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Fall Stocking of Rainbow Trout in Bad Medicine Lake: A Bioenergetics Assessment of Impacts on the *Daphnia pulex* Population

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Abstract.--A bioenergetics model was used to estimate *Daphnia pulex* consumption by approximately 4,200 fall stocked rainbow trout during the winter of 1998/99 in Bad Medicine Lake, a large (323 ha), deep (mean depth =10.0 m) lake in north central Minnesota. Fish stocked on 24 November 1998 had grown, on average, 36 mm (1.4 in) and gained 111 g (0.24 lb) by 15 May 1999. Analysis of stomach contents indicated that large *D.pulex* >1.3mm in length made up a substantial portion of the mid-winter diet of the rainbow trout in Bad Medicine Lake. Based on the model simulations, each fish consumed 11,975 *D.pulex* per day to produce the observed growth rate. Whole lake biomass and production estimates were calculated for the population of *D.pulex* >1.3mm in length to determine the biomass available for consumption. Consumption estimates revealed that rainbow trout consumed between 1.5% and 25.5% of this available biomass over various segments of the winter. The bioenergetics simulations included a high dietary proportion of *D.pulex*, probably overestimated growth rates, and low mortality rates, which would tend to maximize consumption estimates. *D.pulex* in this lake may have refuges from predation based on size, and on survival in low oxygen zones below the thermocline in summer. The low to moderate predation pressure exerted by the fall stocked rainbow trout during the winter of 1998-1999 did not substantially lower *D.pulex* densities and biomass, or lower water clarity relative to previous years.

Introduction

Bioenergetics modeling was used to estimate the consumption of *Daphnia pulex* by fall stocked rainbow trout during the winter of 1998/1999 in Bad Medicine Lake, Becker County, Minnesota. Rainbow trout *Oncorhynchus mykiss* yearlings have been stocked annually during the spring into Bad Medicine Lake since 1977. The trout were originally introduced as a crayfish control measure, but since that time they have turned Bad Medicine Lake into an excellent "two story" sport fishery. As an alternative management strategy, approximately one-quarter of the 1999 Bad Medicine Lake stocking quota of rainbow trout was stocked into the lake in November 1998. It was anticipated that the fall stocked fish would provide an even better fishery the following season because they were larger and older (1997 year class) than those typically stocked during the spring.

Typical of many "two-story" trout lakes, the zooplankton community in Bad Medicine

Lake is dominated by the large cladoceran *Daphnia pulex*. Rainbow trout are known to be size-selective zooplankton feeders, and large-bodied zooplankton, especially *D. pulex* greater than 1.3mm in length, can compose a substantial portion of the diet of lake-dwelling rainbow trout (Galbraith 1967; Galbraith 1975; Tabor et al. 1996; Wang et al. 1996). *D. pulex* are very efficient grazers, and when present in moderate densities can depress the biomass of phytoplankton in a lake which in turn helps maintain water clarity. Bad Medicine Lake has a history of excellent water quality with average summer Secchi disk depths in the 6 m (20 ft) range (Figure 1). There has been concern expressed over the impacts that stocked rainbow trout may have on the *D. pulex* population, and in turn on the water quality in Bad Medicine Lake.

Rainbow trout select *D.pulex* individually and are thought to use visual cues to target prey. Bad Medicine Lake is large (323 ha), deep (mean depth = 10.0 m), and has an abundant winter *D.pulex* population (1.5/L). There was no easy way to predict what impact 4,188 stocked trout would have on a *Daphnia* population during winter when snow and ice cover significantly limit available light. Bioenergetics modeling was used to estimate winter consumption of *D. pulex* by fall stocked yearling rainbow trout in Bad Medicine Lake and thereby estimate the impacts that might occur.

Methods

On 24 November 1998, 4,188 Kamloops strain rainbow trout were stocked in Bad Medicine Lake. These fish weighed 1,583 kg (3,489 lb), or approximately 378 g (0.83 lb) each. The mean total length was 312 mm (12.3 in).

Fish Bioenergetics 3.0 software (Hanson et al. 1997) was used to model consumption by the rainbow trout stocked into Bad Medicine Lake. Using given parameters designed for each species , this model requires inputs of water temperature, diet, prey energy density, mortality, growth, and population numbers. The output is expressed as grams of each diet item consumed. The simulation was run for 173 days, from 24 November 1998 (stocking date) to 15 May 1999 (fishing opener), to estimate consumption of *D. pulex* during the winter months.

The Hanson et al. (1997) model comes with a set of parameters for steelhead, and alternate parameters have recently been published for stream rainbow trout (Railsback and Rose 1999). The Kamloops strain of rainbow trout that were stocked into Bad Medicine Lake was originally anadromous like steelhead, but it is apparently quite adaptable and survives well in inland lakes. Kamloops also tend to be more efficient than steelhead at converting food to growth (Mark Gottwald, French River Coldwater Hatchery, personal communication). Simulations of an individual fish using each of the two sets of model parameters produced different results. The stream rainbow trout model represented an individual that was more efficient at converting energy into growth than the steelhead model, therefore, the stream rainbow trout model was used for the Kamloops stocked into Bad Medicine Lake.

The simulation included an initial stocking mortality of 1.6% over the first 48 hours (Cunningham and Anderson 1992), and an overall mortality rate of 10% during the winter months to account for natural mortality. Water temperature inputs based on actual measurements were 5.0°C on 24 November 1998 and 11.1°C on 15 May 1999. Estimated temperature values for intervening months, based on times of ice cover, were 3°C on 1 December, 4°C on 1 February, and 6°C on 1 May.

Diet proportion values were determined by observing the winter diets of the stocked rainbow trout. On 25 February 1999, rainbow trout from Bad Medicine Lake were sampled by angling through the ice by Minnesota DNR fisheries personnel. Lengths were recorded and a small pump was used to collect stomach contents (Seaburg and Moyle 1964). Stomach contents were preserved in 80%

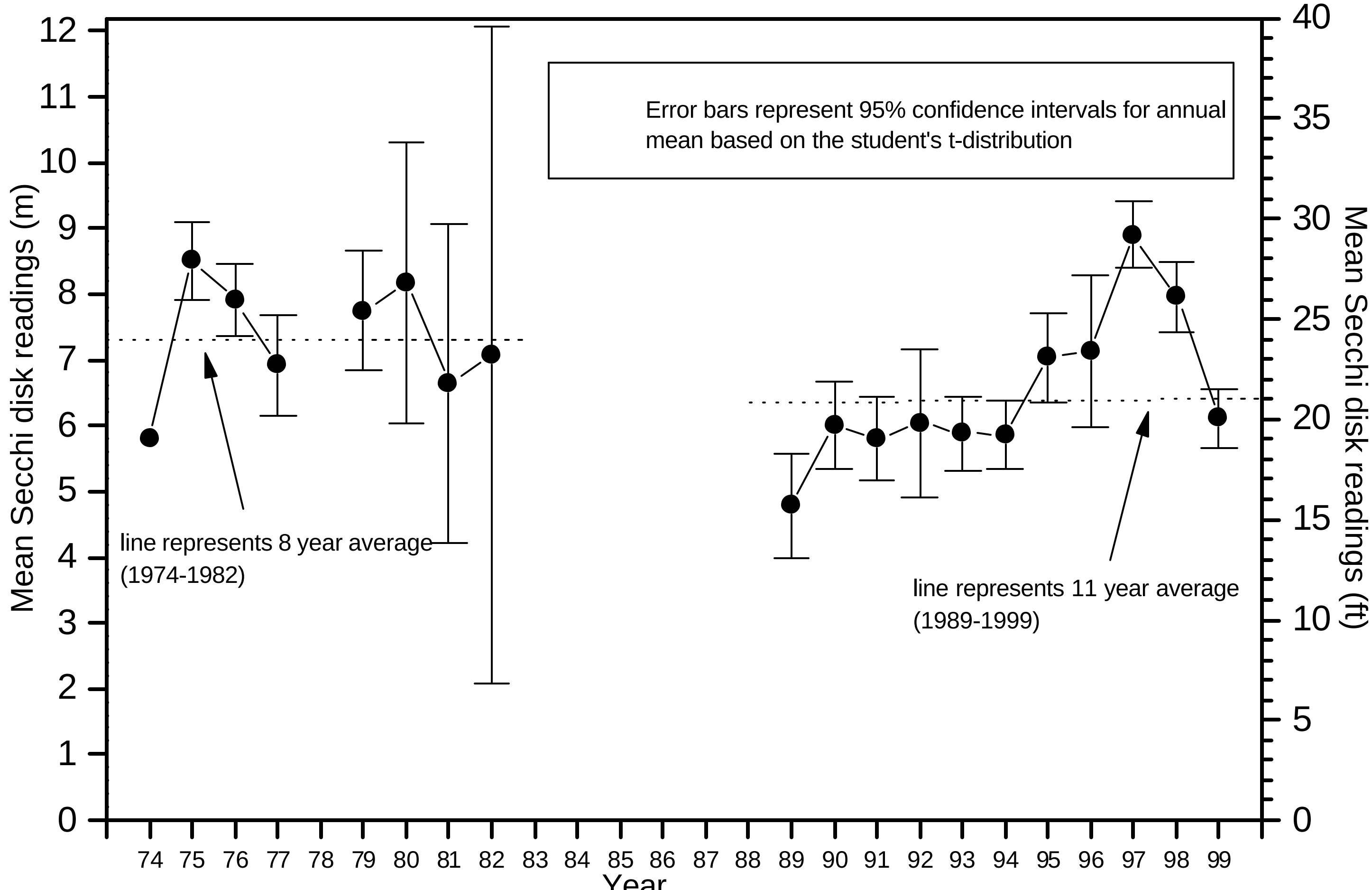

Figure 1. Mean summer Secchi disk readings (June-September) measured in meters (feet) for the years 1974-1999 from Bad Medicine Lake. (Data collected by the MPCA Citizen Lake-Monitoring Program). No data were collected in 1978 and 1983-1988.

ethanol and sent to the Minnesota DNR Ecological Services Biology Laboratory for analysis. All fish were released. All stomach contents were counted and identified to the lowest taxonomic level possible, and *D. pulex* were subsampled and measured to the nearest 0.1mm. Diet proportions entered into the model included 90% *D. pulex*, 5% macro-invertebrates and 5% fish.

Daphnia energy density values range seasonally from 2,214-2,612 joules/g wet mass (Snow 1972). The value used for macro-invertebrates (3,000 joules/g wet mass) was an intermediate value from invertebrate energy densities reported in Hanson et al. (1997). The value used for fish (3,349 joules/g wet mass) was the energy density of juvenile walleye (Hanson et al. 1997).

To obtain growth data, a "mini"creel census was conducted by Detroit Lakes Area Fisheries DNR staff on 15-16 May 1999 (fishing opener). Total length and weight were recorded for each rainbow trout and scale samples were taken. Rainbow trout that ranged between 304 mm (12 in) and 406 mm(16 in) total length or had fin erosion were assumed to be fish that were stocked in November 1998. Scale samples were aged to confirm the year class of these fish.

Zooplankton tows were taken on 5 November 1998 prior to stocking; in mid January, February, and April of 1999; twice monthly during May, June, July and August; and once during September and October 1999. Vertical tows were taken at the deepest portion of the lake at two set sites using a 153μm mesh Wisconsin style zooplankton net. Samples were preserved in 80% ethanol and sent to the Ecological Services Biology Laboratory for analysis. Zooplankton were counted and identified at 25x magnification, and densities and biomass were calculated using a computerized image analysis system and a zooplankton counting software package "ZCOUNT" (Charpentier and Jamnik 1994). These data were compiled along with those collected at the same sampling stations in 1997 and 1998, and at 4 different stations in 1995 (Figures 2-5, Appendices 1-3).

Data from the 1999 winter zooplankton tows, along with a calculated volume of water in Bad Medicine Lake were used to obtain estimates of the standing stock biomass of *D.pulex* for the whole lake. Only *D. pulex* > 1.3 mm in length were used in these standing stock biomass estimates (Galbraith 1975). For the purpose of comparison, the study period was divided into four time intervals: 60, 90, 150, and 173 days after stocking.

Net production was calculated for each time interval to determine the amount of biomass gained through recruitment (growth above the 1.3mm threshold) and lost through mortality during that time period. The biomass attributed to rainbow trout consumption was included in this calculation because this was a known quantity that was removed during the time period. The calculation was thus:

$$\mathbf{P_{t1\text{-}t2} = (B_{t2}\text{-}B_{t1}) + C_{t1\text{-}t2}}$$

where: P = production of *D.pulex* population
B = biomass of *D.pulex* population
C = consumption of *D.pulex* by rainbow trout population
t_1 = starting date for each time interval
t_2 = end date for each time interval

Total biomass available to rainbow trout over each time interval included the biomass at the beginning of each interval plus production over that time interval:

$$\textbf{"Available" Biomass from } \mathbf{t_1 \text{ to } t_2 = B_{t1} + P_{t1\text{-}t2}}$$

The model generated the cumulative consumption of *D. pulex* by the stocked rainbow trout at 30-day time intervals, but for comparison to *D.pulex* population estimates, data were combined into the same time intervals used above: 60, 90, 150, and 173 days after stocking. To calculate the impact of rainbow trout on the *D.pulex* population, consumption over each time interval was divided by available biomass, and multiplied by 100 to obtain a percent of the population consumed:

$$\textbf{\% Consumption} = \mathbf{C_{t1\text{-}t2} / (B_{t1} + P_{t1\text{-}t2}) * 100}$$

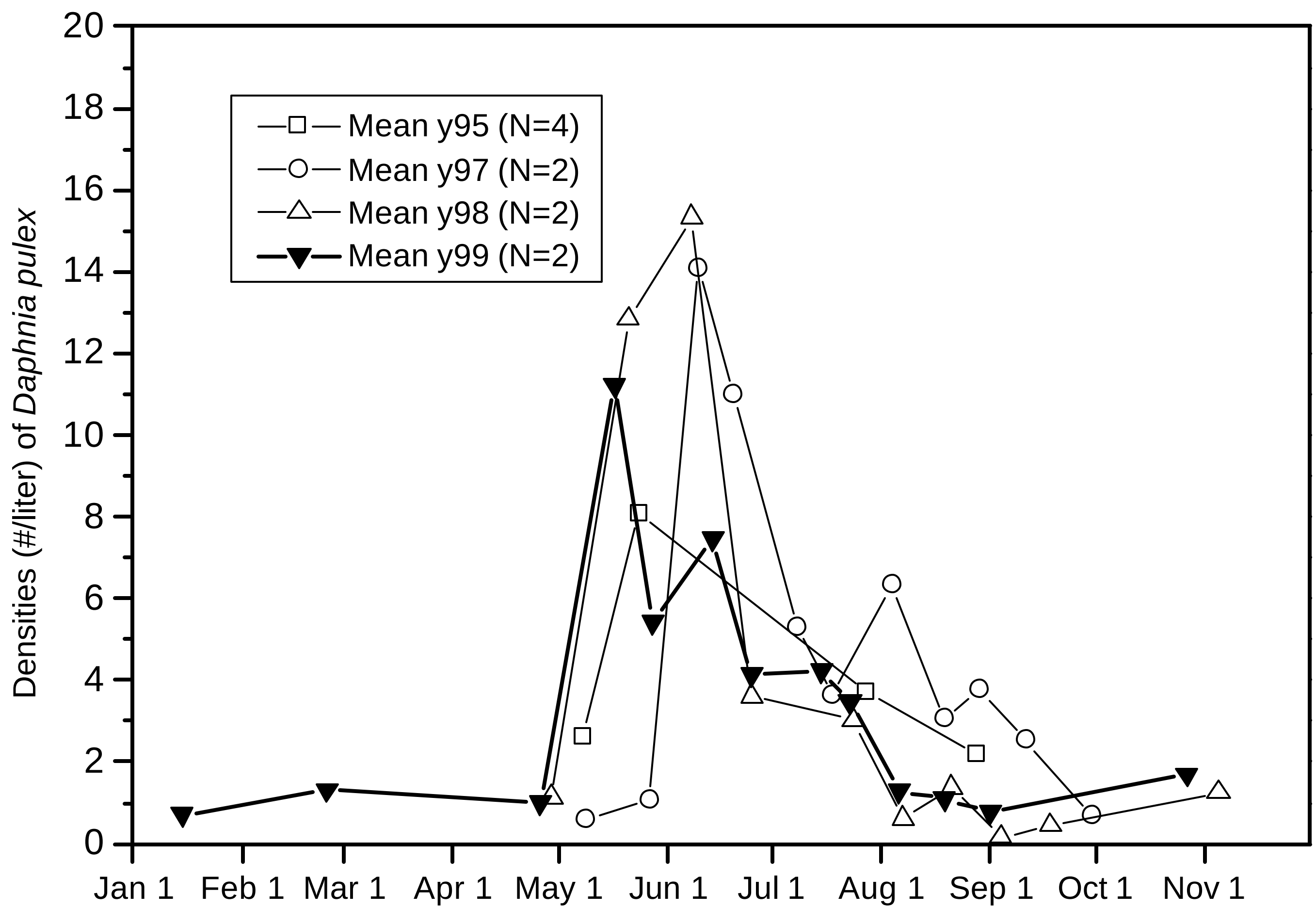

Figure 2. Average densities (#/liter) of *D. pulex* for 1995, 1997, 1998, and 1999 in Bad Medicine Lake, Minnesota.

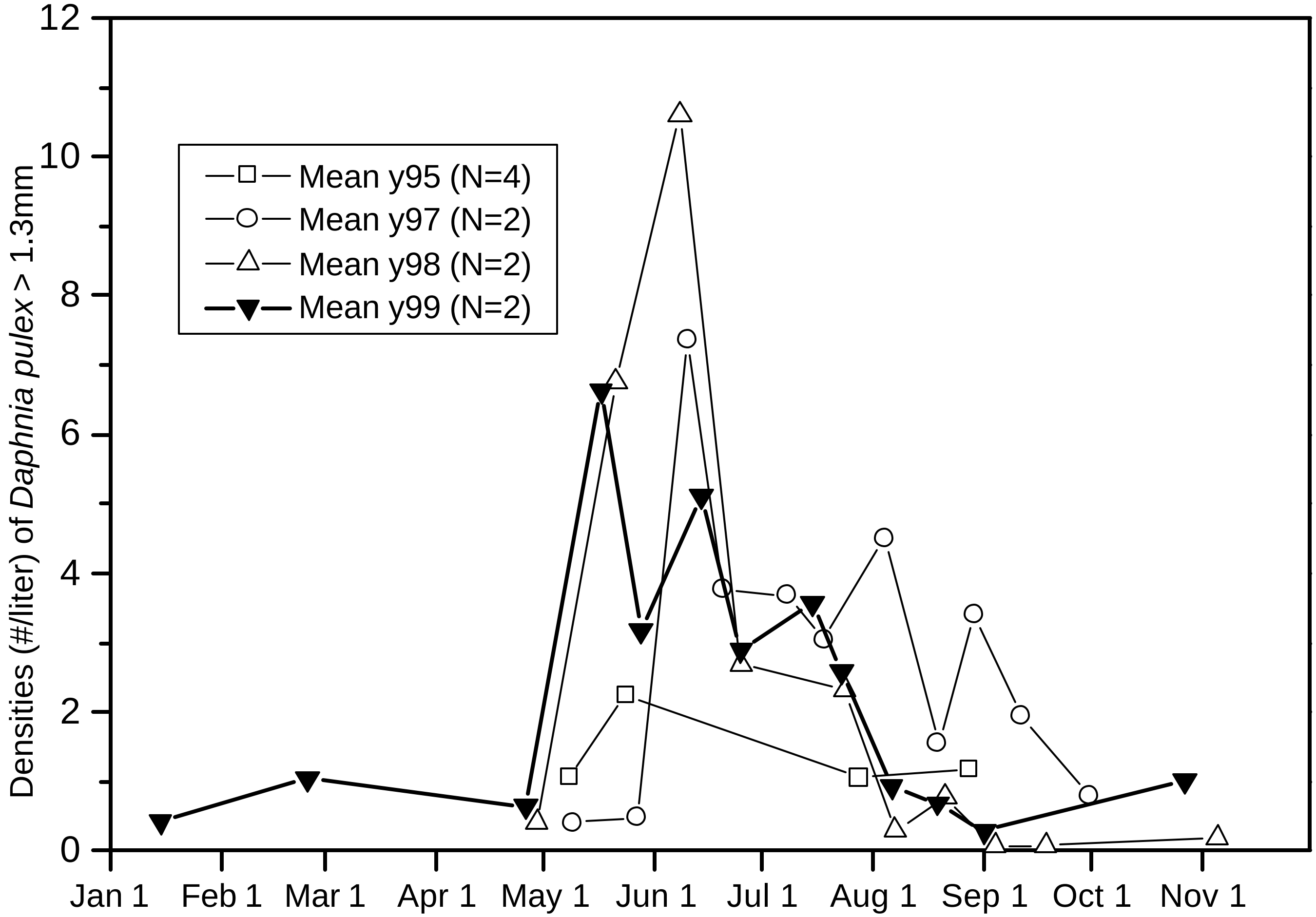

Figure 3. Average densities (#/liter) of *D. pulex* > 1.3 mm in length for 1995, 1997, 1998, and 1999 in Bad Medicine Lake, Minnesota.

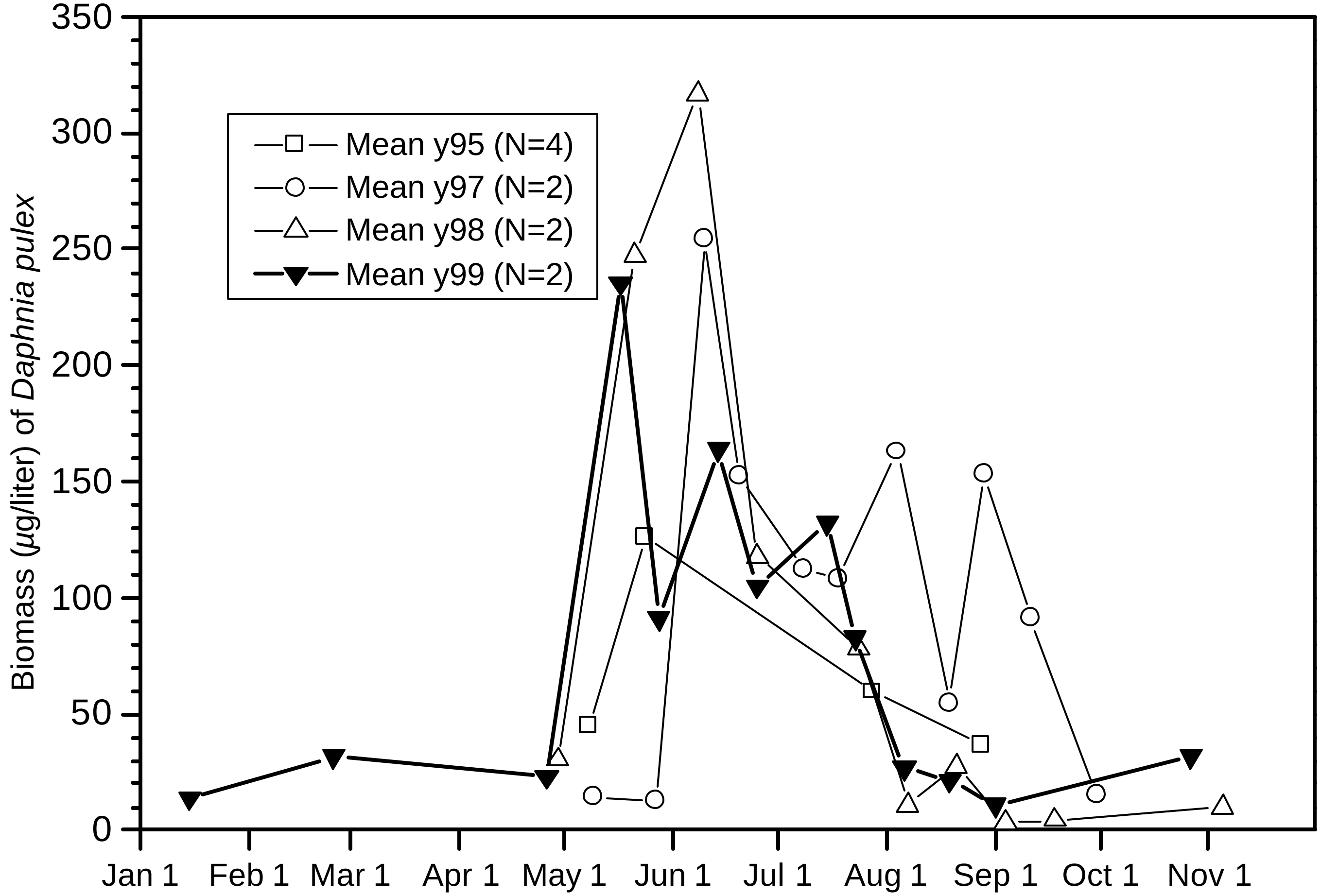

Figure 4. Average biomass (μg/liter) of *D. pulex* for 1995, 1997, 1998, and 1999 in Bad Medicine Lake, Minnesota.

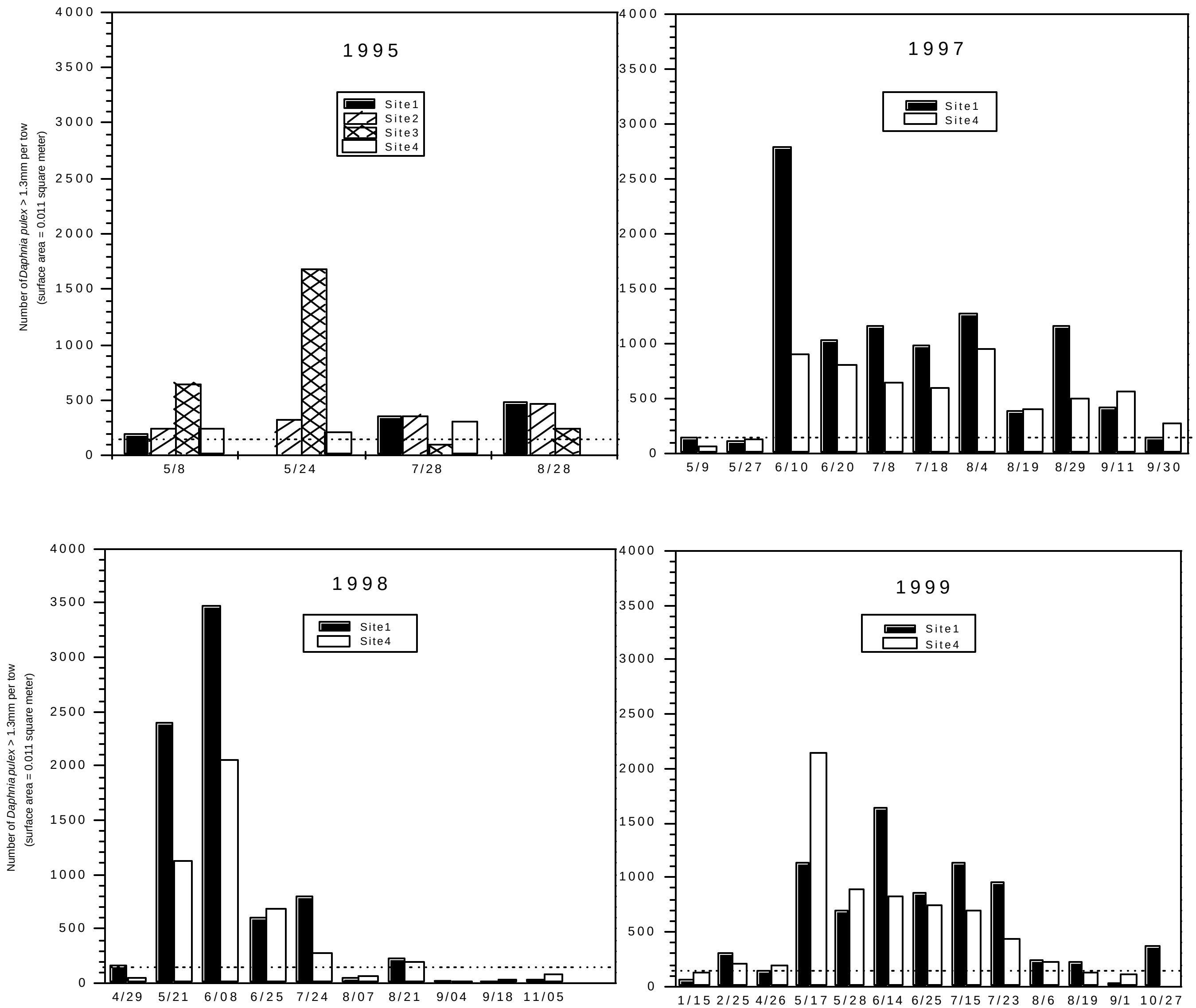

Figure 5. Numbers of *Daphnia pulex* > 1.3mm per tow based on net surface area = 0.011 square meters for 1995, 1997-1999 in Bad Medicine Lake, Minnesota. The dotted line at 150 *D.pulex*/tow = Galbraith's minimum threshold of *Daphnia* > 1.3mm for "good" trout lakes (Galbraith 1975).

Results

Diet Analysis

Twelve rainbow trout were caught on 25 February 1999 by DNR staff angling through the ice. These fish ranged in length from 310 mm (12.2 in) to 526 mm (20.7 in). *D. pulex* were present in all 12 of the stomachs and consisted of over 90% of the diet in 10 of the 12 fish. A minor portion of the diets included benthic macroinvertebrates and small fish (Table 1). The average length of *D. pulex* in the trout stomachs was 2.2 mm while the average length of *D. pulex* collected from the lake on that day was only 1.6 mm. From these data, it is clear that during the winter season, rainbow trout in Bad Medicine Lake were selectively feeding on large *D. pulex*.

"Mini Creel"

Forty-two rainbow trout from the fall stocking were recaptured by anglers during the opening weekend "mini creel" census. The mean total length of these fish was 348 mm (13.7 in) with a mean weight of 489 g (1.08 lb). On average, these fish grew 36 mm (1.4 in) and gained 111 g (0.24 lb) from 24 November to 15 May. The bioenergetics model predicted that over this time period, the fish would need to eat 1.0 g (dry wt) of *D.pulex* for every 1 g of weight gained. Typically, rainbow trout in the hatchery have a food conversion ratio of 1.3 g of fish feed (dry wt) to 1 g of weight gain (Fred Tureson, French River Coldwater Hatchery, personal communication).

Bioenergetics Simulations

From 24 November 1998 to 15 May 1999, a total of 413,523 g (dry wt) of *D. pulex* were consumed by the fall stocked rainbow trout (Table 2). Each fish was estimated to have consumed 2,413,242 individual *D. pulex* throughout the modeling period, or on average, 11,975 *D. pulex* per day. The fall stocked rainbow trout consumed from 1.5% to 25.5% of the available *D.pulex* population > 1.3 mm in length over various time intervals between November 1998 and May 1999 (Table 3).

Zooplankton

Mean densities (#/L) of all *D. pulex*, mean densities of *D. pulex* > 1.3mm, and mean *D. pulex* biomass (μg/L) from 1995, and 1997-1999 were greatest in late May and/or early June, representing the "peak" or spring "bloom" of zooplankton reproduction and growth (Figures 2-4). The highest *D. pulex* peak densities and biomass occurred in 1998, while the lowest occurred in 1995. Overall mean densities and biomass in 1999 did not appear to be substantially lower than any of the previous data. Whole lake biomass estimates of *D. pulex* >1.3mm on specific dates during the study period ranged from 151,204 g to 6,237,588 g dry weight (Table 3). Production estimates reflected the relative biomass shifts from the beginning to end of each time interval, becoming negative during one segment due to mortality from some other source besides rainbow trout predation.

Galbraith (1975) suggested that a minimum threshold (> 150 per tow) of large *D. pulex* was required to provide adequate forage in a "good" rainbow trout lake. During most sampling periods, the numbers of large *D. pulex* in Bad Medicine Lake were much higher than this minimum threshold with the exception of the fall of 1998 (Figure 5). However, the *D.pulex* population was again substantially higher than the minimum threshold by spring 1999. Similar bar graphs summarizing total *D. pulex* densities, biomass and large *D. pulex* densities from all sampling sites for the four years are presented in Appendices 1-3. The 1999 zooplankton data summary tables from the "ZCOUNT" program are presented in Appendix 4.

Discussion

The bioenergetics simulations from this study showed that the rainbow trout in Bad Medicine Lake consumed a small to moderate proportion of the available *D. pulex* > 1.3mm

Table 1. Summary of diet items found in rainbow trout stomachs caught in February 1999, from Bad Medicine Lake, Minnesota.

Length (mm)	Number *D.pulex*	Percent *D.pulex*	Food items other than *D.pulex* present in stomach
NA	20	90.9	2 water boatmen (Corixidae)
NA	7	53.8	3 water boatmen (Corixidae), 1 phantom midge larva (*Chaoborus spp*.), 1 cyclopoid, 1 *Daphnia galeata mendotae*, sticks and vegetation
310	105	100.0	
376	55	98.2	1 small fish
391	6,640	99.9	1 caddisfly larva (Limnophilidae), 1 small fish, 1 *Daphnia galeata mendotae*
394	3,600	100.0	
394	1,100	99.8	1 small fish, 1 whirligig beetle (Gyrinidae)
432	2,120	99.9	1 small fish
470	972	99.8	2 small fish
510	11	91.7	1 small fish, unidentified digested material which resembles zooplankton tissue
513	9	75.0	1 water boatman (Corixidae), 1 whirligig beetle (Gyrinidae), 1 small fish
526	346	99.7	1 cyclopoid

Table 2. Summary of bioenergetics modeling results of November 1998 stocked rainbow trout from Bad Medicine Lake, Minnesota. Wet wt:dry wt ratio for *D.pulex* is 10:1. One gram (dry wt) is the weight of approximately 21,645 *D.pulex*.

Date (day of simulation)	Number of rainbow trout in population	Cumulative consumption of *D.pulex* by rainbow trout population (g; dry wt)	Cumulative consumption of *D.pulex* per rainbow trout (g; dry wt)	Cumulative number of *D.pulex* consumed by rainbow trout population	Cumulative number of *D.pulex* consumed per rainbow trout	Average number of *D.pulex* consumed per rainbow trout per day
Nov 24 (1)	4,165	2,705	0.65	58,549,783	14,057	14,057
Dec 24 (30)	4,052	58,104	14.34	1,257,662,338	310,380	10,346
Jan 23 (60)	3,978	115,549	29.04	2,501,060,606	628,723	10,479
Feb 22 (90)	3,904	181,383	46.46	3,926,038,961	1,005,645	11,174
Mar 24 (120)	3,832	248,104	64.74	5,370,216,450	1,401,413	11,678
Apr 23 (150)	3,762	316,616	84.16	6,853,160,173	1,821,680	12,145
May 15 (173)	3,709	413,523	111.49	8,950,714,286	2,413,242	13,949
					Average=11,975	

Table 3. Summary of consumption estimates from bioenergetics simulations of fall stocked rainbow trout, and *D.pulex* biomass and production estimates in Bad Medicine Lake, Minnesota, 1998/99. All consumption, biomass, and production estimates are based on *D.pulex* >1.3mm in length.

Sampling date (day of simulation)	Consumption of *D.pulex* by rainbow trout between sampling dates (g; dry weight)	Biomass of *D.pulex* (g; dry weight)	Production[a] of *D.pulex* between sampling dates (g; dry weight)	"Available" *D.pulex* biomass plus production between sampling dates (g; dry weight)	% of available *D.pulex* consumed by rainbow trout between sampling dates
t	C	B	P	B_{t1}+P	C/(B_{t1}+P)*100
Nov 24 (1)	2,705	151,204			
Jan 23 (60)	112,844	329,437	291,077	442,281	25.5%
Feb 22 (90)	65,834	892,236	628,633	958,070	6.9%
Apr 24 (150)	135,233	725,665	-31,338[b]	860,898	15.7%
May 15 (173)	96,907	6,237,588	5,608,830	6,334,495	1.5%

[a] $P_{t1-t2}=(B_{t2}-B_{t1})+C_{t1-t2}$

[b] Negative values show losses due to other sources of mortality.

in the lake during the winter and early spring. This estimation was based on the assumption that *D.pulex* supplied 90% of the calories the rainbow trout consumed. Despite the predation by fall stocked rainbow trout, *D. pulex* densities and biomass were not substantially lower in the spring and summer of 1999 than they were in previous years without fall trout stocking. The yearly differences appear to be caused by natural variation, zooplankton patchiness, or differences in sampling dates from year to year rather than a direct effect by trout predation.

Water clarity did not change dramatically in 1999 after the fall stocking of rainbow trout. Historical Secchi disk readings compiled by the Minnesota Pollution Control Agency's Citizen Lake Monitoring Program showed that the mean summer Secchi disk depth for 1999 (6.1 m) is only slightly lower than the average summer Secchi disk depth (6.4 m) for the previous 10 years. No upward or downward trends in Secchi disk depths in Bad Medicine Lake have been documented since 1974 (Jennifer Klang, Minnesota Pollution Control Agency, personal communication).

Rainbow trout are known to be size-selective zooplankton feeders (Galbraith 1967; Galbraith 1975; Tabor et al. 1996; Wang et al. 1996), and in this study large *D. pulex* composed a substantial portion of the winter diet in Bad Medicine Lake. It is postulated that *D.pulex* has a size refuge in this lake as small individuals (<1.3mm) are relatively safe from predation. This species has been found to reproduce at sizes <1.3mm (Galbraith 1967). Wang et al. (1996) found that the rainbow trout in Big Watab Lake, a similar "two-story" trout lake in central Minnesota, fed extensively on large *D. pulex* during the spring and summer months, and switched to feed predominately on Chironomidae in the littoral zone by late summer and autumn. Although trout stomachs were not sampled during the open water season in this study, it is possible that trout in Bad Medicine Lake also use alternate prey as in Big Watab Lake, therefore allowing the *D. pulex* to sustain a moderate population size in spite of heavy predation during winter, spring and early summer. "Two-story" trout lakes such as these can also provide "refugia" for *D. pulex* below the thermocline where the oxygen is limited during thermal stratification. *D. pulex* have the ability to produce their own hemoglobin-like substance and withstand low oxygen levels such as those found in the hypolimnion of deep lakes prior to autumn turnover.

There were several assumptions in this study which should be noted. Calculations of the total lake-wide *D. pulex* biomass at any given time, based on localized density multiplied by the total lake volume, assume that *D.pulex* display a random or homogenous distribution.

However, zooplankton populations generally display a heterogenous or “patchy” distribution both horizontally and vertically (Tessier 1983). The winter diet of the rainbow trout was based on stomach contents from only 12 fish caught in mid- February, and diet proportions may have varied throughout the modeled period. However, *D.pulex* were considered to be 90% of the diet in this study, so any changes in dietary proportion would likely reduce their importance. Rainbow trout growth was estimated from only 42 fish which represented 1% of the initial fall-stocked population. A prior study on Bad Medicine Lake found that larger fish tend to be harvested by anglers (Cunningham and Anderson 1992), so growth was more likely to be overestimated than underestimated in this study.

Another assumption was the low (10%) mortality rate for rainbow trout. The large size of the fish at stocking and the high quality of fishing reported by anglers in spring 1999, along with a closed winter angling season, would suggest that mortality was not high during the period modeled (Dave Friedl, Detroit Lakes Area Fisheries Office, personal communication).

In summary, the predation pressure from the 4,188 fall stocked rainbow trout appeared to have little affect on *D.pulex* population densities or water clarity, which remained at levels similar to those tested in previous years. The bioenergetics analysis of rainbow trout in this study included a high dietary proportion of *D.pulex*, growth rates that may have been overestimated, and low mortality rates, all of which served to maximize estimates of total consumption. However, the percent of the *D.pulex* population utilized by the rainbow trout remained low to moderate, and no significant changes were observed in water clarity.

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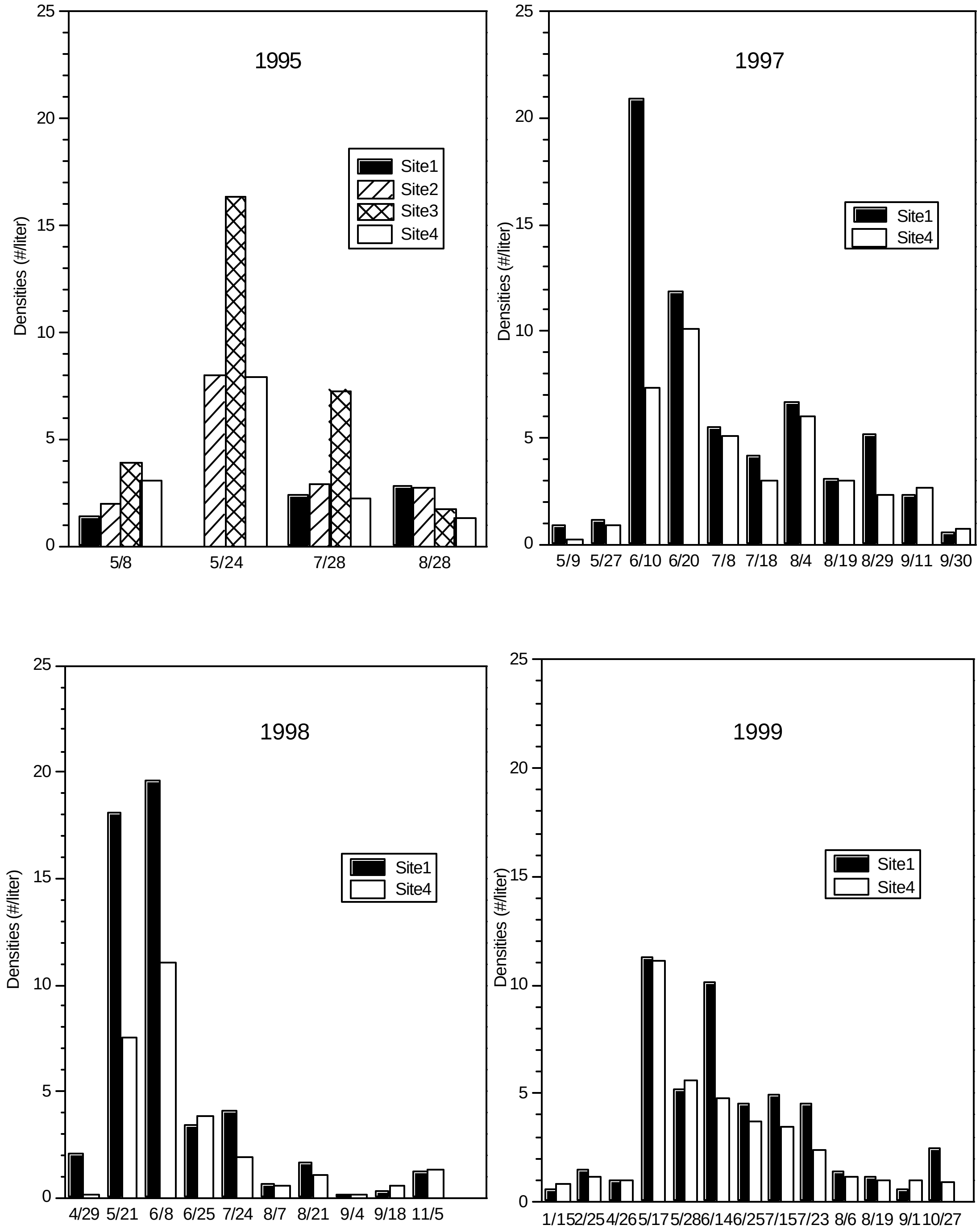
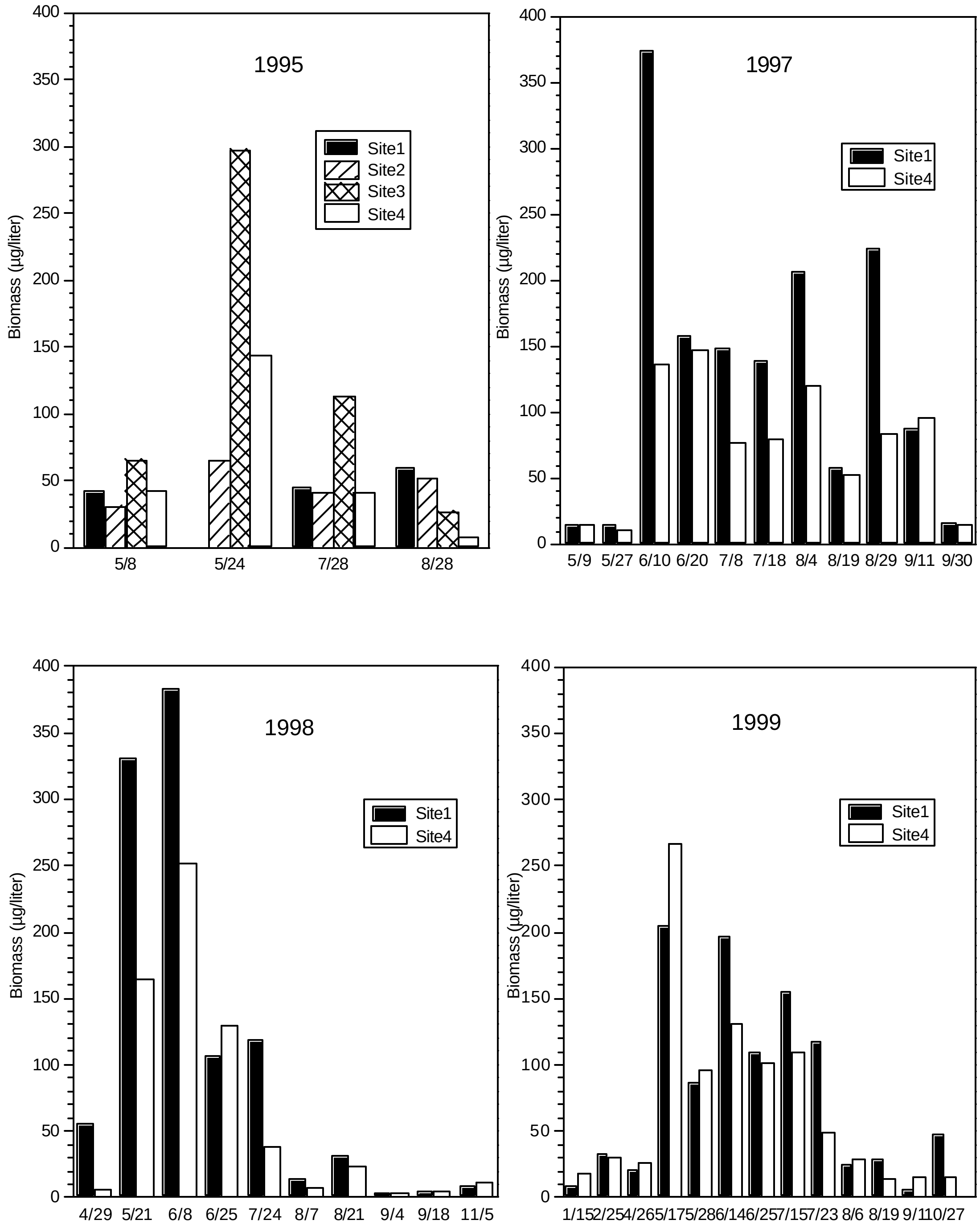
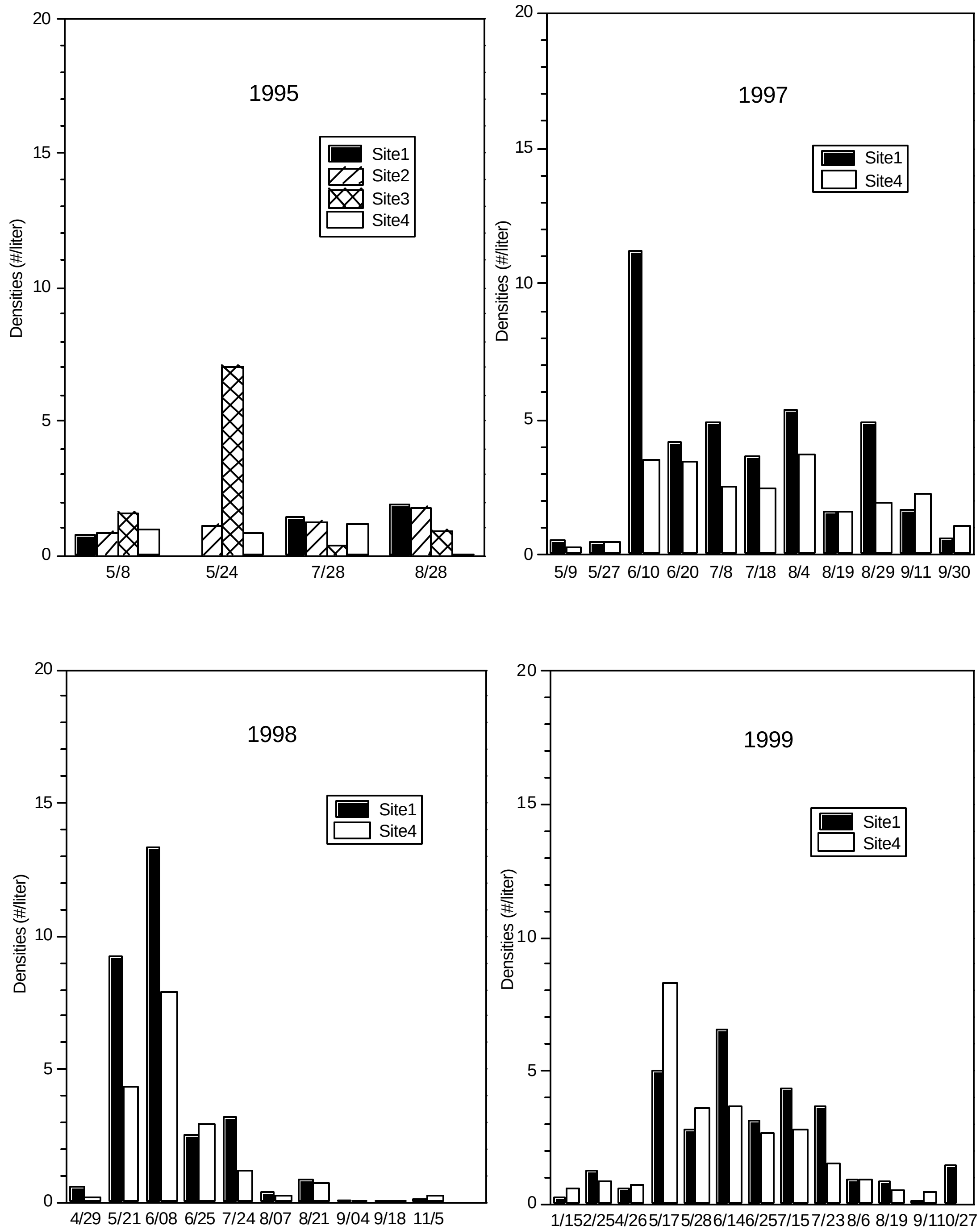
Appendix 1. Densities (#/liter) of *Daphnia pulex* for 1995, 1997-1999 in Bad Medicine Lake, Minnesota.



Appendix 2. *Daphnia pulex* biomass (µg/liter) for 1995, 1997-1999
in Bad Medicine Lake, Minnesota.



Appendix 3. Densities (#/liter) of *Daphnia pulex* > 1.3mm in length for 1995, 1997-1999 in Bad Medicine Lake, Minnesota.



Appendix 4. Summary of 1999 Bad Medicine Lake zooplankton data from "ZCOUNT" program.

Species	Density #/L	Biomass ug/L	Number %	Weight %	Mean weight ug	Mean length mm	Count
	Bad Medicine Lake Site 1			**02/25/1999**			
Copepods							
copepodites	0.02	0.03	0.32	0.05	1.12	0.44	1
calanoids	0.10	1.03	1.29	1.95	10.70	1.32	4
cyclopoids	5.26	14.88	70.32	28.16	2.83	0.74	218
Total copepods	5.38	15.94	71.93	30.16			223
Cladocerans							
Daphnia galeata mendotae	0.22	2.23	2.90	4.23	10.30	1.23	9
Daphnia pulex	1.50	33.67	20.00	63.71	22.52	1.51	62
Bosmina longirostris	0.39	1.00	5.16	1.90	2.60	0.42	16
Total cladocerans	2.10	36.90	28.06	69.84			87
Grand Total	**7.48**	**52.84**	**99.99**	**100.00**			**310**
	Bad Medicine Lake Site 4			02/25/1999			
Copepods							
nauplii	0.05	0.01	0.96	0.04	0.30	0.26	2
calanoids	0.03	0.25	0.48	0.59	9.77	1.26	1
cyclopoids	3.49	9.33	66.35	22.25	2.67	0.73	138
Total copepods	3.56	9.59	67.79	22.88			141
Cladocerans							
Daphnia galeata mendotae	0.20	1.95	3.85	4.65	9.65	1.18	8
Daphnia pulex	1.11	29.35	21.15	70.03	26.40	1.60	44
Bosmina longirostris	0.38	1.02	7.21	2.44	2.70	0.43	15
Total cladocerans	1.69	32.32	32.21	77.12			67
Grand Total	**5.25**	**41.91**	**100.00**	**100.00**			**208**

Appendix 4. Continued

Species	Density #/L	Biomass ug/L	Number %	Weight %	Mean weight ug	Mean length mm	Count
			Bad Medicine Lake Site 1	**04/26/1999**			
Copepods							
nauplii	1.69	0.50	12.54	1.29	0.30	0.26	70
copepodites	0.92	0.83	6.81	2.14	0.91	0.39	38
calanoids	0.14	1.35	1.08	3.46	9.31	1.23	6
cyclopoids	9.57	14.98	71.15	38.43	1.57	0.61	397
Total copepods	12.32	17.67	91.58	45.32			511
Cladocerans							
Daphnia pulex	1.01	20.98	7.53	53.81	20.71	1.46	42
Bosmina longirostris	0.12	0.34	0.90	0.88	2.85	0.44	5
Total cladocerans	1.13	21.32	8.43	54.69			47
Grand Total	**13.46**	**38.99**	**100.01**	**100.01**			**558**
			Bad Medicine Lake Site 4	04/26/1999			
Copepods							
nauplii	1.22	0.38	10.93	0.84	0.31	0.27	53
copepodites	0.67	0.71	5.98	1.55	1.06	0.42	29
calanoids	0.05	0.39	0.41	0.86	8.48	1.17	2
cyclopoids	8.00	18.51	71.55	40.59	2.31	0.69	347
Total copepods	9.94	19.99	88.87	43.84			431
Cladocerans							
Daphnia pulex	0.97	24.86	8.66	54.52	25.66	1.58	42
Bosmina longirostris	0.21	0.60	1.86	1.32	2.89	0.44	9
Holopedium gibberum	0.02	0.04	0.21	0.10	1.94	0.42	1
Chydorus sphaericus	0.05	0.10	0.41	0.22	2.22	0.39	2
Total cladocerans	1.25	25.61	11.14	56.16			54
Grand Total	**11.19**	**45.60**	**100.01**	**100.00**			**485**

Species	Density #/L	Biomass ug/L	Number %	Weight %	Mean weight ug	Mean length mm	Count
			Bad Medicine Lake Site 1		05/17/1999		
Copepods							
nauplii	5.39	1.79	13.44	0.67	0.33	0.28	61
copepodites	5.04	5.52	12.56	2.08	1.10	0.43	57
calanoids	0.44	3.69	1.10	1.39	8.35	1.16	5
cyclopoids	16.89	45.78	42.07	17.28	2.71	0.73	191
Total copepods	27.76	56.78	69.17	21.42			314
Cladocerans							
Daphnia pulex	11.32	204.87	28.19	77.34	18.10	1.39	128
Bosmina longirostris	1.06	3.23	2.64	1.22	3.05	0.45	12
Total cladocerans	12.38	208.10	30.83	78.56			140
Grand Total	**40.14**	**264.88**	**100.00**	**99.98**			**454**
			Bad Medicine Lake Site 4		05/17/1999		
Copepods							
nauplii	5.15	1.63	6.99	0.38	0.32	0.27	67
copepodites	2.92	3.33	3.96	0.77	1.14	0.44	38
cyclopoids	54.20	158.80	73.51	36.91	2.93	0.75	705
Total copepods	62.28	163.75	84.46	38.06			810
Cladocerans							
Daphnia pulex	11.07	265.95	15.02	61.82	24.02	1.54	144
Bosmina longirostris	0.38	0.53	0.52	0.12	1.37	0.32	5
Total cladocerans	11.46	266.48	15.54	61.94			149
Grand Total	**73.73**	**430.23**	**100.00**	**100.00**			**959**

Species	Density #/L	Biomass ug/L	Number %	Weight %	Mean weight ug	Mean length mm	Count
			Bad Medicine Lake Site 1		05/28/1999		
Copepods							
nauplii	1.93	0.41	11.65	0.40	0.21	0.21	24
copepodites	2.49	2.37	15.05	2.30	0.95	0.40	31
calanoids	0.24	1.69	1.46	1.64	7.00	1.07	3
cyclopoids	6.67	12.00	40.29	11.62	1.80	0.64	83
Total copepods	11.33	16.47	68.45	15.96			141
Cladocerans							
Daphnia pulex	5.22	86.79	31.55	84.05	16.61	1.35	65
Total cladocerans	5.22	86.79	31.55	84.05			65
Grand Total	**16.56**	**103.26**	**100.00**	**100.01**			**206**
			Bad Medicine Lake Site 4		05/28/1999		
Copepods							
nauplii	3.13	0.76	12.00	0.59	0.24	0.23	39
copepodites	5.39	4.75	20.62	3.69	0.88	0.38	67
calanoids	0.32	2.30	1.23	1.79	7.15	1.08	4
cyclopoids	11.57	25.28	44.31	19.62	2.18	0.68	144
Total copepods	20.42	33.09	78.16	25.69			254
Cladocerans							
Daphnia pulex	5.63	94.95	21.54	73.70	16.88	1.35	70
Holopedium gibberum	0.08	0.79	0.31	0.61	9.77	1.18	1
Total cladocerans	5.71	95.74	21.85	74.31			71
Grand Total	**26.12**	**128.83**	**100.01**	**100.00**			**325**

Appendix 4. Continued

Species	Density #/L	Biomass ug/L	Number %	Weight %	Mean weight ug	Mean length mm	Count
			Bad Medicine Lake Site 1	06/14/1999			
Copepods							
nauplii	1.53	0.47	7.60	0.21	0.31	0.26	19
copepodites	1.13	1.54	5.60	0.70	1.37	0.49	14
calanoids	1.37	9.55	6.80	4.31	6.99	1.06	17
cyclopoids	5.71	11.82	28.40	5.33	2.07	0.67	71
Total copepods	9.73	23.38	48.40	10.55			121
Cladocerans							
Daphnia galeata mendotae	0.24	1.34	1.20	0.61	5.56	0.83	3
Daphnia pulex	10.13	196.92	50.40	88.84	19.44	1.43	126
Total cladocerans	10.37	198.26	51.60	89.45			129
Grand Total	**20.10**	**221.64**	**100.00**	**100.00**			**250**
			Bad Medicine Lake Site 4	06/14/1999			
Copepods							
nauplii	5.48	1.82	29.52	1.13	0.33	0.28	62
copepodites	1.50	1.86	8.10	1.16	1.24	0.46	17
calanoids	0.88	8.19	4.76	5.10	9.26	1.23	10
cyclopoids	5.57	16.15	30.00	10.06	2.90	0.75	63
Total copepods	13.44	28.02	72.38	17.45			152
Cladocerans							
Daphnia galeata mendotae	0.27	2.07	1.43	1.29	7.79	1.02	3
Daphnia pulex	4.77	130.43	25.71	81.22	27.32	1.62	54
Chydorus sphaericus	0.09	0.08	0.48	0.05	0.88	0.25	1
Total cladocerans	5.13	132.57	27.62	82.56			58
Grand Total	**18.57**	**160.59**	**100.00**	**100.01**			**210**

Appendix 4. Continued

Species	Density #/L	Biomass ug/L	Number %	Weight %	Mean weight ug	Mean length mm	Count
			Bad Medicine Lake Site 1	06/25/1999			
Copepods							
nauplii	0.22	0.07	1.59	0.05	0.33	0.28	3
copepodites	1.77	2.30	12.70	1.58	1.30	0.48	24
calanoids	2.28	19.20	16.40	13.22	8.41	1.17	31
cyclopoids	5.01	13.57	35.98	9.34	2.71	0.73	68
Total copepods	9.28	35.15	66.67	24.19			126
Cladocerans							
Daphnia galeata mendotae	0.07	0.41	0.53	0.28	5.60	0.83	1
Daphnia pulex	4.57	109.73	32.80	75.53	24.02	1.54	62
Total cladocerans	4.64	110.14	33.33	75.81			63
Grand Total	**13.93**	**145.29**	**100.00**	**100.00**			**189**
			Bad Medicine Lake Site 4	06/25/1999			
Copepods							
nauplii	0.42	0.17	4.62	0.13	0.40	0.31	6
copepodites	1.13	1.71	12.31	1.32	1.51	0.52	16
calanoids	1.77	16.15	19.23	12.49	9.13	1.22	25
cyclopoids	1.84	7.92	20.00	6.13	4.31	0.86	26
Total copepods	5.16	25.95	56.16	20.07			73
Cladocerans							
Daphnia galeata mendotae	0.35	3.04	3.85	2.35	8.59	1.09	5
Daphnia pulex	3.68	100.25	40.00	77.57	27.26	1.62	52
Total cladocerans	4.03	103.29	43.85	79.92			57
Grand Total	**9.20**	**129.24**	**100.01**	**99.99**			**130**

Appendix 4. Continued

Species	Density #/L	Biomass ug/L	Number %	Weight %	Mean weight ug	Mean length mm	Count
		Bad Medicine Lake Site 1		07/15/1999			
Copepods							
nauplii	0.23	0.11	2.36	0.06	0.49	0.35	3
copepodites	1.08	1.90	11.02	1.02	1.76	0.57	14
calanoids	1.23	9.93	12.60	5.35	8.07	1.14	16
cyclopoids	0.92	4.12	9.45	2.22	4.47	0.87	12
Total copepods	3.46	16.06	35.43	8.65			45
Cladocerans							
Daphnia galeata mendotae	1.31	14.39	13.39	7.75	11.01	1.28	17
Daphnia pulex	5.00	155.22	51.18	83.60	31.06	1.70	65
Total cladocerans	6.30	169.61	64.57	91.35			82
Grand Total	**9.76**	**185.67**	**100.00**	**100.00**			**127**
		Bad Medicine Lake Site 4		07/15/1999			
Copepods							
nauplii	1.13	0.32	12.61	0.25	0.29	0.25	14
copepodites	1.93	3.02	21.62	2.39	1.56	0.53	24
calanoids	0.80	6.08	9.01	4.82	7.56	1.11	10
cyclopoids	1.04	3.95	11.71	3.13	3.78	0.82	13
Total copepods	4.90	13.37	54.95	10.59			61
Cladocerans							
Daphnia galeata mendotae	0.40	3.30	4.50	2.62	8.21	1.06	5
Daphnia pulex	3.46	109.14	38.74	86.56	31.58	1.71	43
Bosmina longirostris	0.16	0.28	1.80	0.22	1.73	0.35	2
Total cladocerans	4.02	112.72	45.04	89.40			50
Grand Total	**8.92**	**126.08**	**99.99**	**99.99**			**111**

Appendix 4. Continued

Species	Density #/L	Biomass ug/L	Number %	Weight %	Mean weight ug	Mean length mm	Count
			Bad Medicine Lake Site 1	07/23/1999			
Copepods							
nauplii	0.31	0.08	2.20	0.05	0.27	0.25	4
copepodites	0.46	0.72	3.30	0.41	1.56	0.53	6
calanoids	3.77	24.50	26.92	13.85	6.50	1.03	49
cyclopoids	3.08	13.91	21.98	7.87	4.52	0.87	40
Total copepods	7.61	39.22	54.40	22.18			99
Cladocerans							
Daphnia galeata mendotae	1.54	19.85	10.99	11.23	12.91	1.42	20
Daphnia pulex	4.54	117.36	32.42	66.36	25.87	1.59	59
Bosmina longirostris	0.23	0.27	1.65	0.15	1.15	0.29	3
Chydorus sphaericus	0.08	0.15	0.55	0.08	1.94	0.37	1
Total cladocerans	6.38	137.63	45.61	77.82			83
Grand Total	**13.99**	**176.85**	**100.01**	**100.00**			**182**
			Bad Medicine Lake Site 4	07/23/1999			
Copepods							
nauplii	0.64	0.21	9.78	0.31	0.33	0.27	9
copepodites	0.99	1.18	15.22	1.78	1.19	0.45	14
calanoids	0.50	3.32	7.61	5.03	6.71	1.04	7
cyclopoids	1.20	5.17	18.48	7.82	4.30	0.86	17
Total copepods	3.32	9.87	51.09	14.94			47
Cladocerans							
Daphnia galeata mendotae	0.57	7.98	8.70	12.08	14.11	1.50	8
Daphnia pulex	2.40	47.91	36.96	72.51	19.92	1.44	34
Bosmina longirostris	0.21	0.31	3.26	0.47	1.47	0.33	3
Total cladocerans	3.18	56.21	48.92	85.06			45
Grand Total	**6.51**	**66.08**	**100.01**	**100.00**			**92**

Appendix 4. Continued

Species	Density #/L	Biomass ug/L	Number %	Weight %	Mean weight ug	Mean length mm	Count
			Bad Medicine Lake Site 1	08/06/1999			
Copepods							
nauplii	0.64	0.14	11.76	0.34	0.22	0.21	8
copepodites	0.08	0.03	1.47	0.08	0.41	0.24	1
calanoids	2.01	10.84	36.76	26.78	5.39	0.93	25
cyclopoids	0.96	4.01	17.65	9.90	4.15	0.85	12
Total copepods	3.70	15.02	67.64	37.10			46
Cladocerans							
Daphnia pulex	1.45	24.84	26.47	61.39	17.17	1.36	18
Bosmina longirostris	0.32	0.61	5.88	1.51	1.90	0.37	4
Total cladocerans	1.77	25.45	32.35	62.90			22
Grand Total	**5.47**	**40.47**	**99.99**	**100.00**			**68**
			Bad Medicine Lake Site 4	08/06/1999			
Copepods							
nauplii	0.64	0.23	11.11	0.53	0.35	0.28	8
copepodites	0.40	0.47	6.94	1.11	1.17	0.45	5
calanoids	1.04	6.99	18.06	16.42	6.69	1.04	13
cyclopoids	1.21	3.70	20.83	8.68	3.07	0.76	15
Total copepods	3.30	11.39	56.94	26.74			41
Cladocerans							
Daphnia galeata mendotae	0.16	1.65	2.78	3.88	10.29	1.22	2
Daphnia pulex	1.13	28.53	19.44	66.98	25.35	1.58	14
Bosmina longirostris	1.21	1.02	20.83	2.40	0.85	0.26	15
Total cladocerans	2.49	31.20	43.05	73.26			31
Grand Total	**5.79**	**42.59**	**99.99**	**100.00**			**72**

Appendix 4. Continued

Species	Density #/L	Biomass ug/L	Number %	Weight %	Mean weight ug	Mean length mm	Count
	Bad Medicine Lake Site 1		08/19/1999				
Copepods							
nauplii	0.56	0.13	10.00	0.35	0.23	0.22	7
copepodites	0.96	0.81	17.14	2.19	0.84	0.37	12
calanoids	0.56	2.72	10.00	7.32	4.84	0.88	7
cyclopoids	2.09	3.87	37.14	10.42	1.85	0.64	26
Total copepods	4.18	7.54	74.28	20.28			52
Cladocerans							
Daphnia galeata mendotae	0.16	1.02	2.86	2.73	6.32	0.90	2
Daphnia pulex	1.21	28.58	21.43	76.87	23.71	1.54	15
Bosmina longirostris	0.08	0.04	1.43	0.12	0.55	0.21	1
Total cladocerans	1.45	29.64	25.72	79.72			18
Grand Total	**5.63**	**37.18**	**100.00**	**100.00**			**70**

Species	Density #/L	Biomass ug/L	Number %	Weight %	Mean weight ug	Mean length mm	Count
	Bad Medicine Lake Site 4		08/19/1999				
Copepods							
nauplii	0.72	0.14	14.75	0.61	0.19	0.20	9
copepodites	0.96	0.83	19.67	3.64	0.86	0.37	12
calanoids	0.32	1.26	6.56	5.51	3.92	0.79	4
cyclopoids	1.77	5.53	36.07	24.15	3.13	0.77	22
Total copepods	3.78	7.76	77.05	33.91			47
Cladocerans							
Daphnia galeata mendotae	0.08	1.44	1.64	6.31	17.97	1.75	1
Daphnia pulex	0.96	13.66	19.67	59.65	14.16	1.27	12
Bosmina longirostris	0.08	0.03	1.64	0.13	0.38	0.18	1
Total cladocerans	1.13	15.13	22.95	66.09			14
Grand Total	**4.90**	**22.90**	**100.00**	**100.00**			**61**

Appendix 4. Continued

Species	Density #/L	Biomass ug/L	Number %	Weight %	Mean weight ug	Mean length mm	Count
			Bad Medicine Lake Site 1	09/01/1999			
Copepods							
nauplii	0.59	0.13	7.45	0.53	0.22	0.22	7
copepodites	0.67	0.68	8.51	2.80	1.01	0.41	8
calanoids	1.35	5.83	17.02	23.89	4.33	0.83	16
cyclopoids	4.04	7.96	51.06	32.61	1.97	0.66	48
Total copepods	6.65	14.60	84.04	59.83			79
Cladocerans							
Daphnia galeata mendotae	0.59	3.59	7.45	14.71	6.09	0.88	7
Daphnia pulex	0.59	6.04	7.45	24.74	10.24	1.12	7
Bosmina longirostris	0.08	0.17	1.06	0.71	2.06	0.38	1
Total cladocerans	1.26	9.80	15.96	40.16			15
Grand Total	**7.92**	**24.41**	**100.00**	**99.99**			**94**
			Bad Medicine Lake Site 4	09/01/1999			
Copepods							
nauplii	0.48	0.16	8.00	0.59	0.33	0.28	6
copepodites	0.32	0.26	5.33	0.97	0.82	0.36	4
calanoids	1.21	4.45	20.00	16.49	3.69	0.77	15
cyclopoids	2.89	6.45	48.00	23.93	2.23	0.68	36
Total copepods	4.90	11.32	81.33	41.98			61
Cladocerans							
Daphnia galeata mendotae	0.08	0.46	1.33	1.70	5.71	0.84	1
Daphnia pulex	0.96	14.99	16.00	55.60	15.55	1.31	12
Bosmina longirostris	0.08	0.19	1.33	0.72	2.40	0.41	1
Total cladocerans	1.13	15.65	18.66	58.02			14
Grand Total	**6.03**	**26.97**	**99.99**	**100.00**			**75**

Species	Density #/L	Biomass ug/L	Number %	Weight %	Mean weight ug	Mean length mm	Count

Bad Medicine Lake Site 1 10/27/1999

Species	Density	Biomass	Number	Weight	Mean weight	Mean length	Count
Copepods	#/L	ug/L	%	%	ug	mm	
copepodites	0.15	0.13	1.79	0.16	0.86	0.37	2
calanoids	0.92	6.72	10.71	8.16	7.28	1.09	12
cyclopoids	3.61	11.87	41.96	14.41	3.29	0.78	47
Total copepods	4.69	18.73	54.46	22.73			61
Cladocerans							
Daphnia galeata mendotae	1.46	15.40	16.96	18.69	10.54	1.24	19
Daphnia pulex	2.46	48.25	28.57	58.57	19.61	1.43	32
Total cladocerans	3.92	63.65	45.53	77.26			51
Grand Total	**8.61**	**82.38**	**99.99**	**99.99**			**112**

Bad Medicine Lake Site 4 10/27/1999

Copepods							
copepodites	0.07	0.06	1.14	0.13	0.79	0.36	1
calanoids	0.07	0.40	1.14	0.93	5.67	0.96	1
cyclopoids	3.68	11.82	59.09	27.44	3.21	0.78	52
Total copepods	3.82	12.28	61.37	28.50			54
Cladocerans							
Daphnia galeata mendotae	1.49	15.55	23.86	36.09	10.47	1.24	21
Daphnia pulex	0.92	15.26	14.77	35.42	16.60	1.35	13
Total cladocerans	2.41	30.81	38.63	71.51			34
Grand Total	**6.22**	**43.09**	**100.00**	**100.01**			**88**

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