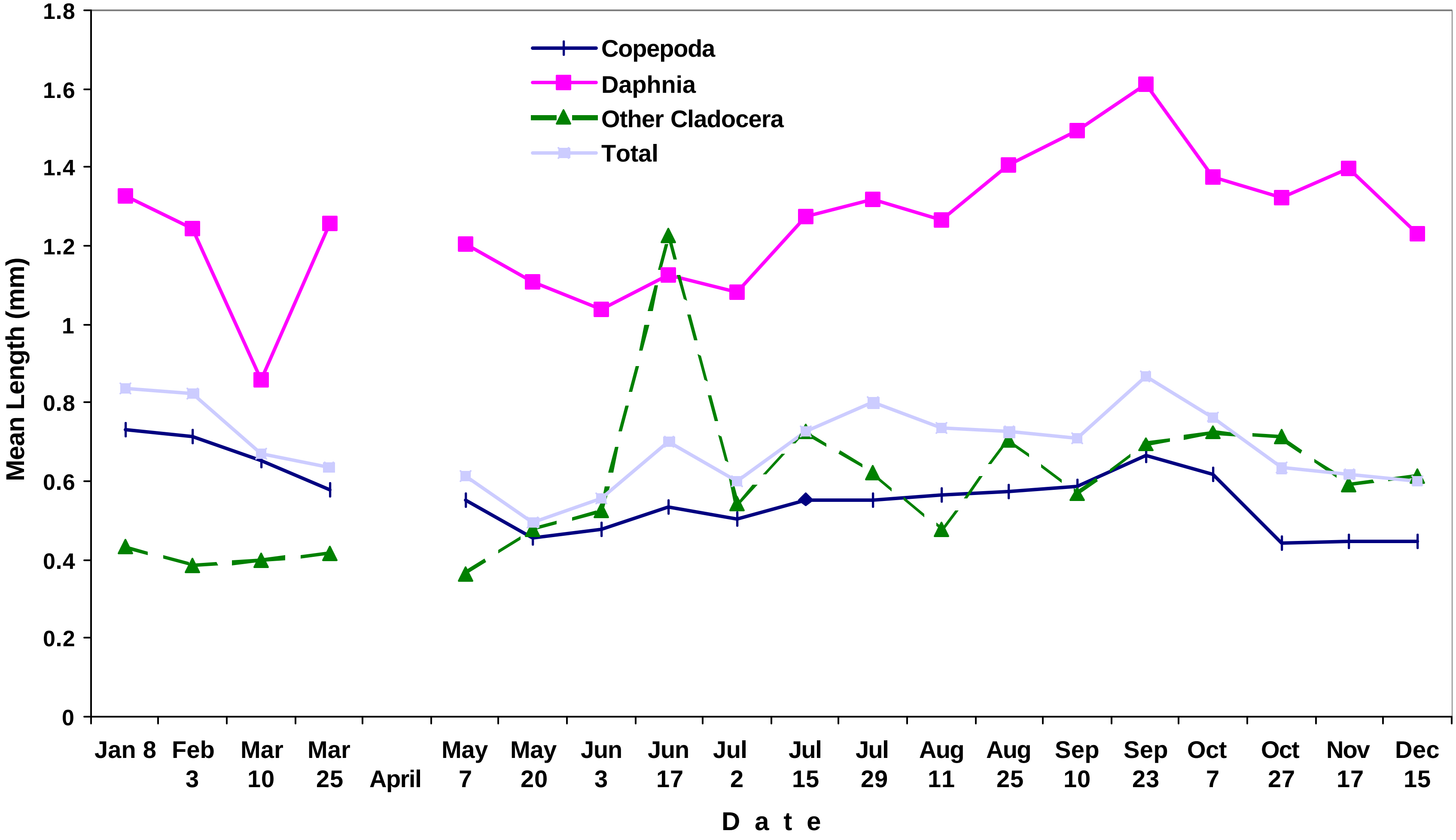

Figure 3.12 **Seasonal variation in total zooplankton mean length and mean length by taxonomic group in Lake Roosevelt, WA (1998).**

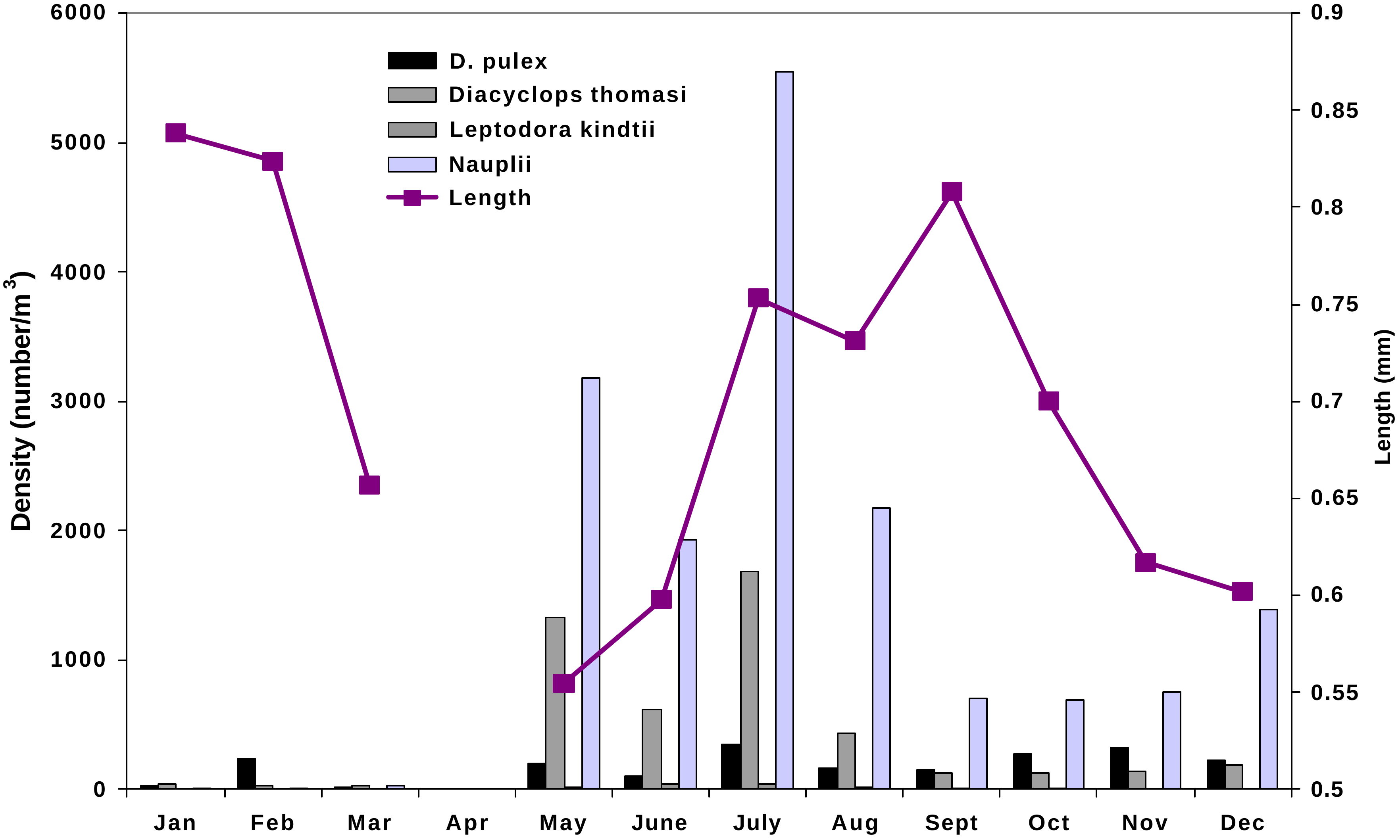

Figure 3.13 **Monthly variation in total zooplankton mean length and *D. pulex, D.b. thomasi, L. kindtii*, and nauplii densities in Lake Roosevelt, WA (1998).**

Mean zooplankton lengths were shortest for the northern locations of the reservoir, with the smallest zooplankton mean lengths (0.414 mm) found at Evan's Landing (Table 3.15). Generally, mean zooplankton length progressively increased with increasing proximity to Grand Coulee Dam in the mainstem Columbia River sections of Lake Roosevelt (Table 3.15). Spring Canyon, the location closest to the dam, was the only exception. Annual mean length of the total zooplankton population was slightly lower than all mid and lower mainstem locations. The decease likely resulted from greater copepod densities combined with decreased *Daphnia* densities (Figure 3.14). The Sanpoil River location had the greatest mean length of the locations examined in 1998, likely resulting from the high density of *Daphnia* present (Figure 3.14). Porcupine Bay, located in the Spokane River arm, had a mean length similar to that found in the central portion of the mainstem section of Lake Roosevelt.

Table 3.15 Annual mean lengths (mm) of pelagic zooplankton by location in Lake Roosevelt, WA (1998).

Location	Reach	Mean Length (mm)	Standard Devation
Evan's Landing	Mainstem - Upper	0.414	0.338
Kettle Falls	Mainstem - Upper	0.457	0.433
Gifford	Mainstem - Upper	0.580	0.465
Hunters	Mainstem - Mid	0.715	0.621
Spokane River Confluence	Mainstem - Mid	0.726	0.576
Seven Bays	Mainstem - Mid	0.727	0.550
Keller Ferry	Mainstem - Lower	0.731	0.494
Sanpoil River Confluence	Mainstem - Lower	0.739	0.586
Spring Canyon	Mainstem - Lower	0.712	0.525
Porcupine Bay	Spokane River Arm	0.728	0.619
Sanpoil River	Sanpoil River Arm	0.816	0.584

Analysis of zooplankton lengths during the growing season (May through October) indicate the same trends observed for annual mean zooplankton lengths. Mean length increases with increasing proximity to Grand Coulee Dam for the mainstem Columbia

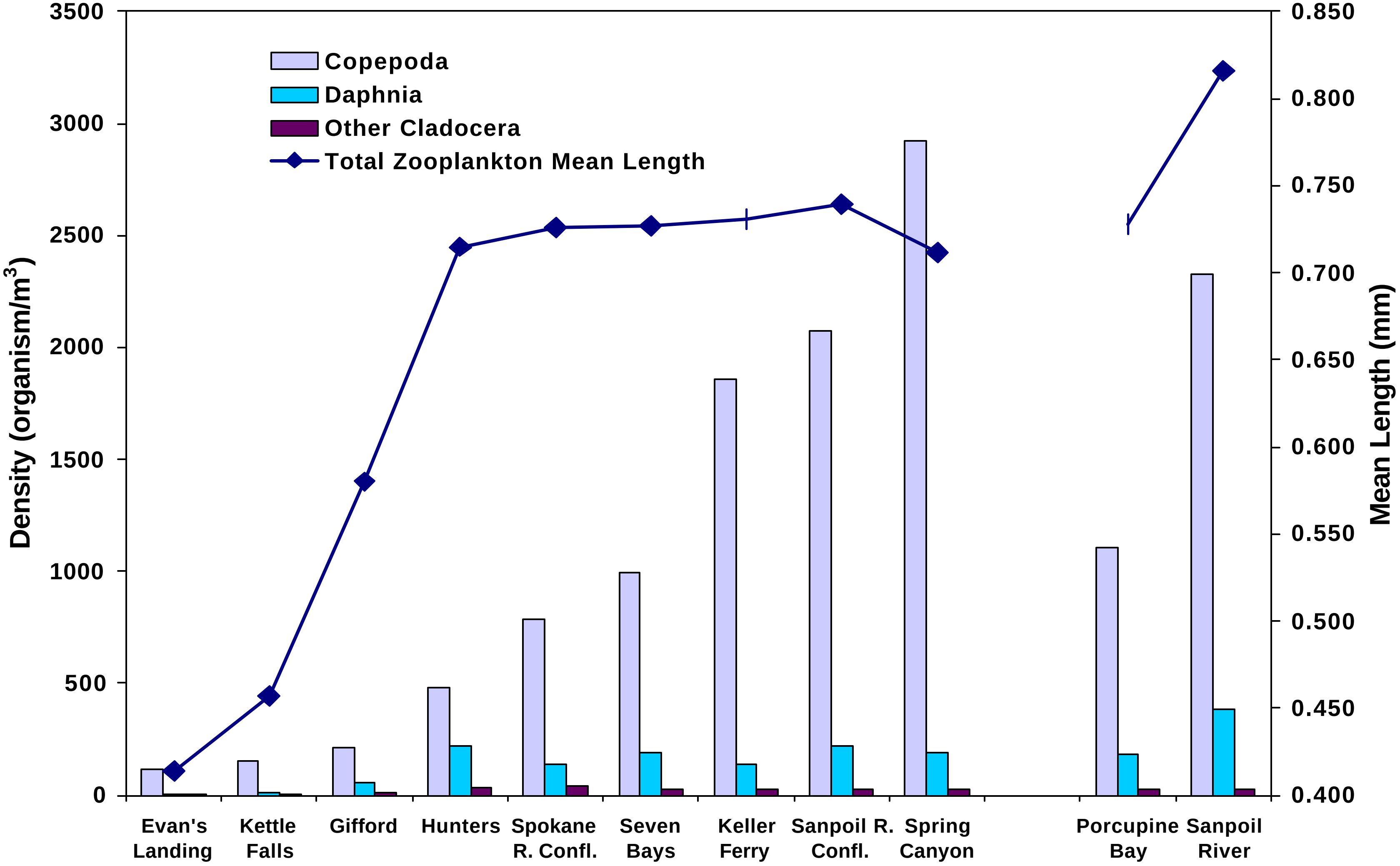

Figure 3.14 **Mean densities by taxonomic group and total zooplankton mean length for sampling locations in Lake Roosevelt, WA (1998).**

River locations with the exception of Spring Canyon, which exhibited the same slight decrease in mean length (Table 3.16). The Sanpoil River arm had the greatest mean zooplankton length observed during the growing season in Lake Roosevelt, while the mean length at Porcupine Bay was similar to what was observed at Seven Bays, a mainstem location (Table 3.16). The larger size of zooplankton at the Sanpoil River location likely resulted from a slightly greater density of *Leptodora kindtii*, the largest zooplankter found in Lake Roosevelt, as well as a much greater density of *Daphnia*, compared with other locations in the reservoir. Temperature, phytoplankton density, and biovolume do not appear to be notably different from what was observed at nearby locations. Temperature and phytoplankton chlorophyll *a* were not significantly different between sites (ANOVA; $p<0.05$). It may be possible that a higher quality food source was available to zooplankton at that location, but further examination of the phytoplankton at the Sanpoil River location would be necessary.

Table 3.16 Mean lengths (mm) of pelagic zooplankton during the growing season (May – October) in Lake Roosevelt, WA (1998).

Location	Reach	Mean Length (mm)	Standard Devation
Evan's Landing	Mainstem - Upper	0.370	0.320
Kettle Falls	Mainstem - Upper	0.437	0.437
Gifford	Mainstem - Upper	0.579	0.489
Hunters	Mainstem - Mid	0.683	0.626
Spokane River Confluence	Mainstem - Mid	0.719	0.588
Seven Bays	Mainstem - Mid	0.732	0.575
Keller Ferry	Mainstem - Lower	0.739	0.517
Sanpoil River Confluence	Mainstem - Lower	0.759	0.620
Spring Canyon	Mainstem - Lower	0.738	0.556
Porcupine Bay	Spokane River Arm	0.733	0.646
Sanpoil River	San Poil River Arm	0.831	0.613

The role of body size in planktonic herbivores has intrigued plankton ecologists since the concept of competitive superiority of large-bodied species was first suggested by Hrbacek (1962) and Brooks and Dodson (1965). It has been hypothesized that small-bodied zooplankton are less vulnerable to predation by visually oriented planktivores, and thus will exhibit greater abundance in aquatic systems where planktivorous fish are present (Zaret, 1980; Kerfoot and Sih 1987; Gliwicz and Pijanowska 1989). Alternatively, in the absence of planktivorous fishes, large-bodied species competitively exclude small-bodied species by monopolizing resources with more efficient feeding abilities (Hall et al. 1976). The Copepoda comprised 89.2 % of the zooplankton less than 0.5 mm in length. The small size of the Copepoda is driven largely by the immature stage of the copepods (nauplii) and *Diacyclops thomasi*, the most predominant species identified in the reservoir. Combined, they comprised 55.7 % of the total zooplankton abundance in 1998. Small copepods are an important resource in most lakes and reservoirs as they frequently support early life-stage growth of many fish species. They have been considered less important in Lake Roosevelt in the past because research has focused on the needs of adult fishes. Large bodied species of zooplankton are required to support growth and reproduction of larger visually oriented predators.

Daphnia and Copepoda comprised 47.8 % and 48.2 %, respectively, of the zooplankton greater than 1.0 mm. The *Daphnia* group comprised the largest overall group of zooplankton found in Lake Roosevelt with mean lengths ranging between 1.09 and 1.75 mm (Table 3.14). As expected, these groups were consistently found in the diets of Lake Roosevelt fish, as kokanee salmon and rainbow trout are large visual predators. Larger bodied prey are preferred because they allow optimal feeding behaviors for visual predators and planktivores (Mittelback, 1981). Continued presence of large (>2.0 mm), medium (1.0 – 2.0 mm), and small (< 1.0 mm) zooplankton in Lake Roosevelt suggests that the influence of fish predation on zooplankton in the system is low (Brooks and Dodson, 1965). The relatively low impact of the fish population on the zooplankton in Lake Roosevelt suggests there is a potential to increase fish populations through manipulation of stocking strategies and habitat improvements in the future.

3.5 Zooplankton Biomass

3.5.1 Total Pelagic Zooplankton Biomass

Total zooplankton exhibited low biomass values during the winter and early spring (January through March) in Lake Roosevelt in 1998, but began to increase in May, followed by a slight decrease in June (Figure 3.15a). Mean total zooplankton biomass peaked in July, and then steadily declined from August through December (Figure 3.15a). Although biomass was decreasing during the late summer and fall, the July spike combined with a relatively slow reduction in biomass levels allowed a large standing crop of zooplankton to be available for utilization by planktivores during the typical growing season of most fish species in Lake Roosevelt.

July was characterized by spikes in both density and biomass for mean total zooplankton density. However, density spiked in early in July and biomass spiked in late July. Explanation for the discrepancy lies in taxonomic group density versus biomass differences, which result from disparity in sizes. Although *Daphnia* exhibit a lower annual abundance, they tend to be relatively large-bodied, and so contribute more to biomass levels than the comparatively small-bodied copepods and other Cladocera (Figures 3.9b and 3.15b; Table 3.17). So while the peak density of copepods was much greater than that of the *Daphnia,* the much greater size and biomass of the *Daphnia* ultimately drove peaks in total zooplankton biomass (Table 3.17).

In 1998, *Daphnia* accounted for 53.6 % of the total zooplankton biomass observed in Lake Roosevelt, compared with 10 % of the total abundance (Table 3.17). In contrast, copepods contributed 44.0 % of the total zooplankton biomass and 88 % of the total abundance, while other Cladocera contributed 2.5 % biomass and 2.1 % abundance (Table 3.17). Ninety-one percent of all zooplankton biomass in 1998 was contributed by just seven species; *D. pulex* (30.8 %); *D. b. thomasi* (17.0 %), *L. ashlandi* (14.2 %), *D. schødleri* (9.5 %), *E. nevadensis* (7.5 %), *D. galeata* (6.8 %), and *D. retrocurva* (5.4 %). The remaining eleven species and nauplii accounted for the remaining nine percent of the total biomass observed in Lake Roosevelt in 1998.

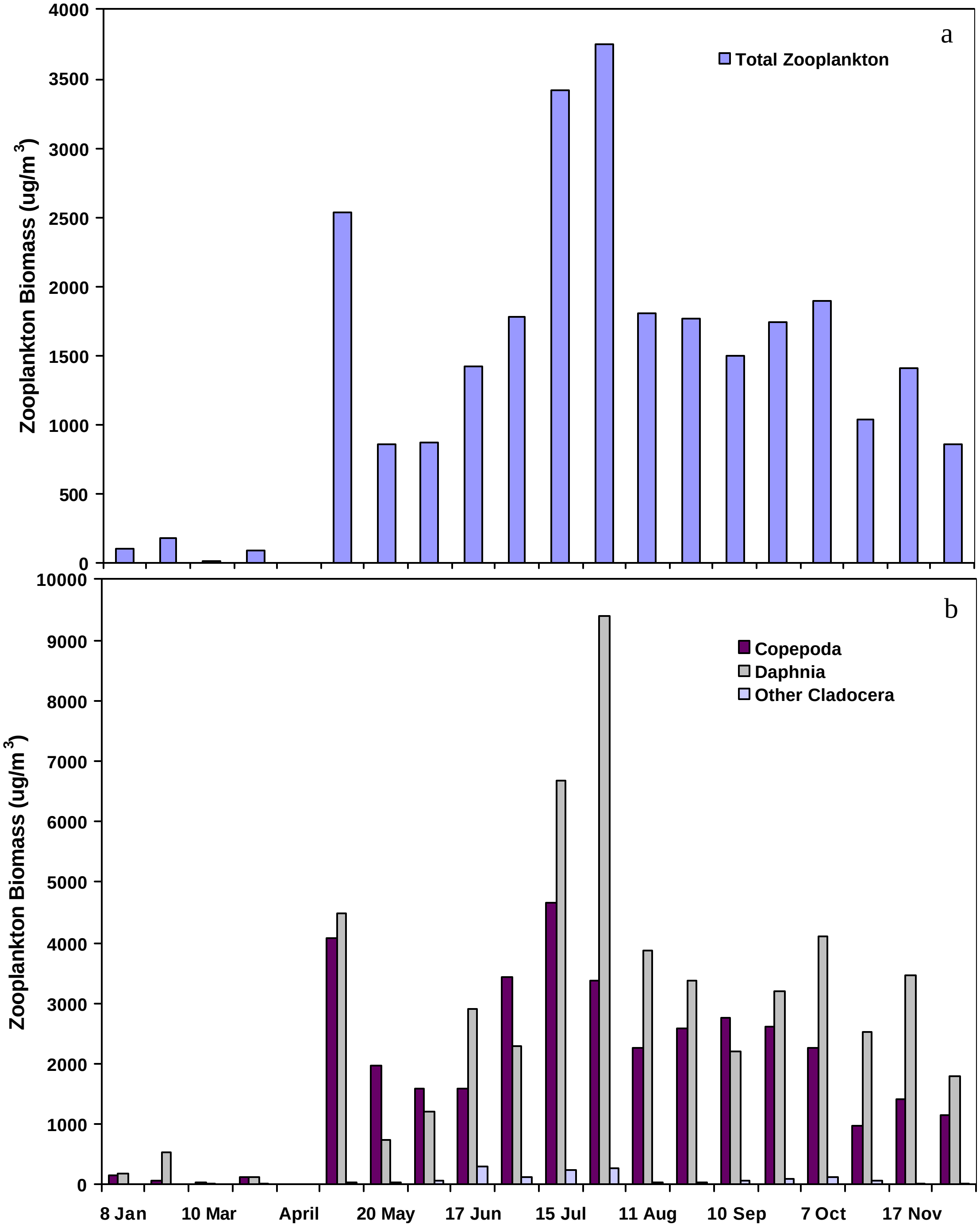

Figure 3.15 Mean total zooplankton biomass (a) and mean zooplankton biomass by taxonomic group (b) in Lake Roosevelt, WA. Includes all sites sampled in 1998.

Table 3.17 **Annual total zooplankton biomass, total biomass by taxonomic group, and percent biomass and density of each taxonomic group in Lake Roosevelt, WA (1998).**

	Total biomass (ì g/m^3)	Percent Biomass	Percent Density
Copepods	2,881,026	44 %	88 %
Daphnia	3,512,502	54 %	10 %
Other Cladocerans	161,328	2 %	2 %
Total	6,554,856		

In 1998, the highest annual mean total zooplankton biomass values by location were recorded at the Sanpoil River confluence (3,303 ìg/m^3), followed by Spring Canyon (2,279 ìg/m^3; Figure 3.16a; Table 3.18). The lowest annual mean total zooplankton biomass values were found at Evan's Landing (22 ìg/m^3), followed by Kettle Falls (54 ìg/m^3; Table 3.18), which coincides with what was observed previously for mean density (Table 3.14). Although biomass generally increased with increasing proximity to Grand Coulee Dam, there were some exceptions. Total zooplankton biomass at Hunters and Sanpoil River confluence were much higher than values observed at adjacent locations, both upriver and downriver (Fig. 3.16A; Table 3.18). As expected, the comparatively higher biomass values observed at the Sanpoil River confluence and Hunters were also exhibited in the length comparisons between these locations (Table 3.15). The greater biomass values both at the Sanpoil River confluence and Hunters resulted from the greater abundances of *Daphnia* found at those locations (Table 3.18, Figure 3.9a).

Total zooplankton biomass was consistently low (< 500 ìg/m^3) at all locations except one from January through March in 1998 (Table 3.19). The Sanpoil River confluence exhibited a small increase in biomass in February, which resulted from a spike in *D. pulex* density (Table 3.23; Figure 3.13). *Daphnia pulex* is one of the larger zooplankters found in Lake Roosevelt, and as such, have the capacity to strongly impact overall biomass when present in large numbers.

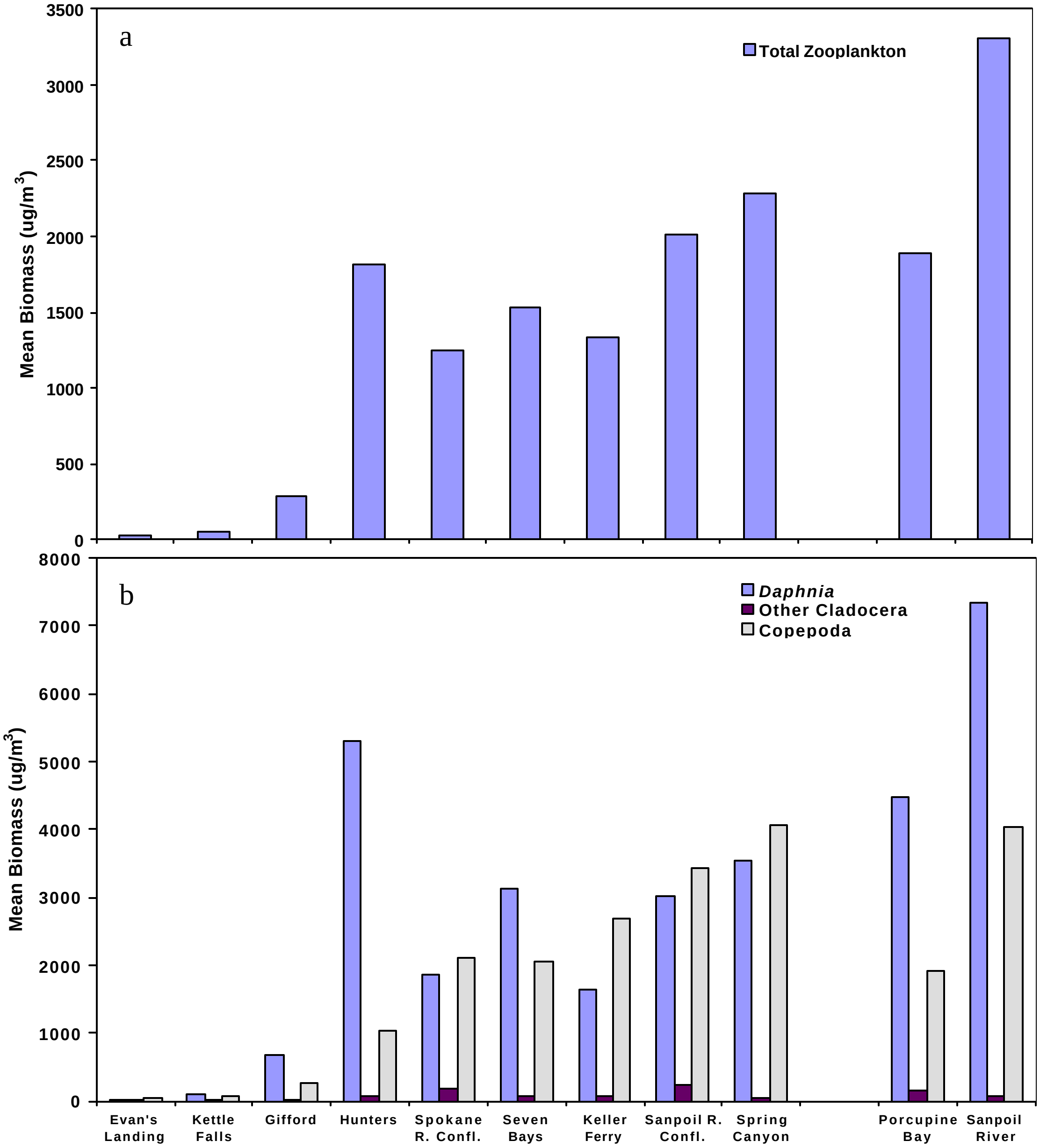

Figure 3.16. Annual mean total zooplankton biomass, and biomass for individual taxonomic groups by location in Lake Roosevelt, WA (1998).

Table 3.18 **Mean total zooplankton biomass (µg/m^3) and mean biomass (µg/m^3) and percent biomass for each taxonomic group for all locations sampled in Lake Roosevelt, WA (1998).**

	Daphnia	**Other Cladocera**	**Copepoda**	**Total Zooplankton**
Evan's Landing	7.0 (73.7)	9.7 (8.6)	51.6 (17.7)	**22.3**
Kettle Falls	106.6 (36.7)	12.3 (54.0)	62.0 (9.3)	**53.8**
Gifford	683.5 (30.0)	24.1 (66.5)	264.1 (3.5)	**280.3**
Hunters	5,310.3 (18.3)	80.1 (79.9)	1,044.6 (1.8)	**1,813.4**
Porcupine Bay	4,478.8 (32.3)	147.2 (64.5)	1,922.3 (3.2)	**1,893.4**
Spokane R. Confluence	1,849.9 (53.4)	190.2 (40.4)	2,097.6 (6.2)	**1,249.7**
Seven Bays	3,128.1 (42.6)	60.9 (55.7)	2,050.1 (1.6)	**1,530.3**
Keller Ferry	1,648.6 (64.1)	76.3 (33.6)	2,693.3 (2.3)	**1,337.8**
Sanpoil R. Confluence	7,328.0 (38.8)	58.6 (60.5)	4,024.6 (0.7)	**3,303.1**
Sanpoil River	3,025.9 (54.3)	235.0 (40.9)	3,440.8 (4.8)	**2,016.2**
Spring Canyon	3,529.9 (56.8)	54.0 (42.2)	4,069.0 (1.0)	**2,279.5**
Reservoir Mean	**2,828.1**	**86.6**	**1,988.3**	**1439.4**

Table 3.19 Monthly mean total zooplankton biomass (ì g/m^3) for all locations sampled in Lake Roosevelt, WA (1998).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Evan's Landing	5	6	6	--	28	48	30	20	24	18	7	10	**22**
Kettle Falls	3	--	3	--	12	62	84	199	35	27	54	4	**54**
Gifford	7	3	2	--	37	130	365	288	521	1,216	54	14	**280**
Hunters	--	10	7	--	121	189	813	981	3,038	7,045	8,017	38	**1,813**
Porcupine Bay	21	8	34	--	548	851	5,433	2,537	1,935	1,240	1,793	3,562	**1,893**
Spokane R. Confl.	46	39	9	--	1,061	929	2,493	1,518	956	2,483	998	1,268	**1,250**
Seven Bays	33	46	6	--	1,059	657	4,540	1,356	1,815	1,799	1,314	679	**1,530**
Keller Ferry	199	26	28	--	1,306	1,634	2,749	1,689	2,555	578	884	479	**1,338**
Sanpoil R. Confl.	195	1,448	369	--	10,026	3,683	5,428	4,280	2,339	837	799	967	**3,303**
Sanpoil River	405	10	18	--	1,404	2,703	5,305	3,047	2,294	336	1,042	1,329	**2,016**
Spring Canyon	75	--	65	--	3,043	1,714	5,802	3,664	2,065	550	459	1,105	**2,279**
Mean	**99**	**177**	**50**	**--**	**1,695**	**986**	**3,374**	**1,780**	**1,618**	**1,466**	**1,402**	**859**	**1,439**

The log transformation of mean zooplankton biomass varied significantly across locations. The differences were between the upper and lower sections of the study area. Evan's landing was significantly lower than all sites but Kettle Falls, Gifford, Hunters, and Seven Bays (Scheffe's S; $p<0.05$). Kettle Falls was significantly lower than the Sanpoil River and Spring Canyon only.

Examination of the growing season trends in zooplankton biomass indicated that *D. b. thomasi* and *D. pulex* contributed nearly 50 % of the total biomass from May through July (Table 3.20). Beginning in August, *L. ashlandi* began to contribute twice the biomass of *D. thomasi*, combining with *D. pulex* and *D. schødleri* to contribute 50 % of the total biomass (Table 3.20). In October, *D. pulex* contributed 56.7 % of the biomass, with *L. ashlandi* contributing 24.6 % to the total zooplankton biomass (Table 3.20).

Table 3.20 Percent of total biomass (µg/m^3) during the growing season for selected species in Lake Roosevelt, WA (1998).

	May	June	July	Aug	Sept	Oct
Daphnia pulex	22.7%	18.3%	24.1%	19.3%	31.0%	56.7%
Daphnia retrocurva	--	10.2%	11.5%	--	--	--
Daphnia schodleri	18.9%	14.1%	9.2%	15.5%	5.9%	--
Diacyclops thomasi	37.6%	27.6%	22.8%	10.8%	--	--
Epischura nevadensis	12.7%	--	--	--	20.1%	7.7%
Leptodiaptomus ashlandi	--	6.6%	--	18.4%	28.7%	24.6%

3.5.2 Daphnia Biomass

Reservoir wide mean *Daphnia* spp. biomass collected in 1998 from 11 sites on Lake Roosevelt was 2,828.1 µg/m^3. The highest annual mean total *Daphnia* biomass values were recorded at Hunters (6,187 µg/m^3), in the middle reach of the mainstem Columbia River, and the Sanpoil River confluence in the upper section (6,176 µg/m^3; Table 3.21). Mean biomass at the Sanpoil River confluence was significantly greater than mean biomass values for all locations except Hunters, Porcupine Bay, and Spring Canyon

(Fisher's PLSD; $p<0.05$). The lowest annual mean *Daphnia* biomass value was recorded at Evan's Landing (7 $\mu g/m^3$; Table 3.21). Annual mean biomass values at the three upper mainstem Columbia River sites were relatively low (< 600 $\mu g/m^3$) compared with other sites throughout the reservoir. Annual mean *Daphnia* biomass values below Gifford ranged from 1,254 $\mu g/m^3$ at Keller Ferry to 6,187 $\mu g/m^3$ at Hunters (Table 3.21).

The maximum monthly mean *Daphnia* biomass value was recorded in July (6,197 $\mu g/m^3$) and the minimum was noted in March (75 $\mu g/m^3$; Figure 17, Table 3.21). Monthly mean *Daphnia* biomass values were less than 550 $\mu g/m^3$ from January through March. Monthly mean *Daphnia* biomass values increased in May and remained above 1,795 $\mu g/m^3$ for the remainder of the year.

The Sanpoil River confluence was the only site to produce a mean biomass value greater than 50 $\mu g/m^3$ during March (Table 3.21). The highest mean *Daphnia* biomass value was recorded in November at Hunters (28,089 $\mu g/m^3$). Mean *Daphnia* biomass values of 0.0 $\mu g/m^3$ were recorded at five sites; Evan's Landing (March, June and November), Kettle Falls (March), Gifford (February, March and May), Hunters (March), and Seven Bays (March). These low values have a profound effect on the monthly mean *Daphnia* biomass values early in the year, as 5 of the 0.0 $\mu g/m^3$ values were recorded in March, which resulted in the lowest monthly mean *Daphnia* biomass of 1998. Previously, *Daphnia* biomass has been positively correlated with temperature in Lake Roosevelt (Cichosz et al. 1999), which could explain low biomass values observed early and late in the year. Alternately, it is possible that these values could be the result of human error in the collection or analysis of the samples.

Table 3.21 ***Daphnia*** **biomass means (μg/m^3) by month and location in Lake Roosevelt, WA (1998). Samples were not collected in April.**

	Jan	Feb	Mar	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Evan's Landing	5	7	0	4	0	15	23	5	9	0	9	**7**
Kettle Falls	1	-	0	2	8	151	612	44	70	136	2	**102**
Gifford	3	0	0	0	34	802	706	668	4,195	121	18	**595**
Hunters	-	2	0	2	57	1,476	2,423	7,522	22,181	28,089	116	**6,187**
Porcupine Bay	10	6	14	200	1,567	14,304	5,727	4,903	1,582	4,785	9,397	**3,863**
Spokane River. Confl.	130	44	3	25	649	4,778	3,198	309	3,341	1,129	4,460	**1,642**
Seven Bays	81	50	0	12	635	11,848	3,320	2,682	3,207	1,898	2,145	**2,353**
Keller Ferry	388	58	19	760	2,583	4,863	2,056	2,116	266	371	316	**1,254**
Sanpoil River. Confl.	164	4,770	734	25,669	10,277	9,879	9,240	4,564	1,058	325	1,253	**6,176**
Sanpoil River.	978	9	2	43	4,855	9,301	5,008	3,158	166	747	1,390	**2,332**
Spring Canyon	3	-	47	2,089	1,920	10,752	7,577	3,184	454	433	648	**2,711**
Mean	**176**	**550**	**75**	**2,619**	**2,053**	**6,197**	**3,626**	**2,651**	**3,321**	**3,458**	**1,796**	

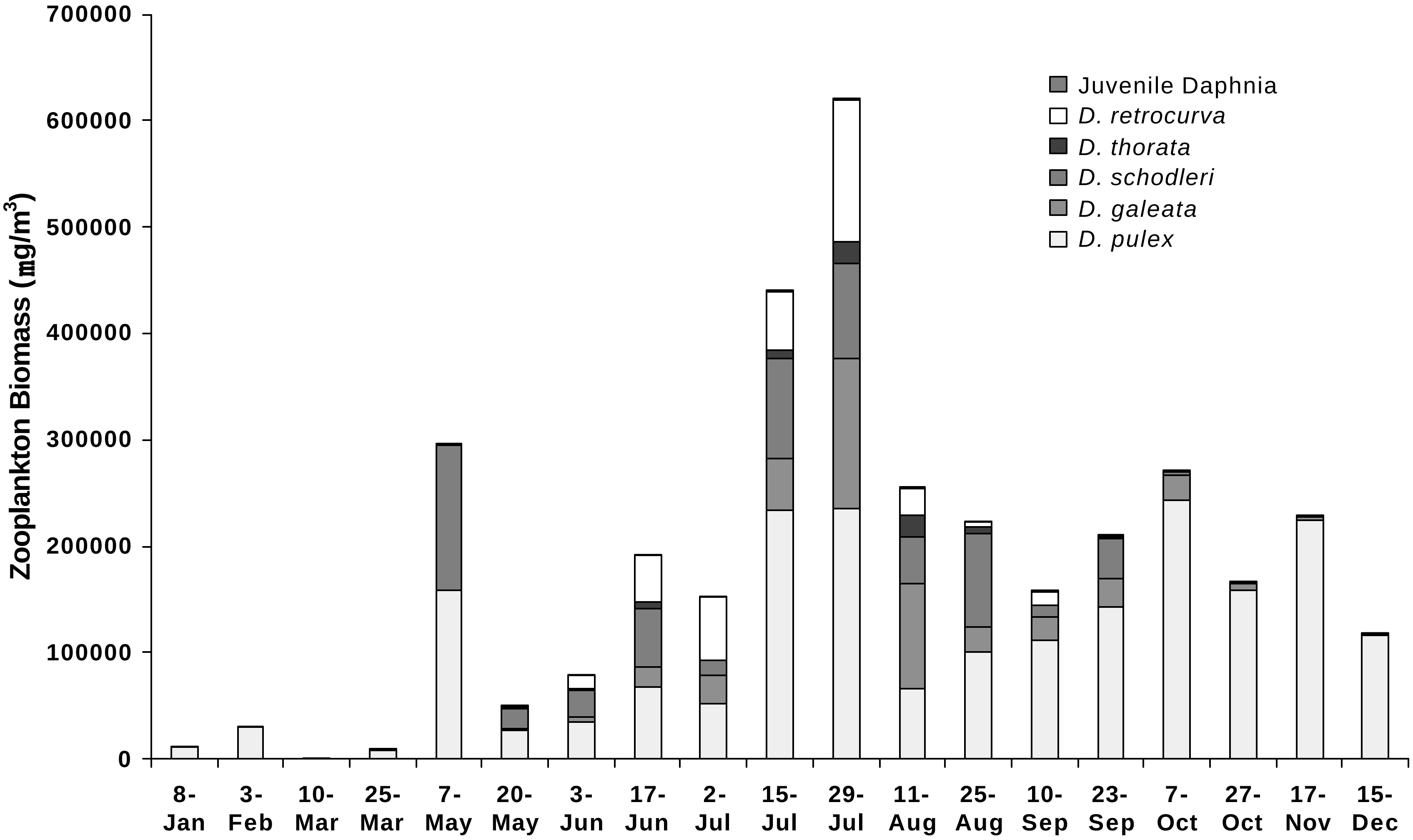

Figure 3.17 **Monthly mean *Daphnia* spp. biomass collected from eleven locations in Lake Roosevelt, WA (1998). No data was collected in April.**

Daphnia pulex accounted for 57.5 % of the annual reservoir wide *Daphnia* biomass, followed by *D. schødleri* (17.6 %), *D. galeata* (12.7 %), *D. retrocurva* (10.1 %), *D. thorata* (1.8 %) and, juvenile *Daphnia* spp. (0.3 %; Table 3.22). Presence of *D. pulex* was substantial throughout the year. They were the dominant zooplankter January through March, and again from September through December (Figure 3.17). *D. schødleri* first appeared in the samples in May and persisted through September (Figure 3.17). *Daphnia galeata* and *D. retrocurva* first appeared in June, peaked at the end of July and remained prominent through early October (Figure 3.17). *Daphnia thorata* was initially observed in June and was documented in the samples until August (Figure 3.17).

Table 3.22 Total mean biomass (µg/m^3) and percent biomass of *Daphnia* spp. collected from eleven locations on Lake Roosevelt, WA (1998).

Species	Total Biomass	% Biomass
Daphnia pulex	2,020,614.136	57.5
Daphnia. schodleri	619,893.911	17.6
Daphnia. galeata	445,250.558	12.7
Daphnia. retrocurva	353,800.522	10.1
Daphnia thorata	6,3495.989	1.8
Juvenile *Daphnia* spp.	9,446.924	0.3
Totals	**3,512,502.04**	**100.0**

Beginning in 1991, reservoir mean zooplankton biomass was computed as an average of biomass values observed at five index stations (Gifford, Porcupine Bay, Seven bays, Keller Ferry, and Spring Canyon). As previously discussed in section 3.4.2, between year comparisons of zooplankton biomass used the five site average in order to preserve comparability across years. Biomass estimates were only computed for *Daphnia* spp. prior to 1997; therefore, between year comparisons of zooplankton biomass can only be made for this group.

Mean annual *Daphnia* biomass values were highly variable over the past eight years. The maximum mean *Daphnia* biomass occurred in 1994 (29,660.0 ìg/m^3), while the minimum occurred in 1998 (1,464.3 ìg/m^3; Table 3.23). Rough comparisons of years indicate that *Daphnia* biomass was generally low in January, followed by further decreased levels during early spring (February and March). From late spring to summer (May to July) *Daphnia* showed increased biomass, followed by decreased levels from September through December (Table 3.23). *Daphnia* biomass peaked in August four of the eight years examined (1992, 1993, 1994, 1997), suggesting that *Daphnia* biomass may peak most frequently in late summer. Very late peak biomasses occurred twice in the historical record, once in 1991 when biomass peaked in November, and once in 1996, when peak biomass occurred in October. The cause of these late increases in *Daphnia* biomass are difficult to explain. Cooper and Black (1999) found that decreased water retention time had detrimental effects on overall zooplankton biomass and densities. However, examination of water retention time and outflow over the eight year period indicate that the hydro-operations of Grand Coulee Dam were similar in November across years, and so were unlikely to affect biomass levels in November. Water retention time during the spring and summer were lower in 1991 and 1996 compared to other years, indicating the potential importance of the reservoir being allowed to transition into a more lake-like condition, which would allow the reservoir to "brew". When water is held for longer periods in the reservoir basin, temperatures begin to warm, which increases the rate of primary production. Additionally, higher water temperatures increase the rate at which zooplankton reproduce, increasing overall zooplankton density and biomass. Because of lower water retention times greater zooplankton biomass and density would be supported by greater food resources, driven by warmer water temperatures and a longer opportunity to reproduce and grow in the reservoir before being entrained.

Table 3.23 Mean *Daphnia* spp. biomass (µg/m^3) collected in Lake Roosevelt, WA (1991-1998).

	1991	1992	1993	1994	1995	1996	1997	1998
Jan	12.8	1,168.0		55,075.0	2,050.0	--	1,435.2	97.0
Feb	--	121.6	518.2	1,350.0	1,985.0	--	68.0	28.6
Mar	--	327.9	61.0	1,625.0	346.7	10.0	58.6	16.2
Apr	23.4	35.1	56.0	2,950.0	157.5	40.0	200.3	--
May	20.5	146.0	2,655.4	475.0	437.5	55.0	58.3	612.4
Jun	58.0	1,497.1	26,063.3	22,875.0	47,787.5	1,335.0	180.2	1,228.4
Jul	3,108.0	1,704.4	13,060.7	35,725.0	31,800.0	66,010.0	7,662.8	9,064.7
Aug	3,843.2	7,100.0	81,122.9	147,200.0	71,825.0	39,775.0	60,937.0	3,877.3
Sep	3,467.3	1,830.6	27,992.9	15,400.0	78,425.0	37,150.0	9,244.9	2,753.8
Oct	5,755.5	2062.22	7,938.5	13,925.0	15,675.0	64,566.7	5,763.8	1,940.8
Nov	7,633.5	2158.025	6,906.4	--	--	11,600.0		1,521.7
Dec	2,066.4	--	9,907.0	--	--	50,035.0	3,763.7	2,504.7
Annual Mean	**2,599**	**1,650**	**16,026**	**29,660**	**25,049**	**27,058**	**8,125**	**1,464**

3.5.3 Copepoda Biomass

Reservoir wide mean copepod biomass for 1998 was 1,988.3 µg/m^3. Annual mean copepod biomass ranged from 42 µg/m^3 at Evan's Landing to 3,441 µg/m^3 at Spring Canyon (Table 3.24). Low annual mean biomass values (< 219 µg/m^3) were observed in three upper reservoir sites (Gifford, Kettle Falls, and Evan's Landing; Table 3.24). In contrast, biomass values from the lower reservoir sites (Sanpoil River, Sanpoil River Confluence, Keller Ferry, and Spring Canyon) were much higher (> 2,300 µg/m^3; Table 3.24). Significantly, higher copepod biomass values were revealed at Spring Canyon, Sanpoil River, and Sanpoil River confluence than at Gifford, Kettle Falls, and Evan's Landing (Scheffe's S; $p<0.05$). Biomass means at Keller Ferry were substantially higher than the means recorded at upper reservoir sampling locations, yet statistically insignificant. Central reservoir sites (Hunters, Porcupine Bay, Spokane River confluence and Seven Bays) had intermediate annual biomass means ranging from 1,078 µg/m^3 at Hunters to 1,768 µg/m^3 at the Spokane River confluence.

The maximum monthly mean biomass value was recorded in February (86 µg/m^3) and the minimum was observed in July (3,826 µg/m^3; Table 3.24). Monthly mean copepod biomass values were less than 158 µg/m^3 from January through March. During those three months, the highest mean biomass value was recorded at the Sanpoil confluence (525 µg/m^3; Table 3.24). The lowest mean biomass value was recorded in March at Gifford (6 µg/m^3). Seasonal increases in copepod biomass were observed as the reservoir was refilled and temperatures began to rise. Copepod biomass has been positively correlated with temperature in Lake Roosevelt (Cichosz 1999). The largest mean biomass value recorded during 1998 was in May at the Sanpoil confluence (9,322 µg/m^3 Table 3.24). Annual mean copepod biomass generally increased with proximity to Grand Coulee Dam.

Diacyclops bicuspidatus thomasi accounted for 38.8 % of the annual reservoir wide copepod biomass, followed by *L. ashlandi* (32.3 %), *E. nevadensis* (17.2 %), *M. edax*

Table 3.24 **Mean Copepod biomass (µg/m^3) by month and location for Lake Roosevelt, WA (1998).**

	Jan	Feb	Mar	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Evan's Landing	10	12	18	81	131	57	30	53	23	20	22	**42**
Kettle Falls	7	-	10	30	150	101	84	57	20	47	9	**51**
Gifford	17	9	6	113	347	397	263	948	203	62	27	**218**
Hunters	-	29	23	376	481	808	931	2,986	2,983	1,097	18	**1,078**
Porcupine Bay	57	20	86	1,456	1,099	3,940	3,046	1,842	2,478	1,519	3,093	**1,694**
Spokane River. Confl.	32	84	26	3,242	1,549	3,248	1,885	2,470	4,734	2,031	149	**1,768**
Seven Bays	33	102	18	3,290	1,494	3,946	1,328	3,283	2,731	2,417	274	**1,720**
Keller Ferry	292	33	71	3,428	2,666	4,453	3,490	6,002	1,267	2,412	1,231	**2,304**
Sanpoil River. Confl.	465	463	525	9,322	2,661	8,561	5,506	3,349	1,486	2,211	1,947	**3,318**
Sanpoil River.	429	24	55	4,323	3,553	7,612	5,136	4,438	752	2,608	2,966	**2,900**
Spring Canyon	232	-	165	7,665	3,443	8,964	5,004	3,708	1,277	1,055	2,901	**3,441**
Mean	**158**	**86**	**91**	**3,030**	**1,598**	**3,826**	**2,428**	**2,649**	**1,632**	**1,407**	**1,149**	

(4.5 %), and nauplii (7.2 %; Figure 3.18; Table 3.25). Harpacticoids and unknown cyclopoids made up < 1 % of the total copepod biomass collected (Table 3.25). Maximum mean biomass values for *D. b. thomasi* (60,540 $\mu g/m^3$) were collected July 2, *L. ashlandi* (38,627 $\mu g/m^3$) September 10, *E. nevadensis* (76,761 $\mu g/m^3$) May 7, *M. edax* (18,280 $\mu g/m^3$) July 15, Harpacticoids (257 $\mu g/m^3$) August 11, and nauplii (14,003 $\mu g/m^3$) July 15 (Figure 3.18).

Table 3.25. Total biomass ($\mu g/m^3$) and percent biomass of copepods collected from eleven locations on Lake Roosevelt, WA (1998).

Species	**Total Biomass (mg/m^3)**	**% Biomass**
Diacyclops thomasi	1,117,574.4	38.8
Leptodiaptomus ashlandi	930,650.0	32.3
Epischura nevadensis	494,380.2	17.2
Mesycyclops edax	130,142.8	4.5
Unknown Cyclopoid	643.7	<1.0
Harpacticoid	473.7	<1.0
Nauplii	206,694.0	7.2
Totals	**2,880,558.8**	**100.0**

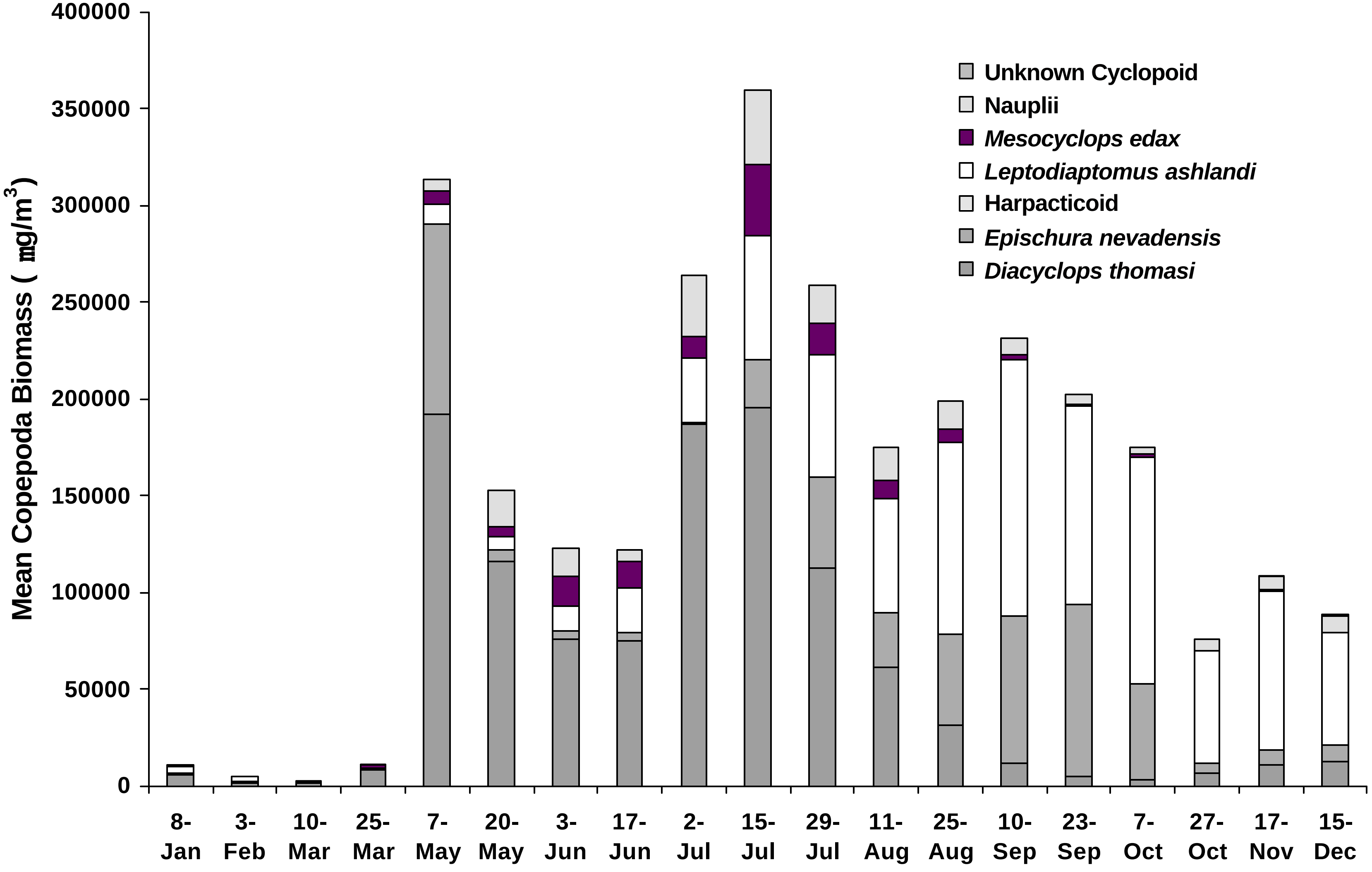

Figure 3.18 Monthly mean Copepoda biomass collected from eleven locations on Lake Roosevelt, WA (1998). No data was collected in April.

3.5.4 Other Cladocera Biomass

The biomass of other Cladocera was 2.5 % of the total zooplankton biomass (Table 3.17), which was similar to the low contribution other Cladocera contributed in 1997 (0.8 %) (Cichosz et al. 1999). Annual biomass means for other Cladocera were highest at the Sanpoil River (166 $\mu g/m^3$), and the lowest means were observed at Evan's Landing (8 $\mu g/m^3$; Table 3.26). Differences between locations were significant (ANOVA, $p=0.0124$). Other Cladocera biomass at the Sanpoil River was significantly greater than all sites but Porcupine Bay, the Spokane River confluence, and Sanpoil River confluence (ANOVA, $p<0.05$). Other Cladocera biomass from the Spokane River confluence was significantly greater than Evan's Landing, Kettle Falls, Gifford, and Spring Canyon (ANOVA, $\alpha=0.05$). Biomass from Porcupine Bay was also significantly greater than Evan's Landing. Other Cladocera biomass appeared to be influenced by the interface between major tributaries and the more pelagic areas of the reservoir. In, or near, the Sanpoil River and Spokane River, other Cladocera biomass was generally higher than other sites on the mainstem (Table 3.26).

Mean biomass of other Cladocera peaked in July (235 $\mu g/m^3$), and minimum mean biomass occurred in February (0 $\mu g/m^3$; Table 3.26). In July, mean biomass for other Cladocera was significantly greater than all months other than April, June, and September (ANOVA, $p<0.05$). Mean biomass in June was significantly greater than values for January, February, March, May, and December (ANOVA, $p<0.05$). The temporal pattern for other Cladocera biomass lags behind the spring peak in phytoplankton biovolume and temperature (Figure 3.8 & Figure 3.19). Other Cladocera biomass was dominated by *Leptodora kindtii*, which accounted for 55 % of the total, followed by *Bosmina longirostris* (18 %), *Diaphanosoma brachyurum* (15 %) and *Sida crystallina* (8 %). The remaining biomass was divided almost equally between the remaining species. *Leptodora kindtii* biomass peaked in June and achieved annual lows during mid spring and late fall (Figure 3.19). *Bosmina longirostris* biomass was low during the winter and then held relatively stable from late spring to late fall (Figure 3.19). *Diaphanosoma brachyurum* was prominent throughout the fall and peaked in early October (Figure 3.19)

Table 3.26 **Other Cladocera mean biomass (µg/m^3) by month and location for Lake Roosevelt, WA (1998). No data was collected April.**

	Jan	Feb	Mar	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Evan's Landing	1	0	1	2	16	19	10	14	19	3	0	**8**
Kettle Falls	1	-	0	5	31	27	13	12	4	5	1	**10**
Gifford	1	0	0	3	26	48	28	90	18	4	2	**20**
Hunters	-	1	0	2	49	374	59	89	114	17	1	**71**
Porcupine Bay	1	0	7	75	180	679	14	30	49	11	37	**98**
Spokane River. Confl.	1	1	0	56	633	383	113	209	161	108	10	**152**
Seven Bays	0	0	0	21	21	130	70	95	135	67	16	**50**
Keller Ferry	1	0	1	20	199	15	44	166	251	38	3	**67**
Sanpoil River. Confl.	5	0	4	144	81	24	19	69	184	16	16	**51**
Sanpoil River.	4	0	0	41	608	847	115	52	125	21	14	**166**
Spring Canyon	0	-	1	83	233	43	12	40	48	14	13	**49**
Mean	**1**	**0**	**1**	**41**	**189**	**235**	**45**	**79**	**101**	**28**	**10**	

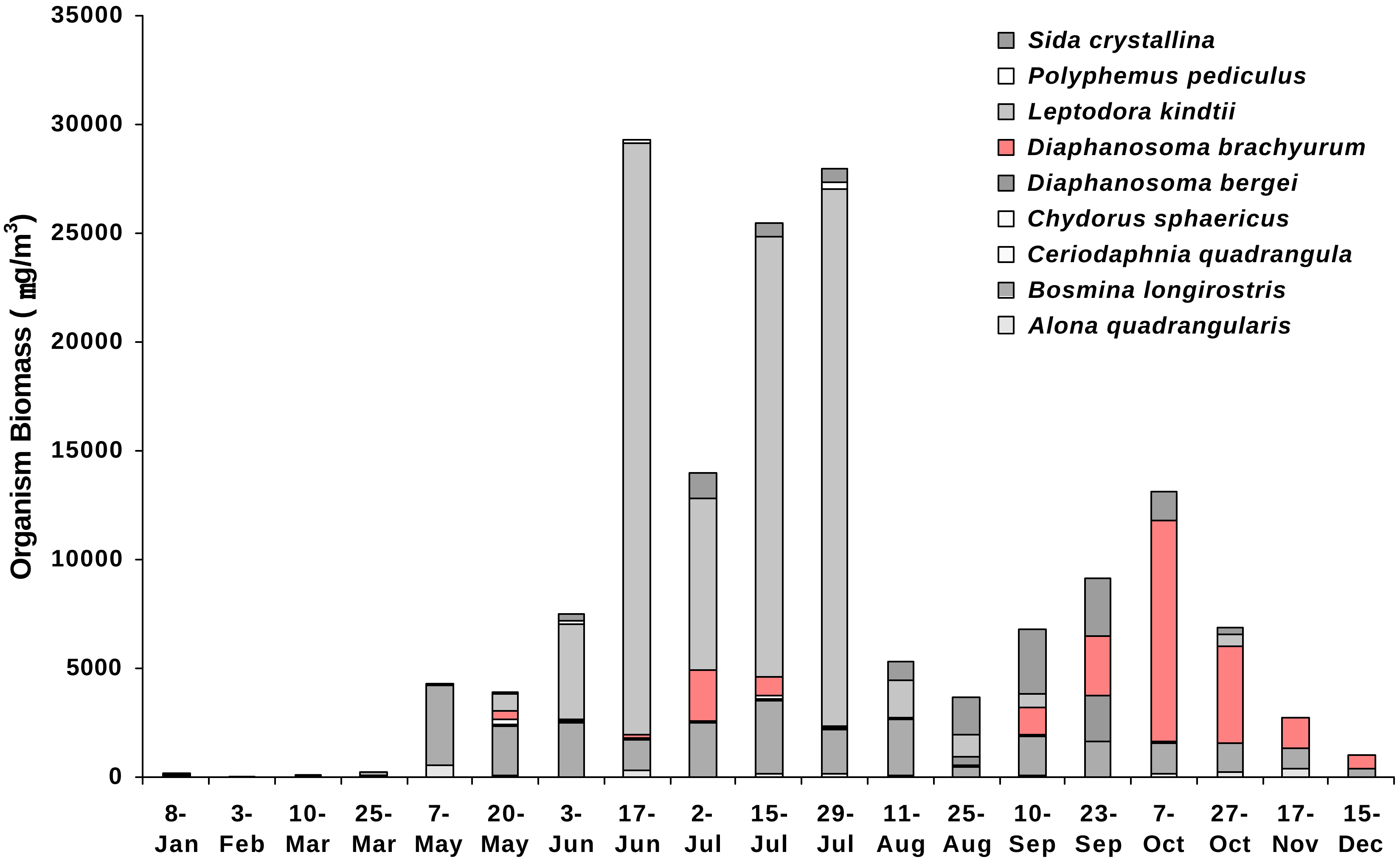

Figure 3.19 **Monthly mean other Cladocera biomass collected from eleven locations in Lake Roosevelt, WA (1998). No data was collected in April.**

4.0 Recommendations and Research Needs.

- Maintain current zooplankton and water quality sampling locations and intensity to better relate the effects of reservoir operations on zooplankton production.

- Examine the influence plant nutrients in the reservoir have on primary production.

- Compare primary production across years in Lake Roosevelt to better assess the trophic state of the reservoir.

- Investigate differences in zooplankton and water quality between littoral and pelagic areas of the reservoir.

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